

Seal Design QuickFind

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The Evolution of Radial Lip Seals

The challenge of sealing against a dynamic surface has been around since the frontier era. The first known seals were leather straps used to retain animal fat on the end of a wheel axle. This crude method of sealing often leaked and required routine maintenance.

The Industrial Revolution spawned the development of engines, transmissions and gearboxes. All of these systems had challenging sealing requirements. The seals of the industrial age were organic ropes or packings.

These seals proved to be very effective until speeds, temperatures 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 take advantage of a metal pressfit as an outside diameter (O.D.) seal.

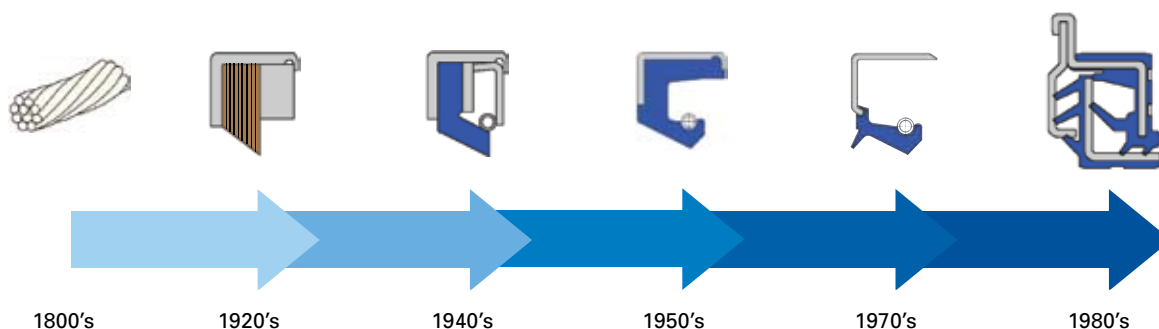
The most significant development in the evolution of the radial lip seal happened toward the end of World War II. A synthetic, oil-resistant rubber nitrile replaced the leather element, forever changing seal design. Methods for bonding rubber to metal soon followed



and, by the 1950's, direct bonded seals were available. High temperature elastomers were developed in the 1960's and included silicone, polyacrylate and fluorocarbon. The increased price of these materials encouraged manufacturers to reduce material volume to stay cost effective. The resulting seal of the 1970's remains one of the most common designs today.

The 1980's brought an important change in radial lip seal design. The dynamic sealing surface was incorporated into the seal assembly. Doing this created a series of lips with vertical and horizontal contact points. This integral system was the first step manufacturers took to take responsibility for the entire sealing system and not just the seal. This allowed them to provide a value added package, not just a commodity.

The future of radial lip seals will be centered around the relationship between customer and manufacturer. The advancement of machinery design will depend on these relationships; the first to be successful will lead the next phase in seal evolution.



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 the seal. If the design engineer does not know how shaft preparation affects the sealing mechanism, then **lead** 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.

Engineered Seal Products 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 organizes the industry standards for radial shaft seals.

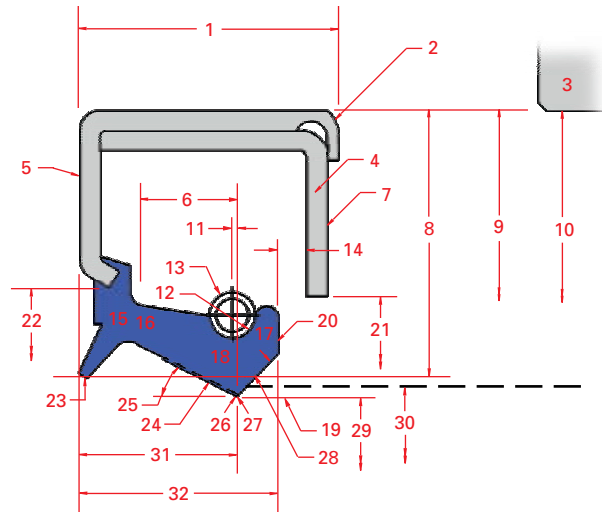
In the design process, engineers may not have time to research all of the operation details of each part. Often seal selection is compromised and the chance of failure increases. This handbook will reduce the research time without losing education.

Radial shaft seals are designed and selected based on profile characteristics. Before getting into the selection process it is important to get to know a typical cross-section. The sections listed below are the first step in the education process:

- **Profile Terminology**
- **The Hydrodynamic Effect**
- **Dynamic Sealing Mechanism**

Understanding fluid mechanics and terminology provides invaluable insight into why given design parameters can affect the life and efficiency of a radial shaft seal. The remaining sections of this chapter build on these concepts. These sections will provide information to select the correct profile, design a system that optimizes life and is cost effective.

