IMPORTANCE OF EDUCATION

Understanding how a radial shaft seal performs in an application creates an invaluable awareness of the entire sealing system. Knowing what physical principals are at work, a design engineer is more likely to be thinking about seal selection earlier in the design process.

The life cycle of mobile machinery can be limited by the effectiveness of the radial shaft seal. When failure occurs, the seals are believed to be at fault. But in fact, the root cause of failure is usually unknown and lies buried in the network of sealing parameters. Not understanding these parameters can be detrimental to the life of a seal. If the design engineer does not know how shaft preparation affects the sealing mechanism, then lead, which is spiral grooves on the shaft surface, is more likely to occur. By understanding how different parameters affect the sealing mechanism, the correct profile is more likely to be selected and the system variables controlled.

ESP International understands the importance of education and recognizes the need in our market for a technical presence. The intentions of this handbook are to provide a resource for engineers that organize the industry standards for radial shaft seals. In the design process, engineers may not have time to research all of the operation details of each part.

Often seal selection is compromised and the chance of failure increases. This handbook will reduce the research time without losing education. Radial shaft seals are designed and selected based on profile characteristics.

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SEAL DESIGN

SEAL THEORY

The challenge of sealing against a dynamic surface has been around since the frontier era. The first known shaft seals were leather straps used to retain animal fat on the end of a wheel axle. This crude seal required routine maintenance and was unreliable. The Industrial Revolution spawned the development of engines, transmissions and gearboxes, all of which required various seals to retain a variety of lubricants. The seals of the industrial age were organic ropes or packing. These seals were very effective until shaft speeds, temperature and other parameters increased with the development of better transportation systems.

In the late 1920's, a self contained shaft seal was created from oil resistant leather assembled into a metal case. This was the first radial lip seal to be press fit into an outside diameter bore. Radial shaft seals continued to develop further and a synthetic, oil-resistant rubber replaced the leather element, forever changing seal design.

HOW DO THEY WORK?

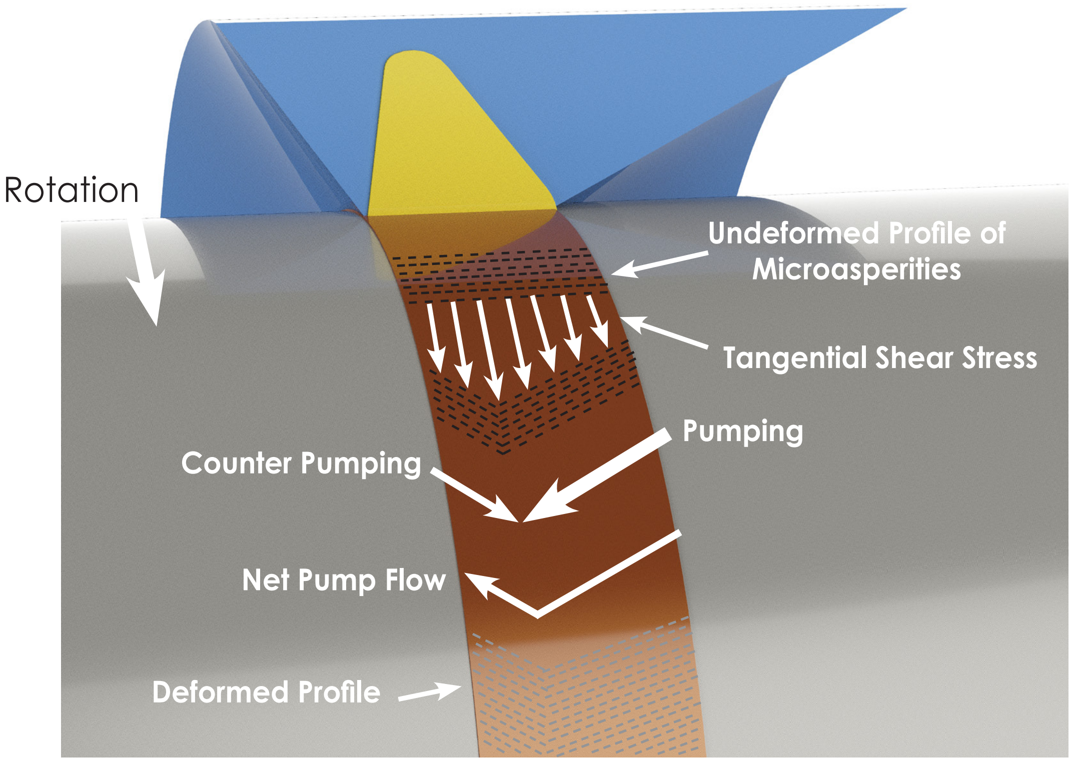
Radial shaft seals prevent leakage through the generation of a pumping action at the interface of the seal lip and the shaft surface. The pumping direction has a direct correlation to the direction of an asymmetrical contact pressure profile. This pressure profile is controlled by the geometric design of the lip seal which is designed to create a larger pressure gradient on the oil side of the sealing lip. The pressure gradient is one aspect that contributes to the function of a radial shaft lip seal.

A second aspect that contributes to the pumping mechanism of a seal lip is the presence of an oil film layer between the seal lip surface and the shaft surface.

SEAL DESIGN

The third aspect in the sealing mechanism that contributes to the net pumping effect is the formation of asperities on the seal lip surface. The asperities become aligned at an angle to the rotating shaft causing the oil film to pump towards the oil side of the seal.

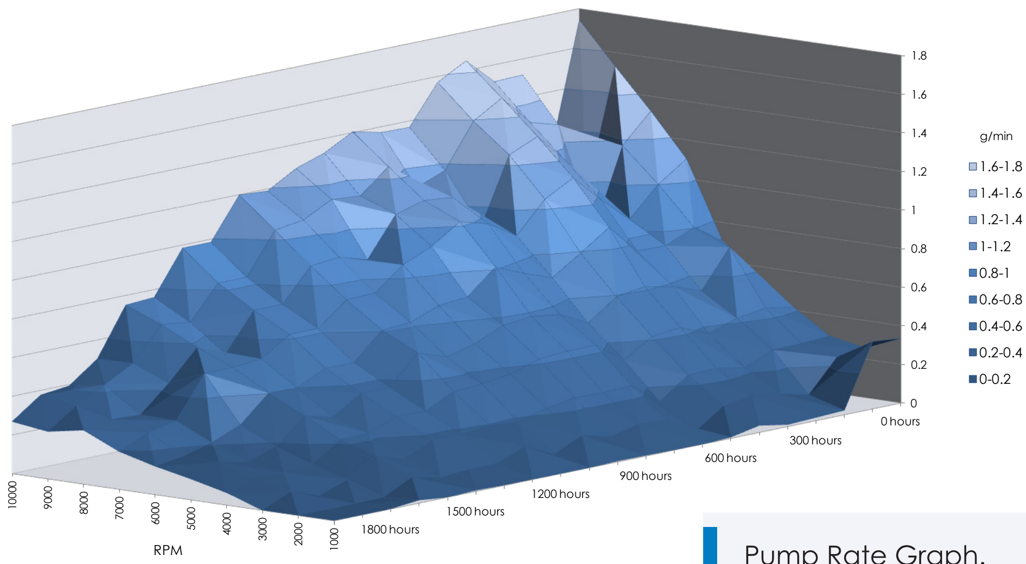
The existence of the asymmetric pressure profile, fluid film and asperities all contribute to the pumping mechanism of the seal. Seal failure occurs over a period of time and can be attributed to many different effects.



Contact Pressure Profile.

The existence of the asymmetric pressure profile, fluid film and asperities contribute to the pumping mechanism of the seal.

SEAL DESIGN



Pump Rate Graph.

The graph displays how the pump rate of a seal lip will change over time.

In a lab environment, where the sealing lip is not affected by the ingress of dirt and debris a seal will eventually develop a leak after many hours of running. Leakage develops as the pressure profile of the lip contact on the shaft modifies and/or the asperities diminish.

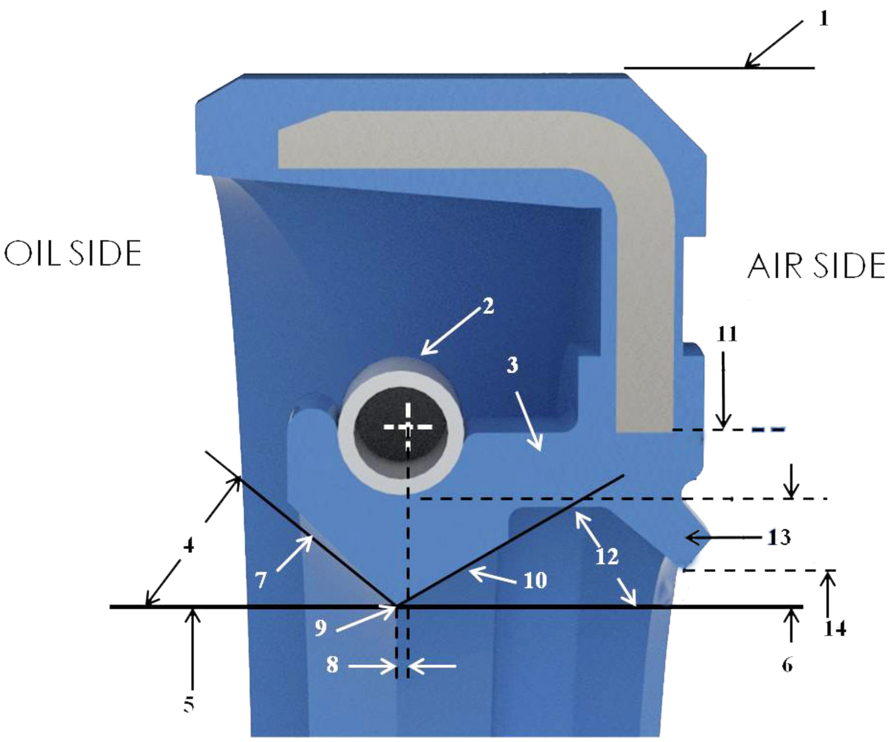
Factors that modify lip pressure are wear and compression set of the elastomer. As the seal wears the contact width of the seal lip grows and the asymmetric pressure profile is modified. As well, the elastomer of the seal will develop compression set over time due to its exposure to fluid at elevated temperatures. The effect of the modification of the asymmetric pressure profile on the pump rate of the lip is shown above. The Pump Rate Graph displays the decrease in seal lip pump vs time vs RPM.

A second failure mode of the seal lip can occur as shaft speed increases. The oil film between the seal lip and shaft surface helps to protect and lubricate the rubber lip on the rotating shaft. Even with the oil film present there is frictional heat generated at the sealing lip. That heat can become significant at high shaft speeds and there are temperature limitations for various elastomers. Nitrile is the most commonly chosen due to cost, but if shaft speed is high, a fluorocarbon or teflon material may be required.

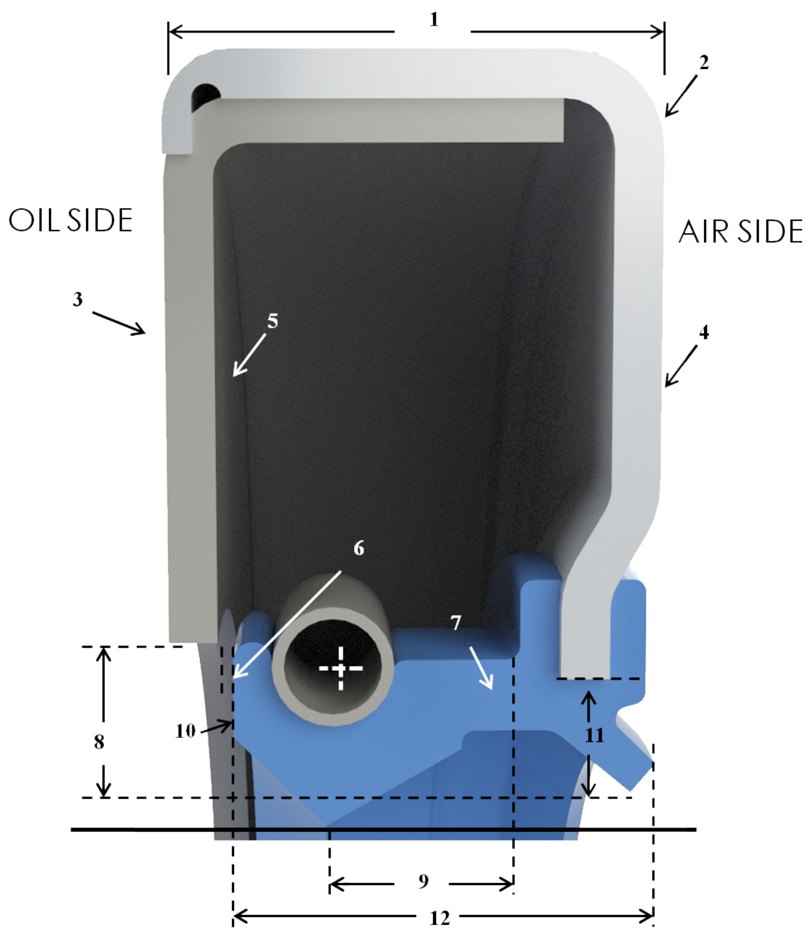
RADIAL SHAFT SEAL TERMINOLOGY

SEAL DESIGN

There are different designs of radial shaft seal, some have more elements than other like for example a dust lip or inner case. The image below shows the terminology of a TC radial shaft seal.



1. Seal OD
2. Garter Spring
3. Flex Section
4. Oil Side Angle
5. Lip ID
6. Head Thickness
7. Oil Side Surface
8. Spring Axial Position
9. Contact Point
10. Air Side Surface
11. Case ID
12. Air Side Angle
13. Dust Lip
14. Shaft Diameter



1. Case Width
2. Outer Case
3. Inside Face
4. Outside Face
5. Inner Case
6. Axial Clearance
7. Heel Section
8. Inside Face Inner Diameter
9. Lip Length
10. Toe Face
11. Outer Case Inner Diameter
12. Lip Height

PARAMETERS AFFECTING SEALING

The process of defining a specific sealing system is the first step toward understanding the true application needs.

Certain parameters can affect the types of profiles that can be used. The design engineers ability to narrow down all of the system variables and understanding their affects will dictate the success of the profile selection.

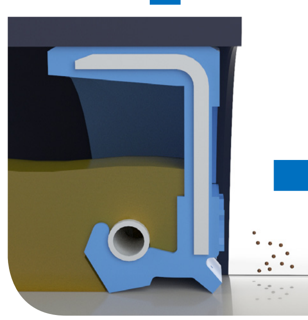
There are four categories of system parameters that list common application variables; the housing, outside, media and shaft parameters.

HOUSING PARAMETERS

- Ferrous or Non-Ferrous
- Surface finish
- Chamfer size available
- Counterbore or straight
- Replacement
- Draft angle
- Ease of removal
- Spring back
- Cocking

MEDIA PARAMETERS

- Viscosity
- Internal pressure
- Sump temperature
- Chemical properties
- Lubrication properties
- Fill level
- Contaminants

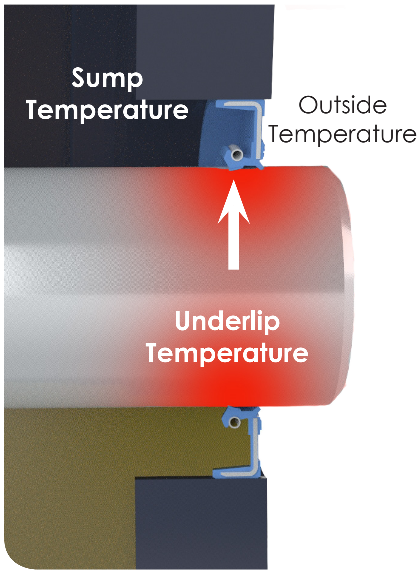


OUTSIDE PARAMETERS

- Contamination type
- Particle size
- Ozone
- Temperature
- Pressure
- Clearance
- Corrosion
- Assembly restrictions

SHAFT PARAMETERS

- Ferrous or Non-Ferrous
- Surface finish
- Hardness
- Finish type
- Lead
- Grooving
- Diameter
- Chamfer size
- Speed (RPM or FPM)
- Offset
- Dynamic runout
- Torque requirments
- Rotation direction
- Downtime
- Cycles / Day



Temperatures affecting the seal.

There are three different forms of temperature: outside, sump and underlip.

TEMPERATURE

There are three different forms of temperature: outside, sump and underlip. The cumulative effect of these temperatures can increase the hardening rate of the elastomeric lip material. This causes the loss of flexibility in the contact area, and ultimately decreases the life of a seal.

The outside temperature can come from any heat source other than the sump or underlip. Long exposure to high outside temperatures can have unexpected effects on the life of a seal. When combining these temperatures with the sump temperatures, an increase in the hardening rate of the elastomer may ocurr. The other end of the spectrum occurs when outside temperatures reach the lower limit of the lip material temperature range.

At low temperatures, the effect on the sealing element may result in tearing if there is dynamic runout of the shaft due to a decrease in flexibility and resilience. Unless the seal experiences catastrophic failure, leakage does not normally occur at these low temperatures because the viscosity of the sump media has increased and due to friction the temperatures quickly elevates.

The sump temperature is the most common measure of the three temperatures. There is a direct correlation between seal life and sump temperature. Even if the seal is operating at sump temperature that is within the given elastomeric temperature range, this does not mean that the seal life is not being compromised. If long life cycles are an important priority, then a low sump temperature is desired. If long life-cycles are not a priority, then a high sump temperature can have a positive effect on the system. Fluid viscosity, seal torque and power consumption all decrease as sump temperature increases.

The underlip temperature of the contact width is a function of shaft speed, material friction, surface roughness, sump and outside temperature. As these parameters increase, the effect is a higher underlip temperature. The material friction is dependent on elastomer properties, radial lip load and lubrication. If there is no fluid film available, the seal element would burn up because of extremely high underlip temperature.

The cumulative effect of all of these temperatures is that the hardening rate of the lip material is increased and seal longevity is lost.

PRESSURE

Standard radial shaft seals are not designed to operate in a pressurized system. The flex section is too thin and has no rigid support. Even a slight increase in pressure can force the outside lip surface to pivot about the contact width, decreasing the air side angle. This condition is called bell mouthing and its effects are irregular wear and shortened seal life. The maximum industry pressure for standard profiles is 7 – 10 psi (0.48 – 0.69 bar). When dealing with pressures in this range it is important to also consider shaft speed. The optimal pressure for a standard radial shaft seal is near zero.

To choose a profile type the system pressure needs to be classified. Most radial shaft seals are designed for the standard pressure range. For applications in the medium/low range, the profile availability is significantly reduced.

To accommodate for these pressures, the lip length must be shortened and the flex section increased in thickness. High classification pressures require an additional structural member to assist the primary lip from deflecting and extruding. For applications with pressures higher than 150 psi contact ESP International for recommendations.

PRESSURE CLASIFICATION	
Standard	0-10 psi (0-0.69 bar)
Low	10-50 psi (0.69-3.45 bar)
Medium	50-100 psi (3.45-6.9 bar)
High	100-150 psi (6.9-10.3 bar)

SEAL DESIGN

LUBRICATION

Lubricants are used to reduce wear of dynamic mechanical components. Radial shaft seals keep these lubricants contained within a cavity or sump. A radial shaft seal also rides on a film of fluid when rotating. This lubricant film is the primary reason the lip does not wear or burn up due to excessive friction. Even with lubricant present at the sealing lip, frictional heat is created and the dissipation properties of the lubricant can impact the life of a radial shaft seal. Also, the availability of lubricant can affect seal life, optimally the seal lip will be immersed in oil, but some applications employ splash or mist lubrication. These applications may have a negative effect on seal life.

The seal lip and the lubricant must be chemically compatible to prevent elastomer degradation. With high demands being placed on the lubricants, additives are used to improve performance of lubrication.

Unfortunately, these additives may have a negative effect and a compatibility problem is often seen when the elastomer hardens at low operating temperatures or the lip is excessively soft from normal use. A complete list of the additives in the lubricant is essential for a thorough analysis.

The following table shows a list of common additives used in lubricants:

CHEMICAL COMPOUNDS OF THE ADDITIVES	
Antifoamants	Silicone Polymers
Corrosion Inhibitors	Overbased Metallic Sulfonates Phenates, Fatty Amines
Detergents	Amines, Phenates, Succinimides
(EP) Antiwear Additives	Organic Phosphates, Chlorine, Sulfer Compounds
Friction Modifiers	Amides, Phosphates, Phosphites, Acids
Metal Deactivators	Metal Phenates, Nitrogen
Oxidation Inhibitors	Aromatic Amines, Hindered Phenols
Pour Point Depressants	LMW Methacrylate Polymers
Rust Inhibitors	Ester, Amines, Sulfonates

VISCOSITY

SEAL DESIGN

Viscosity is be defined as the measured resistance to flow. The molecular weight and composition determine the viscosity.

The Viscosity Index is a unitless measure of the tendency of the lubrication to change viscosity due to a change in temperature. A low VI suggests the lubrication will have a significant change in viscosity with a small change in temperature.

Lubricants with high viscosities will create high levels of friction and therefore decrease seal life. Lubricants with low viscosities will reduce friction and power consumption. However, lower viscosities require an increased pump rate to maintain sealability.

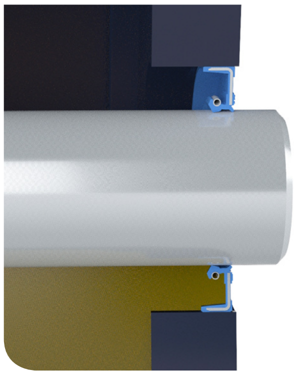
The following formula is used to calculate the viscosity index:

$$V = 100 \frac{(L - U)}{(L - H)}$$

Where:

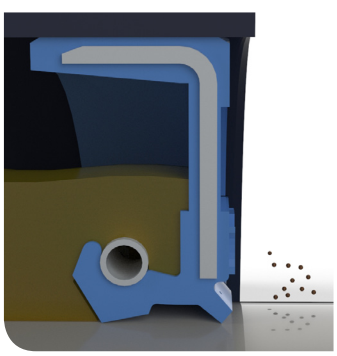
V = viscosity index
U = kinematic viscosity at 40° C
L and H = values based on the kinematic viscosity at 100° C

The kinematic viscosity values are available in ASTM D2270



Sump fill level.