Radial Shaft Seal Terminology



- | | | |
|---------------------------|---------------------------------|--------------------------------|
| 1. Case Width | 12. Spring Groove | 23. Secondary Lip |
| 2. Outer Case | 13. Garter Spring | 24. Outside Lip Surface |
| 3. Housing | 14. Axial Clearance | 25. Air Side Angle (β) |
| 4. Inner Case | 15. Heel Section | 26. Contact Width |
| 5. Outside Face | 16. Flex Section | 27. Static Lip |
| 6. Lip Length | 17. Spring Retaining Lip | 28. Inside Lip Surface |
| 7. Inside Face | 18. Head Section | 29. Lip Diameter |
| 8. Radial Wall Dimension | 19. Oil Side Angle (α) | 30. Unsprung Lip Diameter |
| 9. Seal Outer Diameter | 20. Toe Face | 31. Contact Line Height |
| 10. Housing Bore Diameter | 21. Inside Face Inner Diameter | 32. Lip Height |
| 11. Spring Axial Position | 22. Outer Case Inner Diameter | |

The Hydrodynamic Effect

Ever wonder how a radial lip seal can stop a reservoir of oil from leaking around a shaft rotating at 2000 rpm? The frictional heat created between two surfaces at this speed is enough to damage the shaft, let alone an elastomer material. So how does the lip material keep from burning up? The answer can be explained by taking an in-depth look at the hydrodynamic effect.

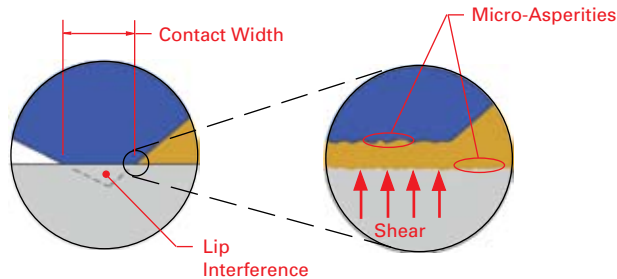
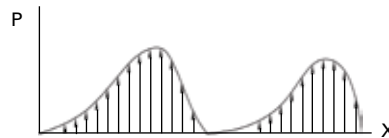


Figure 1: Hydrodynamic Effect (Detail of No. 26, page 16B)

The contact width, shown above, of a radial lip seal is created by the interference between the primary lip and shaft diameter. When these two bodies are at rest the oil is retained due the pre-load stresses of the elastomeric

material. As the shaft begins to rotate the seal lip remains stationary. The fluid is then drawn along the dynamic surface creating shear flow between the two bodies. There are many affects of this dynamic motion but the most important happen at the contact point of the seal lip and shaft. As the fluid converges toward the contact width, a pressure gradient is created. Because the two surfaces have roughness or micro-asperities, the hydrodynamic pressure profile of the contact width is shown in the following illustration.



This pressure profile, combined with the increased pressure gradient, lifts the seal lip away from the shaft, creating a film of fluid. This phenomenon is known as the hydrodynamic effect, and is the method by which the lip material avoids immediate hardening due to excessive frictional heat. In essence, the lip is riding on a layer of fluid and not the shaft.

Dynamic Sealing Mechanism

The Dynamic Sealing Mechanism or pumping action is how the fluid film created from the **Hydrodynamic Effect** is maintained without developing a leak. The pumping direction is a direct correlation to an asymmetrical contact pressure profile. This pressure profile is controlled by designing the proper oil side angle α , air side angle, β and spring offset distance (No. 11, page 16B). For the pumping action to work α needs to be larger than β . This creates a larger pressure gradient on the oil side. The garter spring is offset to the air side and helps maintain the air side angle. The result of properly controlling these design parameters is an asymmetrical contact pressure profile. When this profile is combined with microasperites in the seal lip's contact width, a net pump rate in the direction of the oil reservoir is created, therefore preserving the leak free

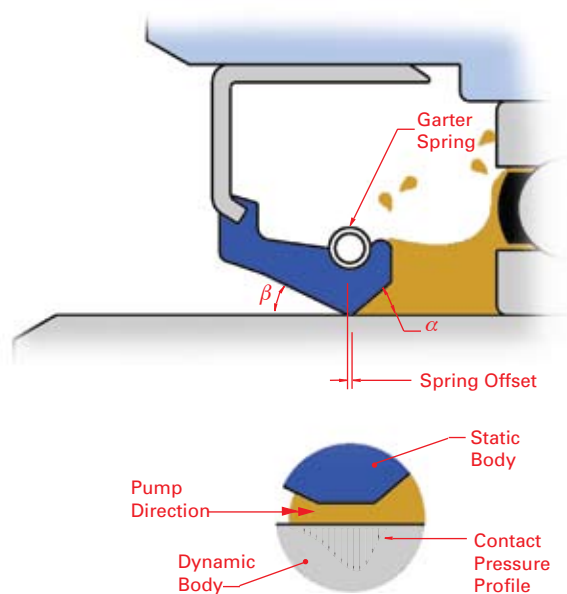


Figure 2: Dynamic Sealing Mechanism

Parameters Affecting Sealing

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

In Figure 3 there are four categories of system parameters that list common application variables. The remainder of this section will break down these variables and discuss how they affect seal profile selection and performance. On page 236K in the **Reference** section, there is a **Radial Shaft Seal Parameters Sheet** that helps organize these variables.