Lubrication is a critial part of the seal's cooling system and should be continually monitored.



Contamination.

If contamination reaches the lip, the pumping action will ingest it into the system.

SUMP FILL LEVEL

As the sump level decreases, the life of the seal decreases. This can be explained through thermal analysis of the seal contact region of the shaft. Lubrication is a critical part of the seal's cooling system and should be continually monitored. When sump levels are not adequate to cool the seal, special lip materials such as PTFE should be considered.

CORROSION

Corrosion of the dynamic surface can cause damage or failure of the radial shaft seal. Elastomers can create an electrochemical reaction in the contact width region when heat and humidity are present. A seal that is idle for long periods is subject to this type of corrosion when temperatures are above 85° F (29° C).

The selection of corrosion resistive lubricants can inhibit the corrosion but will not eliminate it. If an electrochemical reaction is a concern, contact ESP International.

CONTAMINATION

The effect of contamination ingesting into a mechanical system can result in failure of bearings, gears and other dynamic components. Because of the pumping action under the contact width, if contamination is allowed to reach this point it will naturally ingest into the system.

Selecting a radial shaft seal profile that does not allow this to happen is necessary to avoid mechanical failure.

To classify the severity of contamination begin with identifying all potential particle types and sizes. Percentage of cycle exposure should also be considered, defined as the amount of time the seal is exposed to contamination during application. Another variable to consider is the maximum percentage that the seal is submerged.

Most radial shaft seals are designed to operate under a level 1 or 2 contamination environment. This includes radial shaft seal profiles having a secondary dust lip. This lip provides only minor protection and is often misused in applications.

The effect of this additional lip is an increase in underlip temperature and a loss of seal life. When using this profile, it is important to lubricate between the two lips during installation to minimize this effect.

The effect of high percentages of exposure and submergence results in the reduction of available profiles. Severity levels of 4 and 5 requires special consideration of lip types, number and orientation. Contact ESP International for design suggestions.

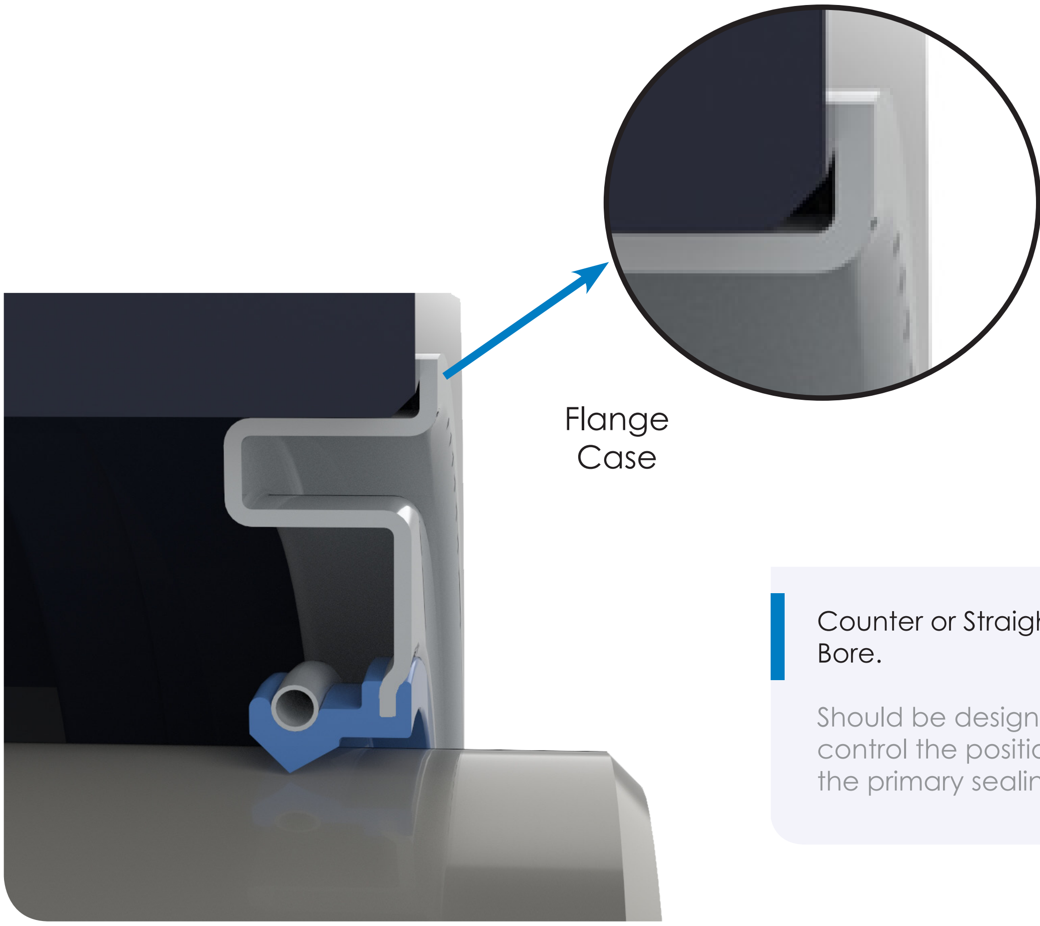
Other important parameters to investigate when dealing with contamination are shaft speed, shaft hardness, duty cycles and down time. The Severity of Contamination can be ranked as fallowing:

Contamination Level	Description	Particle Type	Particle Size	Percent Cycle Exposure	Max Percent Submerged
5	Extreme	Impactment, slurry, water, dust, abrasive particles	Powdery, fine and large	75-100	100
4	Heavy	Dirt, mud, water	Powdery, fine and large	50-75	75
3	Moderate	Dirt, splashing	Small/ Moderate	25-50	25
2	Light	Air travel, dust	Small/ Moderate	0-25	0
1	None	None	None	0	0

CASE DESIGN

COUNTER OR STRAIGHT BORE

The bore type affects the positioning of the primary sealing lip and the O.D. sealability. A counter bore should be designed to control the position of the primary sealing lip. If the case has a nose gasket incorporated into the design, this gasket will provide additional O.D. sealing by forming a face seal. If the bore is straight, then a stopping mechanism needs to be included on the installation tool or a flanged case needs to be used.



Counter or Straight Bore.

Should be designed to control the position of the primary sealing lip.

HOUSING ASSEMBLY

SEAL DESIGN

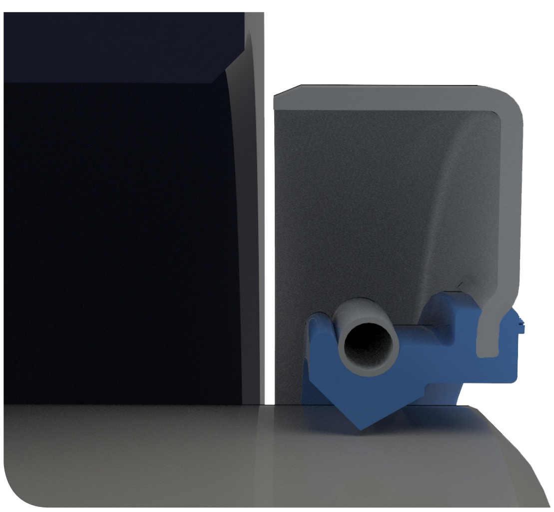
Radial shaft seals are pressed into a bore to form a static seal. The static seal can be created by a metal-metal, rubber-metal, or a combination interference.

The press fitting action positions the seal both axially and radially. The head and heel section are properly aligned if the outside face of the case is perpendicular to the shaft axis. The effect of poor installation is seal cocking or damage to the outside diameter.

Cocking is caused by improper installation methods. If there are such assembly space restrictions as a blind installation or no room to use the proper installation tool, alternative seal designs should be considered.

Failure to design a proper bore chamfer is the primary cause for damaging the seal O.D. A proper use of an installation chamfer allows for a positive pilot gap, positioning the seal against the chamfer prior to installation.

When a proper tool is used, installation forces, cocking and spring back are all minimized. The result is longer seal life and less chance of leakage. If a sufficient chamfer is not possible, a customized seal O.D. should be designed. Contact ESP International for design suggestions.



Housing Assembly.

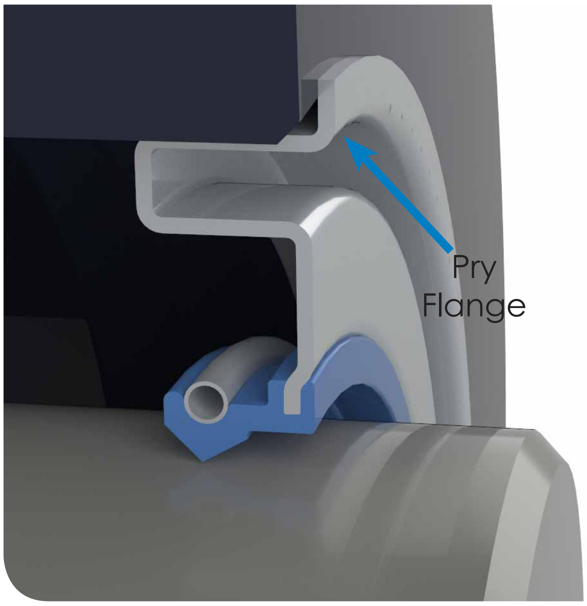
The proper use of an installation chamfer allows for a positive pilot gap.

SEAL DESIGN

REPLACEMENT AND EASE OF REMOVAL

If the radial shaft seal is in a system that is serviced often, then the type of static OD needs to be considered. Metal press-fit OD requires low installation forces but are difficult to remove. There are also small particles of the bore removed when a metal press-fit is uninstalled.

If an application requirs a dozen replacements over the life of the system, a metal press-fit would not be a proper choice. If ease of removal is important and the service may take place outside of a service shop then a pry flange may need to be incorporated into the design. These parameters should be considered and addressed early in the design process to save money and time for the aftermarket.



Ease of Removal.

If an application required several replacements over the life of the system, ease of removal is important.

SHAFT DIAMETER

Increasing shaft diameter results in higher frictional torque and required power. These increases will affect the underlip temperature and would require the revolutions per minute (RPM) to be lowered.

Because of associated costs and sealability it is preferred to minimize the shaft diameter of a radial shaft seal.

SHAFT HARDNESS

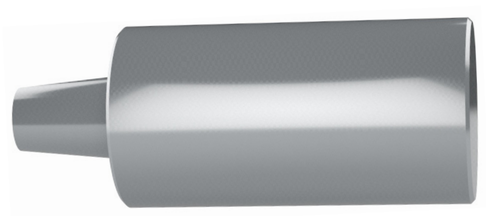
The shaft hardness is important for the contact width of the seal or for any part of the shaft that might contact the sealing lip. If the hardness is so soft that the shaft is susceptible to denting or nicking, then there could be seal damage caused during installation. A Rockwell hardness of 45 HRc or higher is recommended if the shaft is subject to being nicked by handling or assembly.

Such materials as bronze, brass and aluminum should not be used without a hardened steel wear sleeve because of excessive wear and grooving.

SHAFT SPEED

As shaft speed increases, the adverse effects of pressure, temperature, contamination, lead and wear all increase.