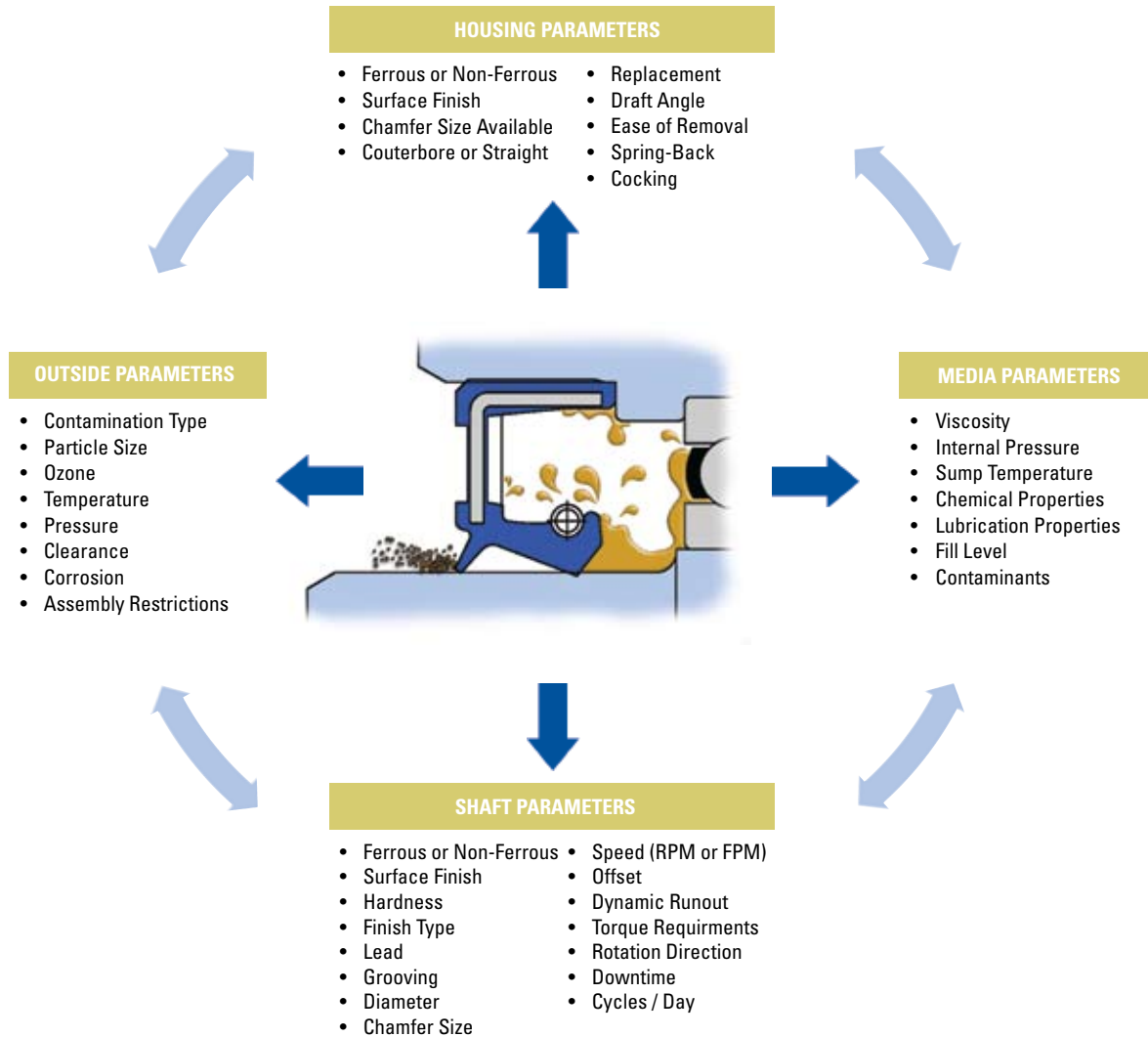


Figure 3: System parameters that make up a radial shaft seal environment; the shaft, housing, media and outside environment all affect profile selection.

Temperature

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

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

Sump temperature is the most common measure of the three temperatures. There is a direct correlation

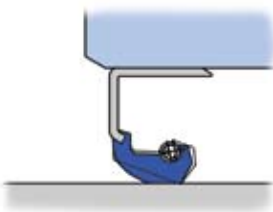
between seal life and sump temperature. Even if the seal is operating at a sump temperature that is within the given elastomeric temperature range does not mean that the seal life is not being compromised. If long life cycles are an important priority, then a low sump temperature is desired. If long life-cycles are not a priority, then a high sump temperature can have a positive affect 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 affect is higher underlip temperature. The material friction is dependant on elastomer properties, radial lip load and lubrication. As was discussed in the **Hydrodynamic Effect** section, if there is no fluid film available, the seal element would burn up because of extremely high underlip temperature.

The cumulative affect of all 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 affects 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 standard radial shaft seals 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

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

significantly reduced (See **Profile Matrix**, page 53D). To accomodate 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 engineering for recommendations.

Lubrication

Lubricants are used to reduce wear of dynamic mechanical components. Radial shaft seals keep these lubricants contained in a cavity or sump.

Referring to the **Hydrodynamic Effect** section, (Figure 1) a radial shaft seal rides on a film of fluid when rotating. This lubricant film is the primary reason the lip does not harden due to excessive heat. The dissipation properties of the lubricant are important and can impact the life of a radial shaft seal.