Sealing against extreme or heavy contamination is difficult for speeds above 500 ft/min. For these speeds, the frictional drag needs to be reduced to accommodate the high underlip temperature making it difficult to keep out contamination.



Shaft.

Increasing shaft diameter results in higher frictional torque and required power.

As shaft speeds reach 3000 ft/min the pumping action across the primary lip will begin to degradate, especially if there is a slight lead angle. A hydrodynamic aid may need to be added to the airside angle to counteract the loss in pumping action and increase the inward pumping rate. This will also help keep the film of lubrication under the contact width, decreasing the underlip temperature and increasing the life of the seal.

Speed (ft/min)	Classification
0-500	1
500-750	2
750-1750	3
1750-4000	4
4000 and up	5

SHAFT ASSEMBLY

Incorrect installation direction or the absence of a shaft chamfer can cause damage to the seal lip of cause it to roll during installation.

Shaft installation direction should be considered for triple lip profile types to insure proper lip orientation for dirt exclusion.

If the shaft chamfer is less than design specifications the chances of rolling the sealing lip increases. If the assembly area is restricted or there is a blind installation, an alternate seal profile may need to be selected.

FINISH TYPE AND LEAD

The finishing process on the shaft will affect the sealability of the system. The microscopic effects of how the fluid media reacts at the contact width determines the hardening rate of the elastomer materials.

The lead angle present on the shaft affects how the fluid transfers itself along the surface of the shaft. Lead acts as a screw during rotation. If the lead angle is along the direction of rotation and the angle is larger than 0.05°, leakage may occur.

Using the steps listed below, a simple process for determining the lead direction and angle can be followed.

SEAL DESIGN

PROCEDURE TO DETECT SHAFT LEAD	
STEP	DESCRIPTION
1	Mount shaft in holding chuck
2	Eliminate any wobbling or runout, level shaft
3	Loop a thin thread over the shaft
4	Attach a 1 oz (30 g) weight to thread with 2/3 contact
5	Set shaft rotation to 60 RPM
6	Observe thread movement in axial direction
7	Record results in both directions of rotation

After gathering data on the rate of axial movement of the thread, the lead angle can be calculated using the formula below:

$$\text{Lead Angle} = \text{ArcTan} \frac{\text{Axial Movement of String}}{(\text{Shaft Circumperence})(\text{No. of Revoluions})}$$

The lead angle of the shaft should be 0° ±0.05. Example: If a string advances 0.4" in 1minute on a 3.0" shaft rotating at 80 RPM.

$$\text{Lead Angle} = \text{ArcTan} \frac{0.4}{(3\pi)(80)}$$

For more detail information about finish type and lead, check Section 10 of SAE Fluid Sealing Handbook Radial Lip Seals (SAE J946).

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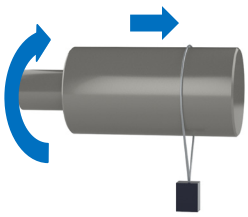
INTERPRETATION OF THREAD MOVEMENT

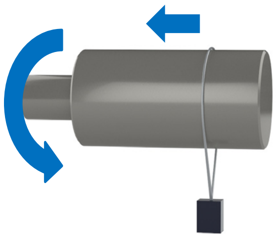
SEAL DESIGN

RIGHT HAND LEAD OR CW

CW Rotation: Moves from chucked end to free end

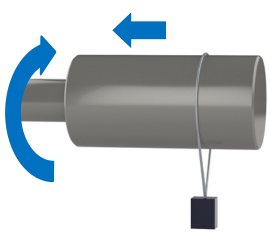


CCW Rotation: Moves from free end to chucked end

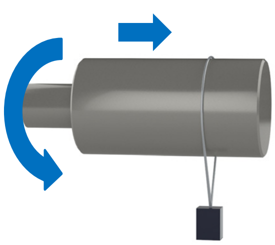


LEFT HAND LEAD OR CCW

CW Rotation: Moves from free end to chucked end

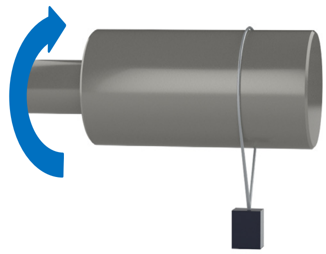


CCW Rotation: Moves from chucked end to free end

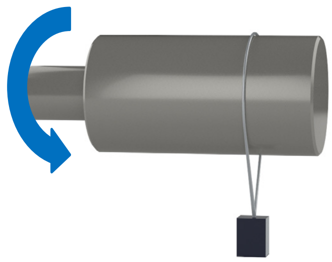


NO LEAD

CW Rotation: Stationary

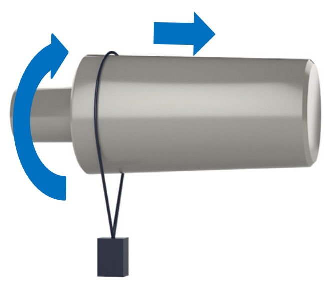


CCW Rotation: Stationary

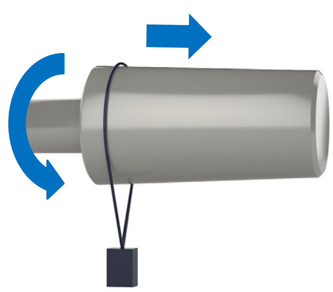


TAPERED SHAFT

CW Rotation: Moves in same direction no matter shaft rotation. Remounting the shaft reverses direction



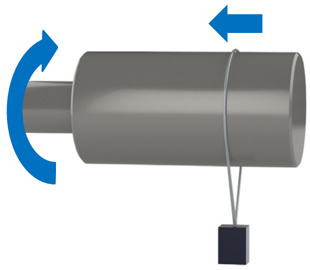
CCW Rotation: Moves in same direction no matter shaft rotation. Remounting the shaft reverses direction.



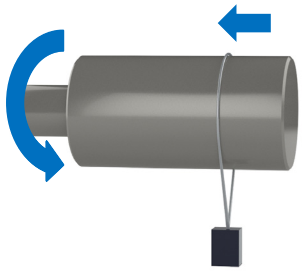
SEAL DESIGN

CUPPED SHAFT

CW Rotation: Moves toward center

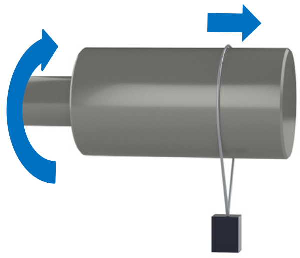


CCW Rotation: Moves toward center

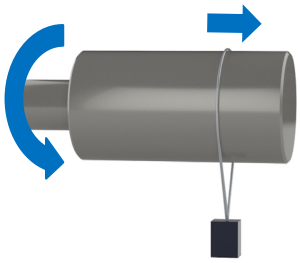


CROWNED SHAFT

CW Rotation: Moves away from center



CCW Rotation: Moves away from center



FERROUS OR NON-FERROUS

The choice of housing and shaft materials will affect the type of materials that can be used for the seal OD and lips.

The most common restriction when considering a housing material is the instance when two materials have a different coefficient of thermal expansion. This effect needs to be considered with larger diameter seals.

If a carbon steel case is pressed into an aluminum bore, a ten-inch diameter seal is more likely to experience OD leakage than a one-inch seal. When non-ferrous materials are used, other parameters should also be analyzed: hardness, surface finish and galvanic corrosion.

If a non-ferrous shaft must be used, contact ESP International for consultation.

Material	Type	Coefficient of Thermal Expansion
Steel	Ferrous	7 μ in/in-°F (12.6 μ m/m-°C)
Aluminum	Non-Ferrous	12.7 μ in/in-°F (22.9 μ m/m-°C)
Nitrile	Non-Ferrous	62 μ in/in-°F (111.6 μ m/m-°C)

SURFACE FINISH OR TEXTURE

The elastomeric lips of radial shaft seals have enough elasticity to insure that the lip will follow the normal form and waviness errors of a shaft to maintain a seal. However, the life of the seal is affected by the microscopic imperfections of the surface finish.

Surface finish, or texture, consists of peaks and valleys that make up a surface and their direction on the surface. During analysis, surface finish can be broken down into three components: roughness, waviness and form.

ROUGHNESS

Is a direct relation to tool marks. Every pass of a cutting tool leaves a groove of some width and depth. Roughness is also what can form a lead angle.

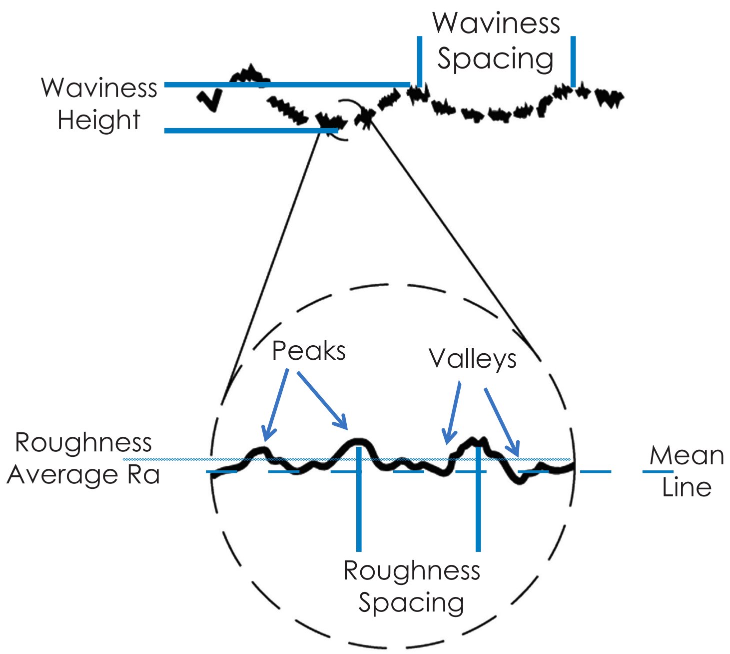
WAVINESS

Is the result of small fluctuations in the distance between the cutting tool and the work piece during machining. This is caused by cutting tool instability and vibration.

FORM ERROR

Is caused by lack of straightness or flatness in the machine tools. Form error is highly repeatable error, because the machine will follow the same path each time.

All these surface finish components exist simultaneously and are superimposed over one another. In some cases, these are determined separately but normally the total profile surface finish incorporates all three.



Surface finish.

Consists of peaks and valleys that make up a surface and their direction on the surface.

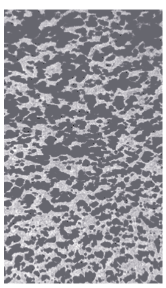
SURFACE PREPARATION

PLUNGE GRINDING

The grinding wheel is normal to the shaft axis at contact and does not traverse back and forth. The result is short to medium grinding marks that have little to no lead. This process can be relatively expensive but only needs to be performed in the seal contact region. Grade A.

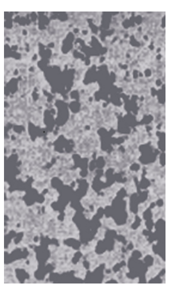
PAPER POLISHING

This method is very effective if constant pressure is applied over the width of the emery cloth. Automatic equipment is more consistent than polishing by hand. Grade B.



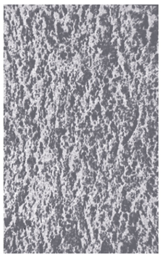
METAL PEENING

Small metal particles are impelled on the surface, imposing compressive stresses in the skin of the shaft. This is a secondary process that eliminates the potential of lead. Grade B.



GRIT BLASTING

Media such as sand is impelled onto the shaft as a secondary process. If correctly applied, machine lead can be eliminated. Grade B.



TUMBLING

Method produces a uniform aggregate apperance and removes minor surface irregularities. Grade C.

TRANSVERSE GRINDING

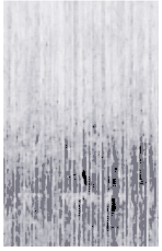
A centerless grinder is used as either the shaft or the wheel moves axially through the grind zone. This method can produce spiral grooves and can result in seal leakage. Grade D.

HONING

The resulting finish is a criss-crossing pattern that produces a pumping condition likely to cause a leakage. Grade F.

DIAMON BURNISHING

In this process the media moves axially and does not remove machine lead, but instead makes it worse. Grade F.



MACHINE TURNING

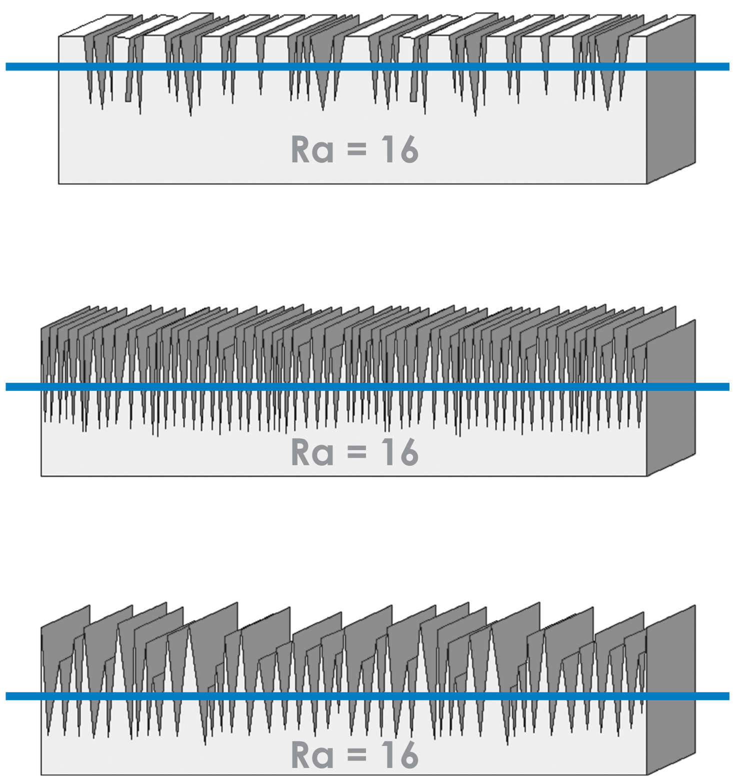
Machine turning will almos always generate lead and should be followed with a subsequent secondary operation. Grade F.

ROUGHNESS MEASUREMENT

SEAL DESIGN

Average roughness or Ra, is the parameter most widely specified and measured. The algorithm for Ra calculates the average height of the entire surface from a mean line. This is an effective way to monitor process stability, and it is used to control surface finish for radial shaft seals.

An important consideration when looking at Ra is that different surfaces may have the same Ra value with more wave heights and spacing. There are more than a dozen roughness parameters specified by ASME Standard B46.1. Many of these can be used to further control the surface finish. Contact ESP International for further discussion.



Surface finish.

Finishes with the same Ra but different surface profiles

CYCLE TIME / DOWN TIME

Cycle time and down time are parameters that when combined with other variables such as underlip temperature, shaft speed and contamination can either increase or decrease their effect on sealing.

The identification of the length of the cycle time will classify the severity of its affect on other parameters. An example of this is an application that runs continuously, it is expected to have a high negative effect on the underlip temperature. An alternate material or lip design may be chosen as a result.

Downtime is generally considered in combination with cycle time. The reason for this can be illustrated in an example where the cycle time is a level 1, but so is the down time.

The resultant effect is equivalent to a continuous cycle time even though the true cycle time is only 30 minutes or less.

Classification	Down Time
1	1 hr/Day
2	2-4 hr/Day
3	5-12 hr/Day
4	Days
5	Weeks
6	Seasonal

Classification	Cycle Time
1	30 min or less
2	1 hr
3	2-4 hr/Day
4	5-12 hr/Day
5	12-16 hr/Day
6	Continuous

SELECTING A RADIAL SHAFT SEAL

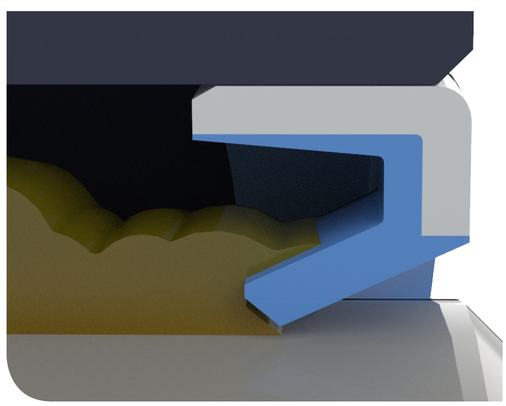
SEAL DESIGN

Deciding on the type of radial shaft seal is a challenging process that requires selecting specific seal design characteristics to match the system parameters. The design engineer should organize the potential parameters and prioritize them in order of severity and importance.

Selecting a radial shaft seal profile requires deciding the following: lip type, case type and the use of a hydrodynamic aid. There are many different radial shaft seal profiles available in the industry and a hydrodynamic aid can be added to the primary lip of most spring loaded lip styles. All three of these design variables need to be considered separately and then combined to form a radial shaft seal profile.

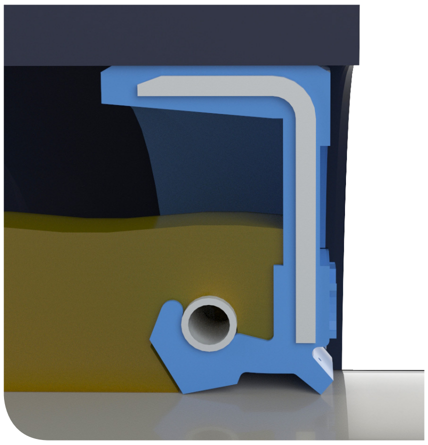
First consider the application basics. This will help to narrow the lip selection immediately. The application study below provides an example of a common separation that usually requires different lip styles. Developing your own application studies that are specific to your industry is a valuable selection tool.

APPLICATION STUDY:
Grease vs. Oil Retention



Grease Retention

The viscosity of grease is much higher than oil and is much easier to retain. Therefore, a non-spring loaded lip is both sufficient and cost effective for this applicatoin. If contamination is the primary control parameter, then the seal should be installed in the opposite direction shown above.



Oil Retention

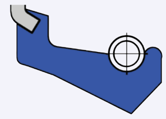
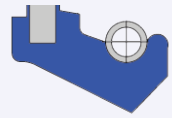
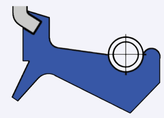
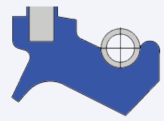
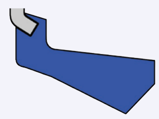
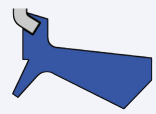
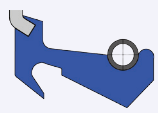
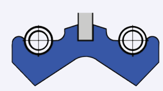
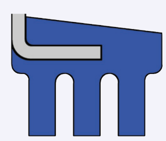
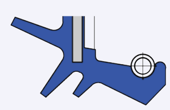
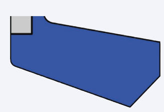
The retention of oil is a more challenging task than grease because of the low viscosity of oil. A spring is required to help maintain the proper radial load for sealing. The spring is installed facing the fluid and hydrodynamic aids are sometimes molded to the air side angle to assist in the sealing action.

LIP SELECTION

Lip style is directly related to the media type, shaft speed, pressure, temperature and contamination parameters. The media used in the application can go from oil and grease, to other types like water, food and dairy products. All of these will affect the choice of available styles.

The effectiveness of your radial shaft seal depends on the lip type selection. This is the most important design variable and will determine both the life expectancy and cost.

The following table shows the most common lip styles, their names, applications and descriptions. There are many other available lip styles when trying to accomodate special parameters or extreme environments.

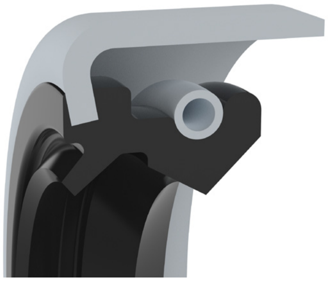
APPLICATION	LIP TYPE	DESCRIPTION	
Oil retention	Standard "S" Lip	This style of lip is used for standard pressure oil sealing in clean environments. May be reversed for extreme grease sealing.	
Oil retention for medium pressure applications	Standard "SN" Lip	This style of lip has a shortened flex section to accommodate medium pressure.	
Oil retention for dusty applications	Standard "T" Lip	This style of lip is used for standard pressure oil sealing in dusty/dirty environments.	
Oil retention for medium pressure applications	Standard "TN" Lip	This style of lip has a shortened flex section to accomodate medium pressure	
Grease retention	Standard "V" Lip	This style of lip is used for standard pressure grease sealing in clean environments. May be reversed to purge grease cavity.	
Grease retension for dusty applications	Standard "K" Lip	This style of lip is used for standard pressure grease sealing in dusty/dirty environments.	
Oil retention for applications with low lubrication	Standard "X" Lip	This style of lip is used for standard pressure sealing of none lubricating fluids. Inverted dust lip retains grease near sealing lip.	
Separating two fluids	Standard "D" Lip	This style of lip is used for standard pressure separation of two fluids	
Gresase retention in heavy contamination environment	Standard "U" Lip	This style of lip is used for standard pressure grease sealing in extreme/heavy contamination environments. Flexible lips allow for purging of grease cavity from either direction.	
Grease retention in heavy contamination environment	Standard " T9" Lip	This style of lip is used for standard pressure grease sealing in extreme/heavy contamination environments. Lip on outside face is designed to act as an axial face seal.	
Contamination exclusion	Standard "WP" Lip	This style of lip used for scraping and wiping in hydraulic and pneumatic cylinder applications.	

SEAL DESIGN

CASE SELECTION

The most common and cost effective case materials are stamped from cold rolled carbon steel. The steel is then phosphate coated to aid in the molding process and to help eliminate corrosion during storage. Other case materials include stainless steel, brass and aluminum. These materials are considered special because of their additional cost, and are not typically used. The other option for case materials is fully coated or partially coated rubber. Carbon steel cans are usually selected for rubber molded options.