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 affect on the sealing element. The affect of a compatibility problem is often seen when the seal lip has experienced hardening without signs of heat or the lip is excessively soft from normal use. A complete list of the additives in the lubricant are essential for a thorough analysis. Table 1 shows a list of the different types of additives that may affect material selection (See **Fluid Compatibility**, page 35C). If lubricant additives are unknown, a Material Safety Data Sheet (MSDS) can be obtained, listing each additive.

Viscosity

Viscosity can be defined as the measured resistance to flow. The molecular weight and composition determine the viscosity. The Viscosity Index (VI) is a unitless measure of the tendency of the lubrication to change viscosity due to a change in temperature. A low VI suggests that the lubrication will have a significant change in viscosity with a small change in temperature.

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. Figure 4 shows the isothermal region at 1/2 shaft sump level. This is a good example of how the sump level affects the underlip temperature. 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 (Teflon) should be considered.

Table 1: Common Additives used in Lubricants

Additives	Chemical Compounds
Antifoamants	Silicone Polymers
Corrosion Inhibitors	Overbased Metallic Sulfonates Phenates, Fatty Amines
Detergents	Amines, Phenates, Succinimides
(EP) Antiwear Additives	Organic Phosphates, Chlorine, Sulfur 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	Esters, Amines, Sulfonates

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 (See **Hydrodynamic Aids**, page 30B).

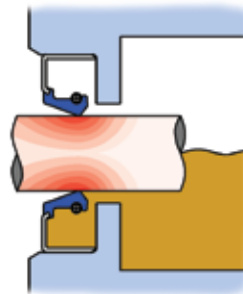


Figure 4: Underlip Temperature Distribution

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 Engineering.

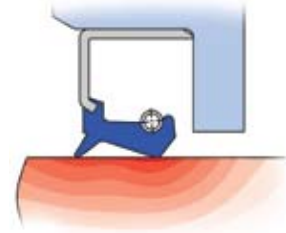
Contamination

The affect of contamination ingesting into a mechanical system can result in failure of bearings, gears and other dynamic parts. Recall from the **Hydrodynamic Effect** and the **Dynamic Sealing Mechanism** (Figures 1 and 2) 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. Once all four contamination variables have been identified refer to Table 2 to determine severity level.



includes radial shaft seal profiles having a secondary dust lip. This lip provides only minor protection and is often misused in applications. The affect 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 affect of high percentages of exposure and submergence results in the reduction of available profiles. Severity levels of 4 and 5 require special consideration of lip type, number and orientation. Contact ESP Engineering for design suggestions.

Other important parameters to investigate when dealing with contamination are shaft speed, shaft hardness, duty cycles and down time. Refer to the corresponding sections in this chapter once a contamination level has been chosen before selecting a radial shaft seal profile.

Most radial shaft seals are designed to operate under a level 1 or 2 contamination environment. This

Table 2: Classification Chart for Ranking the Severity of Contamination

Contamination Level	Description	Particle Type	Particle Size	Percent Cycle Exposure	Max. Percent Submerged
5	Extreme	Impactment, Slurry Water, Dust, Abrasive Particles	Powdery, Fine, & Large	75-100	100
4	Heavy	Dirt, Mud, Water	Powdery, Fine, & 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

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 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 lips. If the hardness is so soft that the shaft is susceptible to denting or nicking, then there could be seal damage done during installation. 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 affects of pressure, temperature, contamination, lead and wear all increase.

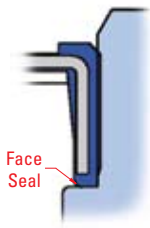
Sealing against extreme or heavy contamination is difficult for speeds above 500 ft/min. For these speeds, the frictional drag needs to be reduced to accommodate the high underlip temperature making it difficult to keep out contamination.

As shaft speeds reach 3000 feet per minute (FPM), the pumping action across the primary lip will begin to degradate, especially if there is a slight lead angle. A hydrodynamic aid (See **Hydrodynamic Aids**, page 30B) 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. After classifying the shaft speed, consult the **Operations Table**, page 56D, before selecting a profile.

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

Counter or Straight Bore



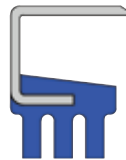
affects the positioning of the primary sealing lip and the O.D. sealability. A counter bore should be designed to control the position of the primary sealing lip. If the case has a nose gasket incorporated into the design, this gasket will provide additional



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 (See **Installation Methods**, page 64D) or a flanged case needs to be used.

Shaft Assembly

Incorrect installation direction or shaft chamfer can cause rolling or damage the sealing lip. 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 (See **Shaft Specifications**, page 59D)



the chances of rolling back the sealing lip increase. If the assembly area is restricted or there is a blind installation, an alternate seal profile may need to be selected.

Housing Assembly

Radial shaft seals are pressed into a bore (See page 22B for Bore Types) to form a static seal. The static seal can be created by a metal-metal, rubber-metal, or a combination interference. The pressfitting 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 affect of poor installation is seal cocking or damage to the outside diameter.