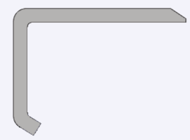
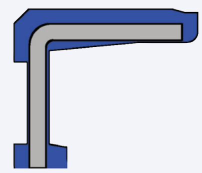
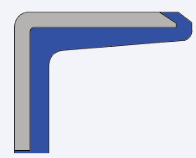
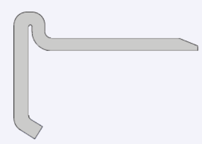
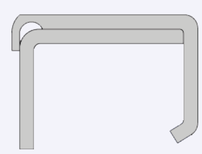
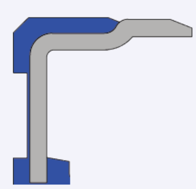
The case geometry controls the positioning and rigidity of the seal lips. Often overlooked, the case type can affect the life of the sealing system. The case forms a static OD radial seal and is susceptible to leakage if not properly designed. The table on the next page shows common case geometries and their advantages.



Case Selection.

Different case styles for radial shaft seals.

SEAL DESIGN

APPLICATION	LIP TYPE	DESCRIPTION	
Spring back is not acceptable Ease of installation	Standard "L" Case	This style of case is the most common and economical design. A chamfer or curl is used to aid in installation.	
Soft alloy housing Frequent removal High surface roughness	Rubber Covered Case	This style of case is used for sorft alloy or plastic housing. Used for frequent removal and installation when damage to housing bore is a concern.	
High surface roughness Counter bore Corrosion by sealing fluid	Nose Gasket Case	This style of case is an economial design used when surface roughness is outside specified limits. Also for use when corrosion by sealing fluid could be a problem.	
Ease of removal Field install	Shotgun Case	This style of case is an economical design used when frequent removal is necessary. Also aids in installation when a field install may be needed.	
Blind installation of shaft Structural rigidity	Secondary or Inner Case	This style is used when damage may occur to the sealing lip when shaft is installed. Also adds structural rigidity to radial shaft seal.	
Reduce spring back Ease of installation	Heel Case	This style combines the ease of installation of metal OD seal with OD sealability of rubber covered case.	

LIP MATERIAL SELECTION

SEAL DESIGN

Selecting an elastomeric material is important to the life of a radial shaft seal. The elastomer's resistance to temperature, abrasion, chemicals, weather, sunlight and ozone can affect a profile's success in an application. The base polymer must be selected to ensure that these parameters are satisfied without creating excessive cost.

There are a variety of compounds available depending on the system parameters. For parameters or chemicals that are not listed, contact ESP International for more information.

Properties	Nitrile	Ethylene Propylene	Fluorocarbon	Silicon	Polyacrylate	HNBR	PTFE (Teflon)
Temp. °F Temp. °C	(-40) - 250 (-40) - 120	(-50) - 300 (-45) - 150	(-30) - 400 (-34) - 200	(-80) - 350 (-60) - 175	(-30) - 300 (-34) - 150	(-10) - 300 (-23) - 150	(-100) - 500 (-75) - 250
Abrasive Resistance	Good to Excellent	Good to Excellent	Good	Poor to Good	Fair to Good	Good to Excellent	Poor to Good
Solvent Resistance							
Aliphatic Hydrocarbons	Good to Excellent	Poor	Excellent	Poor to Fair	Excellent	Good to Excellent	Outstanding
Aromatic Hydrocarbons	Fair to Good	Poor	Excellent	Poor	Poor to Good	Poor to Fair	Outstanding
Ketones	Poor	Good to Excellent	Poor	Poor	Poor	Poor	Outstanding
Lacquer Solvents	Fair	Poor	Poor	Poor	Poor	Fair	Outstanding
Resistance							
Weather	Poor to Fair	Excellent	Excellent	Excellent	Excellent	Good to Excellent	Excellent
Sunlight	Poor	Outstanding	Good to Outstanding	Excellent	Good to Excellent	Fair to Good	Outstanding
Ozone	Poor to Fair	Good to Excellent	Outstanding	Excellent to Outstanding	Good to Excellent	Good to Excellent	Outstanding

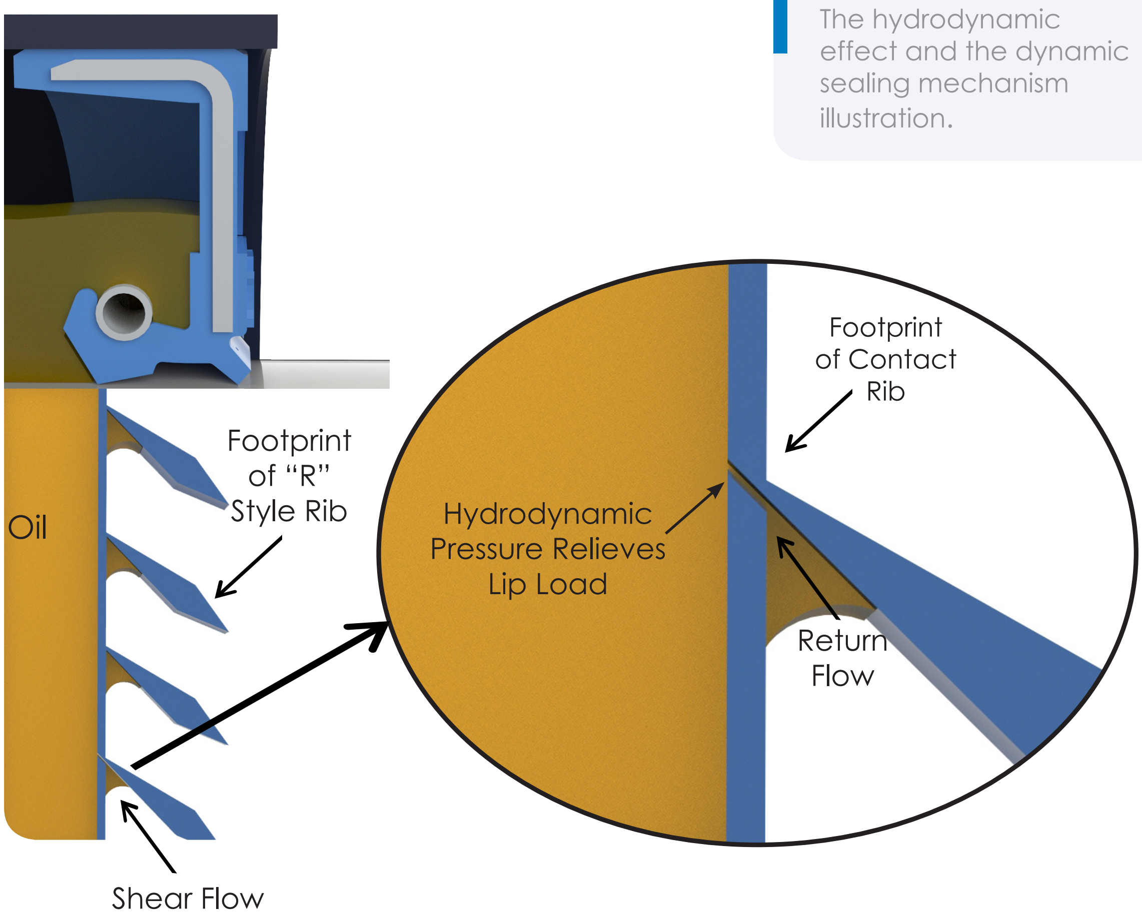
HYDRODYNAMIC SEALING AIDS

The hydrodynamic effect and the dynamic sealing mechanism discussed earlier in this chapter provide an explanation of how a radial shaft seal works in application. The pumping action provides continuous lubrication for the contact width of the elastomer lip.

When certain parameters are pushed to extremes – such as shaft speed, lead and viscosity – the pumping mechanism needs some support.

Hydrodynamics Sealing Aids.

The hydrodynamic effect and the dynamic sealing mechanism illustration.

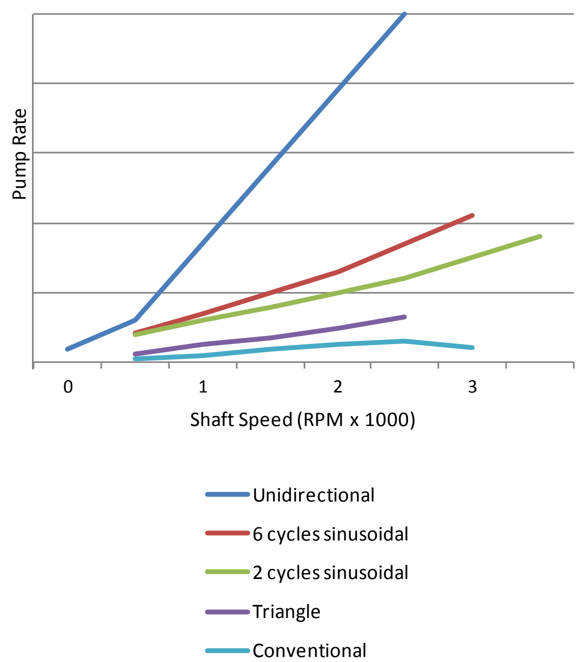


SEAL DESIGN

Hydrodynamic sealing aids assist in the dynamic sealing mechanism, and increase the pumping rate back to sump. Oil that escapes past the contact width is forced back by the rotating shaft into the converging space between the rib and the lip.

The benefit of using hydrodynamic aids is the increase of underlip pressure, decrease in friction, lower running temperature and ultimately can provide longer life. In cases where there is potential for small scratches and nicks on the shaft in the contact region, aids are used to overcome the potential for dynamic leakage.

Hydrodynamic aids are available in different patterns and as both unidirectional and bidirectional. Unidirectional aids are for both clockwise or counter clockwise shaft rotation. Be aware using a clockwise unidirectional aid in a counterclockwise application will result in a large fluid leak. As the hydro-aids will act in reverse, pumping oil out of the sump.

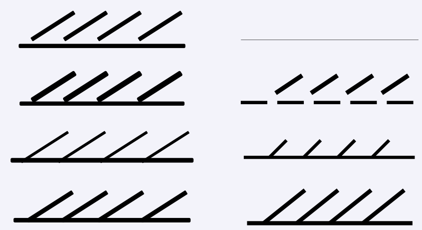


Hydrodynamics Sealing Aids.

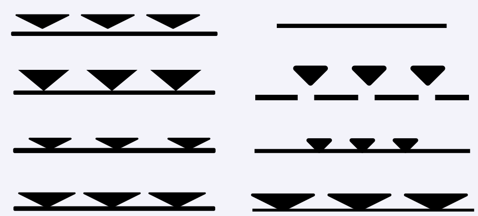
The chart shows the different pump rates that various hydrodynamic sealing aids have.