Cocking is caused by improper installation methods (See **Installation Methods**, page 64D). If there are such assembly space restrictions as a blind installation or no room to use the

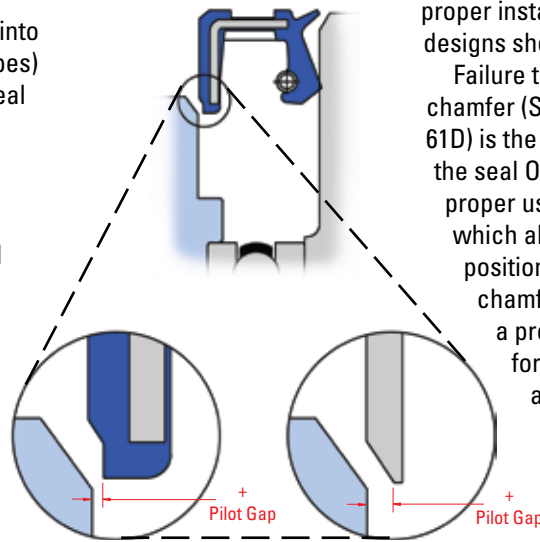


Figure 5. Correct Installation Chamfers

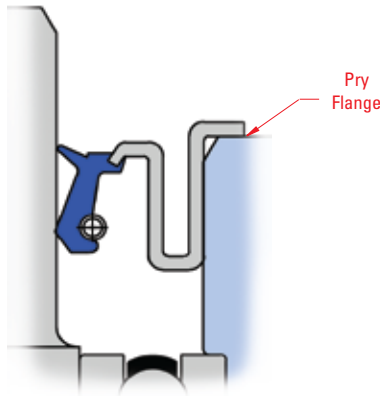
proper installation tool, alternative seal designs should be considered.

Failure to design a proper bore chamfer (See **Bore Specifications**, page 61D) is the primary cause for damaging the seal O.D. Figure 5 illustrates the proper use of an installation chamfer, which 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 Engineering for design suggestions.

Replacement and Ease of Removal

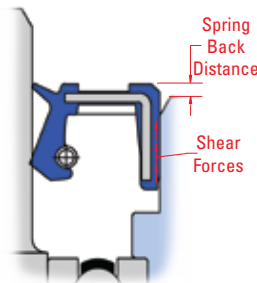
If the radial shaft seal is in a system that is serviced often, then the type of static O.D. needs to be considered. Metal press-fit O.D.s require low installation forces but are difficult to remove. There are also small particles of the bore removed when a metal press-fit is uninstalled. If an application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

Spring Back

Full rubber O.D. radial shaft seals are subject to spring back after installation. Although this may be caused by poor installation methods, the root cause of spring back is shear forces acting against the installation direction. The affect that this has is primarily related to the position of the primary sealing lip. Both the contact



width and the outer face position can vary axially as much as 0.060" (1.5 mm). Cocking can also result from uneven spring back. Both of these scenarios can reduce the life of the radial shaft seal. If the bore has a draft angle, then the spring back distance will be exaggerated and more likely to be a problem.

Finish Type and Lead

The finishing process on the shaft will affect the sealability of the system. Recall the **Hydrodynamic Effect** and the **Dynamic Sealing Mechanism** discussed earlier. 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. Interpret the data to determine the type of lead and the magnitude of the angle.



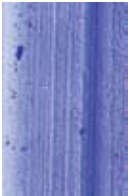

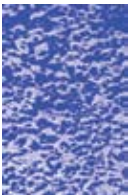

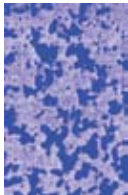


The type of finishing process is what determines the presence of lead. The roughness specification (See **Shaft Specifications**, page 59D) for a radial shaft seal is relatively low requiring a secondary machining of the shaft. The ideal finishing process leaves circumferential lines with no lead. Page 25B shows a variety of finishing processes profiled and graded according to their ability to eliminate lead.

Procedure to Detect Shaft Lead			
Step	Description	Step	Description
1	Mount shaft in holding chuck	5	Set shaft rotation to 60 RPM
2	Eliminate any wobbling or runout, level shaft	6	Observe thread movement in axial direction
3	Loop a thin thread over the shaft	7	Record results in both directions of rotation
4	Attach a 1 oz (30 g) weight to thread with 2/3 contact		

Interpretation	Interpretation of Thread Movement	
	CW Rotation	CCW Rotation
Right Hand Lead	Moves from chucked end to free end	Moves from free end to chucked end
Left Hand Lead	Moves from free end to chucked end	Moves from chucked end to free end
No Lead	Stationary	Stationary
On-Level Shaft	Moves in same direction no matter shaft rotation.	Same as CW
Tapered Shaft	Remounting the shaft end-for-end doesn't help. Moves in same direction no matter shaft rotation.	Same as CW
Cusped Shaft	Moves toward center	Moves toward center
Crowned shaft	Moves away from center	Moves away from center

$$\text{Lead Angle} = \text{ArcTan} \left[\frac{\text{Axial Movement of String}}{(\text{Shaft Circumference})(\text{No. of Revolutions})} \right]$$

Surface Preparation for Radial Lip Seals

Type of Surface Preparation	Description / Comments	Type of Surface Preparation	Description / Comments
<p>Plunge grinding</p> 	<p>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.</p> <p>Grade: A</p>	<p>Transverse grinding</p> 	<p>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.</p> <p>Grade: C</p>
<p>Paper polishing</p> 	<p>This method is very affective if constant pressure is applied over the width of the emery cloth. Automatic equipment is more consistent than polishing by hand.</p> <p>Grade: B</p>	<p>Roller burnishing</p> 	<p>This is a secondary process that uses rollers to compress the surface of the shaft. The shaft surface is only smoothed; lead and other defects remain.</p> <p>Grade: D</p>
<p>Metal peening</p> 	<p>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.</p> <p>Grade: B</p>	<p>Honing</p> 	<p>The resulting finish is a criss-crossing pattern that produces a pumping condition likely to cause seal leakage.</p> <p>Grade: F</p>
<p>Grit blasting</p> 	<p>Media such as sand is impelled onto the shaft as a secondary process. If correctly applied, machine lead can be eliminated.</p> <p>Grade: B</p>	<p>Diamond burnishing</p> 	<p>In this process the media moves axially and does not remove machine lead, but instead makes it worse.</p> <p>Grade: F</p>
<p>Tumbling</p> 	<p>Method produces a uniform aggregate appearance and removes minor surface irregularities.</p> <p>Grade: C</p>	<p>Machine turning</p> 	<p>Machine turning will almost always generate lead and should be followed with a subsequent secondary operation.</p> <p>Grade: F</p>

Ferrous or Non-Ferrous

The choice of housing and shaft materials will affect the type of materials that can be used for the seal O.D. and lips. The most common restriction is when two materials have a different coefficient of thermal expansion. This affect 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 O.D. 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 Engineering 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. When analyzing, 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. These marks can be seen on page 25B. 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 a highly repeatable error, because the machine will follow the same path each time.

All three 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.

Currently Ra, or average roughness, 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 outlined in Figure 6. It is reasonable to 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 Engineering for further discussion.

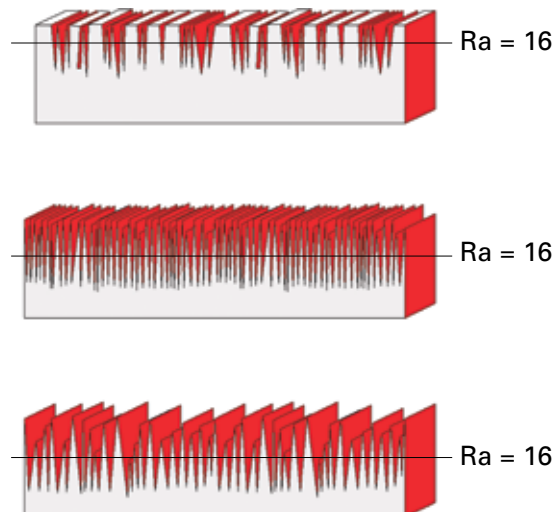
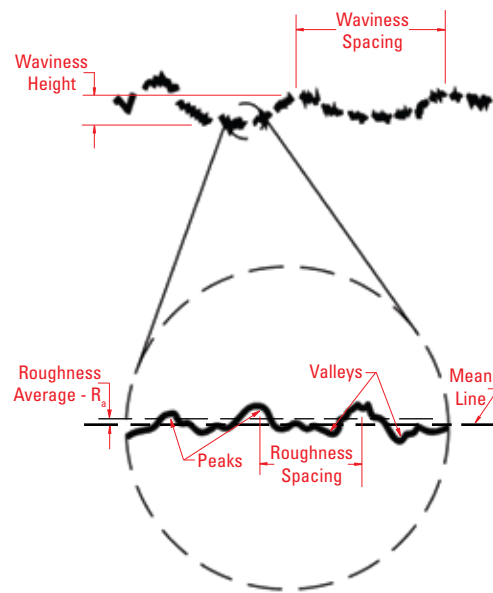


Figure 6. Different Finishes with the same Ra

Dynamic Run Out (DRO)

The dynamic run out of a shaft can be caused by shaft flexing, vibrations, lobbing and other inaccuracies. The DRO is the radial distance that the shaft does not rotate about its true center. To measure, slowly rotate the shaft and read the total movement (TIR) of a dial indicator as shown in Figure 7. The affect that DRO has on sealing is uneven wear and shortened seal life (See **Operations Table**, page 56D, for specifications).

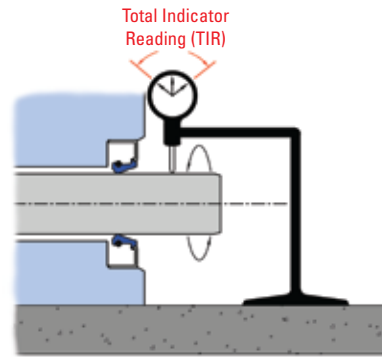


Figure 7: Method for Measuring DRO

Shaft Offset (STBM)

Shaft offset or Shaft-To-Bore Misalignment (STBM) is the radial distance between the axis of both the seal bore and rotation as shown in Figure 8. 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). The result of shaft offset is uneven wear and shortened seal life (See **Operations Table**, page 56D, for specifications).