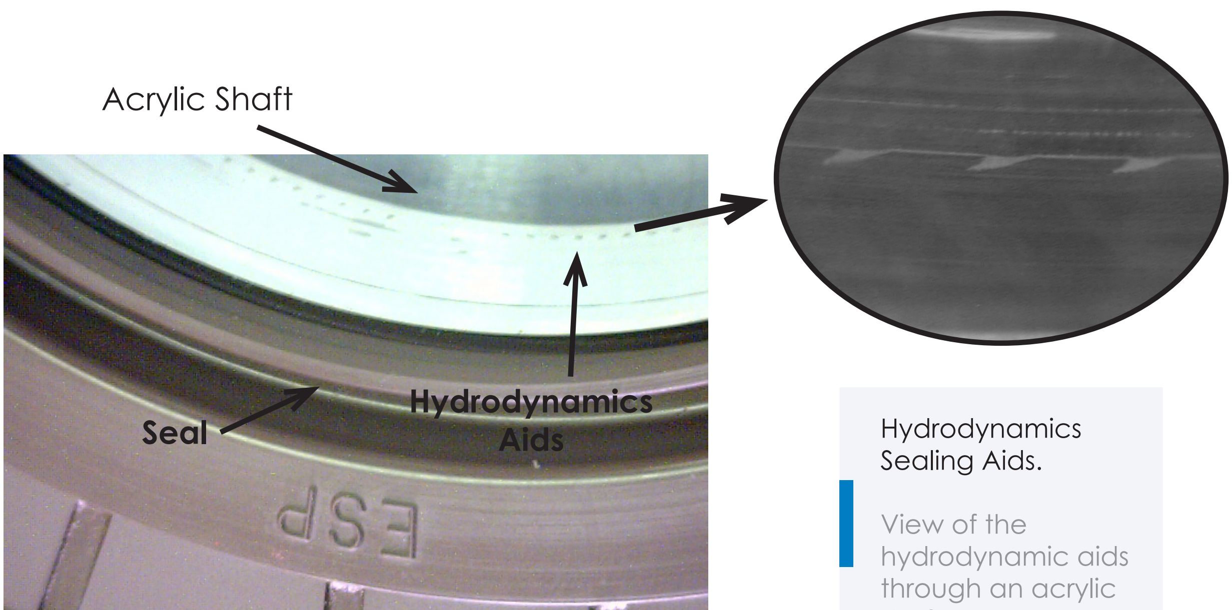
The actual hyrdro aid has very specific geometry requirements. The most common issues are shown below and can be detected by installation on an acrylic shaft.

UNIDIRECTIONAL HELIX RIBS
No contact with primary lip
Helix ribs too high
Helix ribs too shallow
Good helix ribs and contact pattern



BIROTATIONAL PADS
No contact with primary lip
Pads too high
Pads too shallow
Good pads and contact pattern





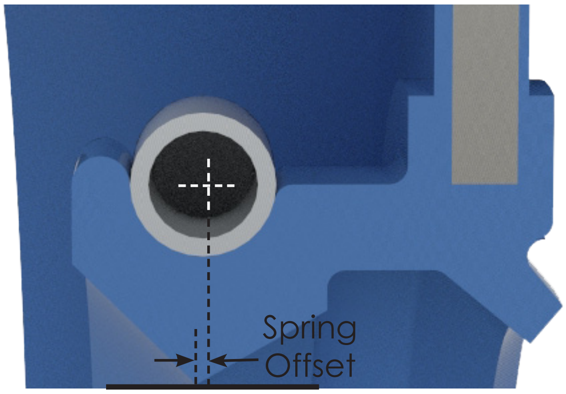
Hydrodynamics Sealing Aids.

View of the hydrodynamic aids through an acrylic shaft.

THE SPRING

When the fluid being sealed has high viscosity, the seal does not need a garter spring because the fluid will not flow easily. But when the fluid has low viscosity, like oil for example, the seal needs to have a garter spring to keep the lip pressed onto the shaft. Also, after the lip material has swelled and softened the spring increases the ability of the lip to follow the shaft dynamics.

Spring location is critical in a seal design, the spring must be set back from the lip towards the air side. Failing to do this will produce an inadequate pressure profile at the lip point and will result in a seal that leaks.



Spring Offset.

The spring must be set back from the lip towards the air side.

CUSTOM PROFILE DESIGN

The process of choosing a radial shaft seal to match all of the system parameters is often challenging, and in some cases not possible with standard profile designs. Each application should be reviewed in detail and the appropriate seal selected for the application. At times a standard cross section will suit a particular application, but in difficult/non-standard applications a custom seal can be designed with little effort.

The future of radial shaft seals is centered around the relationship of the customer and manufacturer. ESP International is dedicated to provide technical solutions at a competitive price. Proposing a custom design solution is not as valuable if the tooling cost is too high to consider prototyping. Our engineering department recognizes this and is confident that we can offer designed solutions at a competitive price.

SHAFT SPECIFICATIONS

SHAFT MATERIAL:

SEAL DESIGN

Most shafts are made from a carbon steel or cast iron, typically a material that can produce a surface hardness above 30 HRc is recommended.

Chrome or nickel plating can provide a hard surface and prevent corrosion in harsh environments. Brass, bronze, aluminum, zinc, magnesium and other soft metals should not be used due to the excessive shaft wear and grooving. Wear sleeves of mild steel should be pressed over the shaft if these materials are used.

SHAFT HARDNESS: Rockwell C30

The seal contact area of the shaft should be hardened to a minimum of 30 HRc under normal conditions. There is no conclusive evidence that a hardness above HRc will improve wear resistance except under extreme abrasive conditions. A Rockwell hardness of 45 HRc or higher is recommended if the shaft is subject to being nicked by handling prior to assembly.

SHAFT SURFACE FINISH: 10-20 Micro Inches

Seal leakage in some applications could be directly linked to such shaft imperfections as machining lead. Therefore, machine lead is held to a tight tolerance of 0°±0.05°. Seal countersurfaces should be plunge ground to 10-20 micro-inches Ra roughness (0.25-0.50 micro-meters) in order to create satisfactory sealing performance.

Machining Lead:	<0°±0.05°
Grinding Chatter:	No grinding chatter allowed > 45 cycles
Roundness:	Out of roundness must be less than 0.0002" (0.00508 mm) and a minimum number of lobes
Lobing:	Maximum of 7 lobes at 0.0001"

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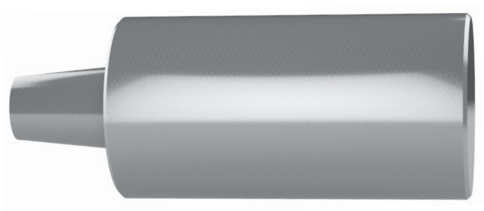
SHAFT TOLERANCE

Shaft tolerances are normally held tight because they are often used in conjunction with bearings or bushings. In general applications, be sure the shaft diameter is within the following recommended tolerances. The tolerance range should be decreased for high speed or high pressure applications.

Shaft Diameter (millimeters)	Tolerance
Over 6 to 10	+0.000/-0.090
Over 10 to 18	+0.000/-0.110
Over 18 to 30	+0.000/-0.130
Over 30 to 50	+0.000/-0.160
Over 50 to 80	+0.000/-0.190
Over 80 to 120	+0.000/-0.220
Over 120 to 180	+0.000/-0.250
Over 180 to 250	+0.000/-0.290
Over 250 to 315	+0.000/-0.320
Over 350 to 400	+0.000/-0.360
Over 400 to 500	+0.000/-0.400

Shaft Diameter (inches)	Tolerance
Up to and including 4.000	±0.003
4.001 to 6.000	±0.004
6.001 to 10.000	±0.005
10.001 and larger	±0.006



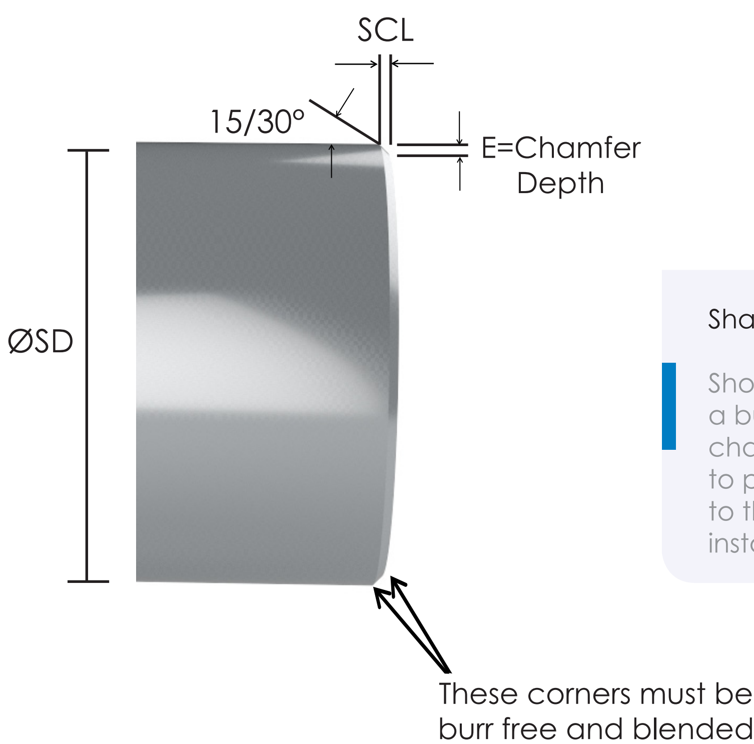
Shaft Specifications.

When designing the shaft, the material, hardness, surface finish and tolerance need to be considered.

SEAL DESIGN

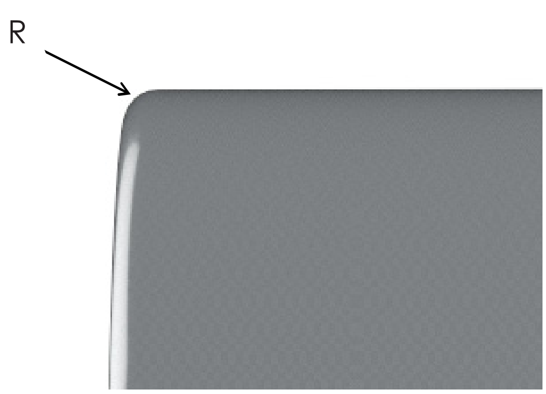
SHAFT CHAMFER OR LEAD IN RADIUS

A shaft should always have a burr free lead-in chamfer or radius to prevent damage to radial shaft seal during installation. The chamfer or radius allows the seal to change from its free diameter to the installed diameter without the sealing lip rolling or tearing. If a shaft does not have the recommended lead-in chamfer or radius, an assembly cone should be used during installation.



Shaft Chamfer.

Should always have a burr free lead-in chamfer or radius to prevent damage to the seal during installation.



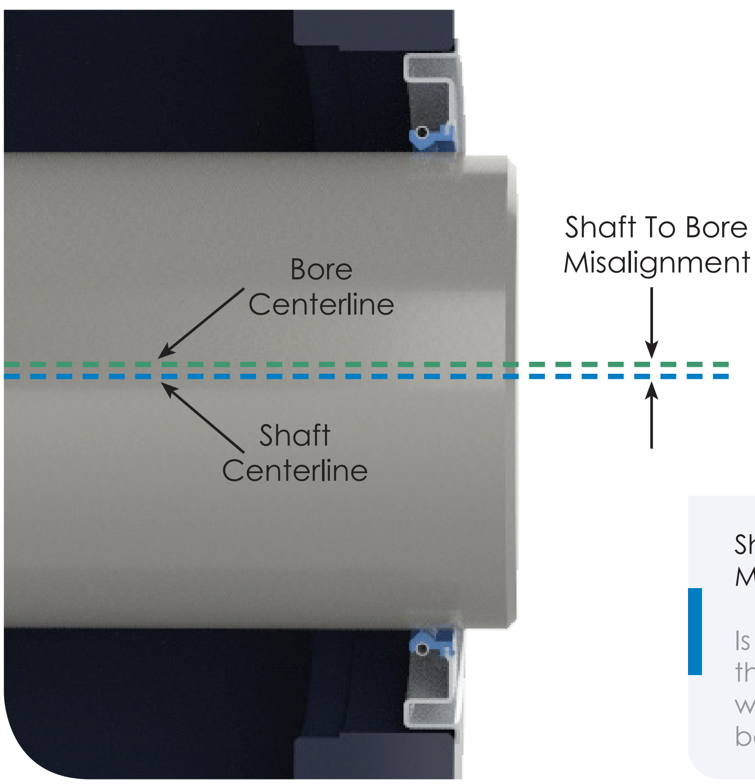
Shaft Dia. ØSD (inches)	E	R	Preferred SCL@15°	Optional SCL@30°
Up to 4.000	0.093	0.188	0.347	0.156
4.001 to 7.000	0.125	0.250	0.466	0.218
7.001 to 40.000	0.188	0.375	0.702	0.323
40.001 and up	0.250	0.500	0.933	0.433

Shaft Dia. ØSD (millimeters)	E	R	Preferred SCL@15°	Optional SCL@30°
Up to 100.0	2.5	4.5	8.5	4.0
100.1 to 180.0	3.0	6.0	11.5	5.0
180.1 to 1000.0	5.0	9.5	18.0	8.0
1000.1 and larger	6.5	12.7	24.0	11.0

SHAFT ECCENTRICITY

To ensure a high performing radial shaft seal, Shaft-To-Bore-Misalignment (STBM) and Dynamic Run-Out (DRO) should be kept to a minimum.