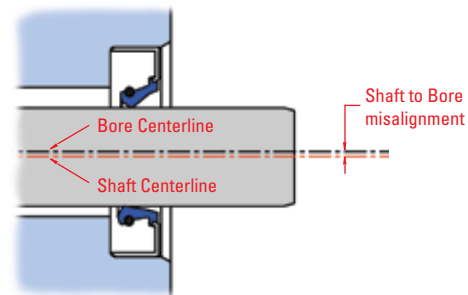


Figure 8: Definition of STBM

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 affect on sealing.

The identification of the length of cycle time will classify the severity of its affect on other parameters. An exmple of this is ian application that runs continuously, it is expected to have a high impact on the negative affect of 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. Use the tables below to help classify both cycle and down time.

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

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 prioritizes them in order of severity and importance. At the end of this chapter is a **Radial Shaft Seal Parameters Sheet** (page 32B) that will help organize these requirements. Performing this exercise will help clarify the driving variables of the sealing system.

The beginning of this chapter focused on the education of how radial shaft seals work and the parameters that affect a seal's environment. Using that knowledge to scan over a completed **Radial Shaft Seal Parameters Sheet** will help in selecting a few key parameters that will limit the profile selection. The more familiar you are with radial shaft seal parameters and their affects on sealing, the more comfortable you will be in selecting seal design variables. 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. All of these choices can be

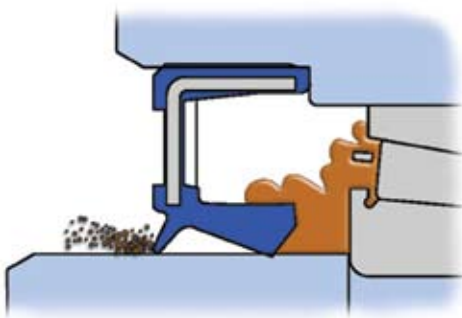
a challenge to a design engineer who does not know why certain lips and case geometries are used. For the purposes of design discussion, most case geometries can be paired with a lip style and vice versa. A hydrodynamic aid can be added to the primary lip of most spring loaded lip styles. All three of these design variables need to be considered separately and then combined to form a radial shaft seal profile.

For starters, 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. Use the following guidelines for profile selections:

- **Application Study**
- **Lip Selection**
- **Case Selection**
- **Hydrodynamic Aids**

Once these design variables have been chosen, a radial shaft seal profile can be selected (See **Profile Matrix**, page 48D).

Application Study: Grease vs. Oil Retention



Grease Retention

The viscosity of grease is much higher than oils and is much easier to retain. Therefore, a non-spring loaded lip is both sufficient and cost effective for this application.

If contamination is the primary control parameter, then the seal should be installed in the opposite direction shown above. Below are some other design options used for grease retention:



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. Below are some other design options used for oil retention.




Lip Selection

Lip style is directly related to the media type, **shaft speed, pressure, temperature and contamination** parameters. The media type discussed in the application study was grease versus oil retention. Other types of media include water, food and dairy products. All of these will affect the choice of available styles. Shaft speed, temperature and pressure parameters should all be reviewed in the parameter section to reveal their affect on sealing.

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

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.

Application	Lip Type	Description	Example
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 pressures.	
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 accommodate medium pressures.	
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 retention 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 non-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.	
Grease 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 is used for scraping and wiping in hydraulic and pneumatic cylinder applications.	

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



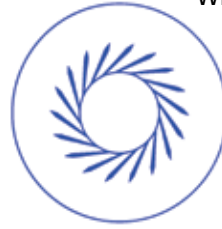
stainless steel, brass and aluminum. These materials are considered special because of their additional cost, and are not typically

used. The other option for case material 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 O.D. radial seal and is susceptible to leakage if not properly designed. The table below shows common case geometries and their advantages.

Hydrodynamic Sealing Aids







The **Hydrodynamic Effect** and the **Dynamic Sealing Mechanism** discussed earlier in this chapter provide and 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.

Hydrodynamic sealing aids assist in the **Dynamic Sealing Mechanism**, and increase the pumping rate back to sump. To

explain this phenomenon in more detail, Figure 9 on page 31B shows the footprint of a unidirectional hydrodynamic aid. The "L" style aid is a series of molded ribs located on the air side at an angle of 15° to 20° to the circumferential contact width. Oil that escapes past the contact width is forced back by the rotating shaft into the converging space between the rib and the lip.

Application	Case Type	Description	Example
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 soft alloy or plastic housings. 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 is an economical 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 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 O.D. seal with O.D. sealability of rubber covered case.	

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 either left or right shaft rotation. Mixing these two can result in catastrophic leakage. At the end of the **Profile Selection** chapter (page 58D), a chart shows the available aid patterns and their style designation.