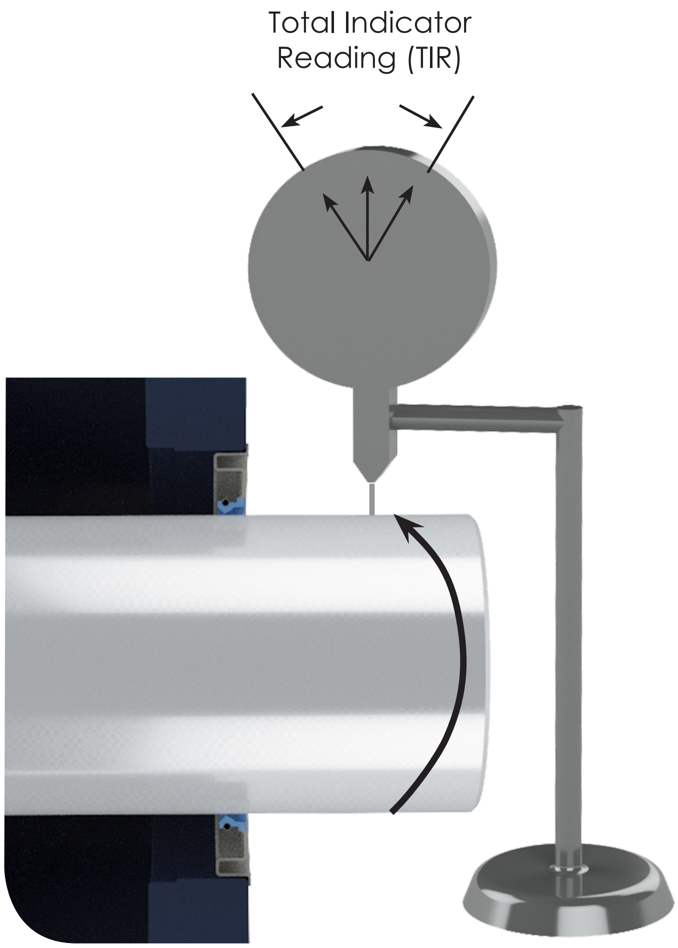
STBM is the amount by which the shaft is off center with respect to the bore's center. STBM is caused by machining and assembly inaccuracies. To measure, attach a dial indicator to the shaft (between shaft and bore), rotate the shaft and read the indicator. STBM is HALF the Total Indicator Reading (TIR).



Shaft-To-Bore-Misalignment.

Is the amount by which the shaft is off center with respect to the bore's center.

DRO is the amount by which the shaft does not rotate around the true center. Misalignment, shaft bending, lack of shaft balance and other manufacturing inaccuracies are common causes. To measure, slowly rotate the shaft and read the TIR of a dial indicator as shown below.



Dynamic-Run-Out.

Is the amount by which the shaft does not rotate around the true center.

BORE SPECIFICATIONS

BORE MATERIAL

SEAL DESIGN

Ferrous metal such as steel and cast iron are acceptable, but aluminum and plastic housings may also be used. If an aluminum or plastic housing is used, then a rubber OD radial lip seal is recommended due to the differences in thermal expansion between the seal and the housing, because rubber has a higher thermal expansion than carbon steel, rubber will tighten in the bore as the temperature rises.

BORE SURFACE FINISH: 100 micro-inches

Excessively rough bore finishes may allow paths for fluid to leak between the radial lip seal OD and bore. For metal OD radial lip seals, a maximum bore finish of approximately 100 micro-inches (2.5 micro-meters) should be maintained to avoid leakage.

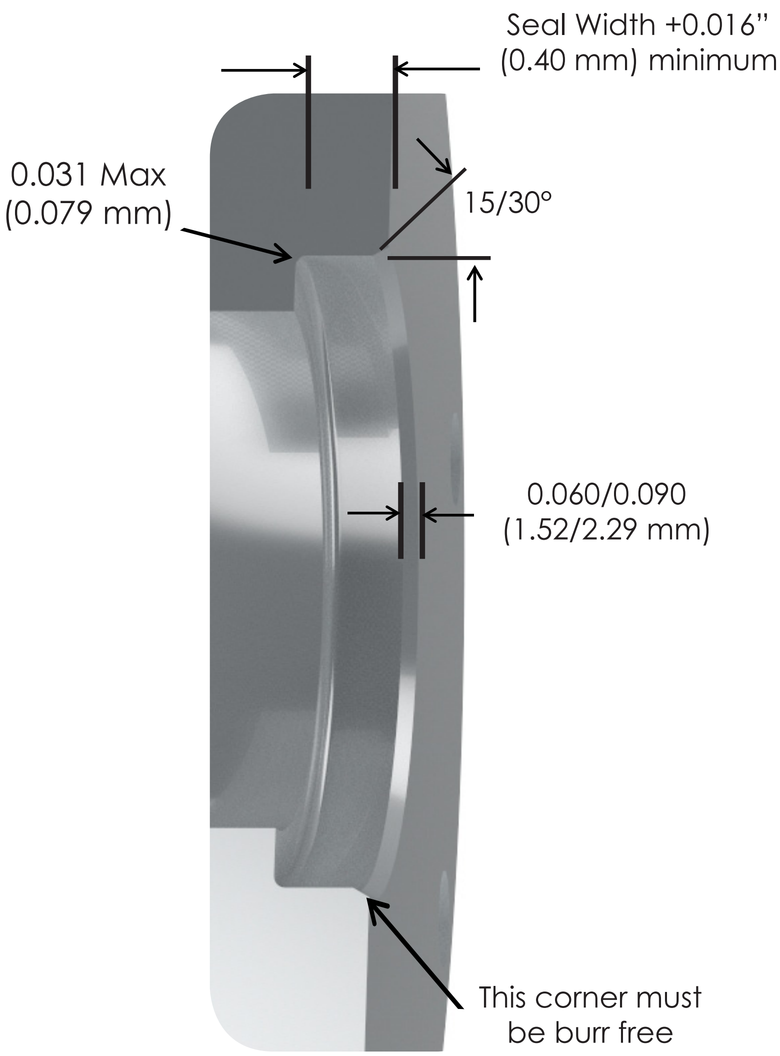
For rubber OD radial lip seals, a maximum bore finish of approximately 150 micro-inches (3.7 micro-meters) should be maintained to avoid leakage. Rubber will conform to the housing roughness and allows the rubber OD radial lip seal to function with a rougher finish.

BORE HARDNESS

No specific hardness is recommended here. However, bore hardness should be high enough to maintain interference with the seal's outside diameter after it is installed. If the bore is too soft and a seal is installed, the material in the bore will likely be abraded away, allowing the seal to be installed, but resulting in a reduced interference fit with the bore due to the abraded material.

BORE CHAMFER AND DEPTH

The bore should always have a burr free lead in chamfer to allow for problem free installation of the radial shaft seal. The inside corner should have a maximum radius of 0.03" (0.8mm).



Bore Chamfer.

Should always have a burr free lead-in chamfer to allow for problem free intallation of the seal.

BORE TOLERANCE

The interference between the radial shaft seal and bore is controlled by the bore and seal OD tolerance. A seal's press-fit is designed according to the following standard.

Bore Diameter (inches)	Tolerance
Up to and including 2.000	±0.001
2.001 to 3.000	±0.001
3.001 to 5.000	±0.0015
5.001 to 7.000	±0.0015
7.001 to 12.000	±0.002
12.001 to 20.000	+0.002/-0.004

Bore Diameter (millimeters)	Tolerance
Over 6 to 10	+0.022/-0.000
Over 10 to 18	+0.027/-0.000
Over 18 to 30	+0.033/-0.000
Over 30 to 50	+0.039/-0.000
Over 50 to 80	+0.046/-0.000
Over 80 to 120	+0.054/-0.000
Over 120 to 180	+0.063/-0.000
Over 180 to 250	+0.072/-0.000
Over 250 to 315	+0.081/-0.000
Over 315 to 400	+0.089/-0.000
Over 400 to 500	+0.097/-0.000

RADIAL SHAFT SEAL INSPECTION TOLERANCES

SEAL DESIGN

Radial Shaft Seal Width Tolerance		
Units	Width Range	Tolerance
Inches	All	+0.015/-0.015
Millimeters	Up to 10	+0.20/-0.20
Millimeters	Over 10	+0.30/-0.30

Radial Shaft Seal Press Fit Allowance (millimeter)			
Bore Dia. (millimeters)	Metal Case	Rubber Covered Case	Permissible Eccentricity
Up to 50.0	+0.20/+0.10	+0.30/+0.15	0.25
50.1 to 80.0	+0.23/+0.13	+0.35/+0.20	0.35
80.1 to 120.0	+0.25/+0.15	+0.35/+0.20	0.50
120.1 to180.0	+0.28/+0.18	+0.45/+0.25	0.65
180.1 to 300.0	+0.30/+0.20	+0.45/+0.25	0.80
300.1 to 500.0	+0.35/+0.23	+0.55/+0.30	1.00

Radial Shaft Seal Press Fit Allowance (inch)				
	Press-fit Allowance		Tolerance	
Bore Dia. (inches)	Metal Case	Rubber Covered Case	Metal Case	Rubber Covered Case
Up to 1.000	+0.004	+0.006	+0.002/-0.002	+0.003/-0.003
1.001 to 2.000	+0.004	+0.007	+0.002/-0.002	+0.003/-0.003
2.001 to 3.000	+0.004	+0.008	+0.002/-0.002	+0.003/-0.003
3.001 to 4.000	+0.005	+0.010	+0.002/-0.002	+0.004/-0.004
4.001 to 6.000	+0.005	+0.010	+0.003/-0.002	+0.004/-0.004
6.001 to 8.000	+0.006	+0.010	+0.003/-0.002	+0.004/-0.004
8.001 to 10.000	+0.008	+0.010	+0.004/-0.002	+0.004/-0.004
10.001 to 20.000	+0.008	+0.010	+0.006/-0.002	+0.004/-0.004