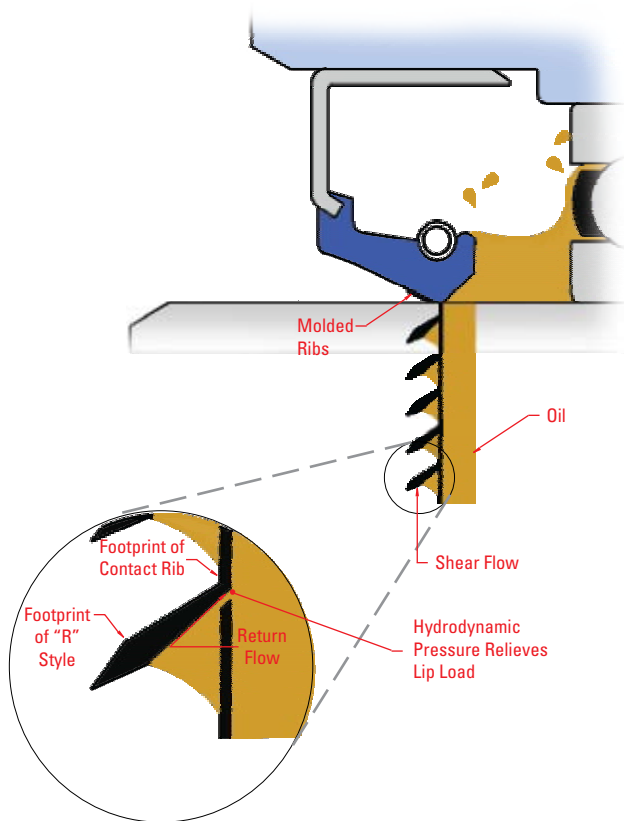
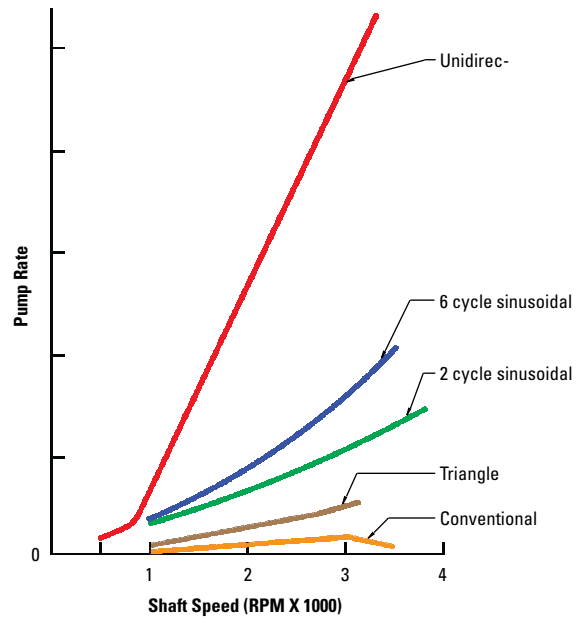


Figure 9: Schematic of Hydrodynamic Aids



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. Having the ability to tweak the case geometry to accommodate a small housing clearance can be the difference between selecting the proper lip style and compromising the system by using an alternative.

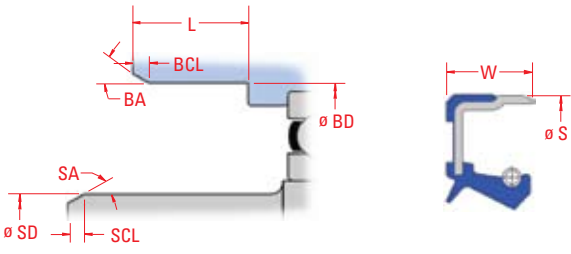
As discussed in the **Evolution Section** of this chapter, the future of radial shaft seals will be centered around the relationship of the customer and manufacturer.

Engineered Seal Products is dedicated to providing 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.

Radial Shaft Seals Parameters

Company: Contact Name: Phone:	Date: E-Mail: Fax:
-------------------------------------	--------------------------

Dim	Description	Value
SD	Shaft Diameter	
BD	Bore Diameter	
L	Bore Depth	
SA	Shaft Chamfer Angle	
SCL	Shaft Chamfer Length	
BA	Bore Chamfer Angle	
BCL	Bore Chamfer Length	
W	Seal Width	



Shaft

Horizontal

Vertical

Material: _____

Hardness: _____

Surface Finish: _____

Lead Angle: _____

Dynamic Run Out (DRO): _____

Bore

Straight Counterbore

Material: _____

Hardness: _____

Surface Finish: _____

Chamfer: Yes No

Shaft Motion

Rotating RPM: Normal Max

Shaft Speed Classification (Ft / Min) **

1 2 3 4 5

(0-500) (500-750) (750-1750) (1750-4000) (4000-Up)

Reciprocating Oscillating

Stroke Length: Normal Max

Degrees of Arc: Cyc / Min

Contamination Level **

1 2 3 4 5

Particle Type: _____

% of Exposure: _____

% Submerged: _____

Temperature **

Sump: Underlip: Outside:

Pressure (PSI) **

Standard Medium Low Medium High

(0-10) (10-50) (500-1000) (0-1500)


Assembly


Removal: Rare Often

Space Restrictions: Yes No

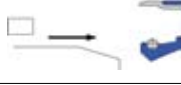
Pilot Gap: ** Yes No


Shaft Installation Direction





Installation Direction into Bore





Fluid / Lubrication

Grease Oil

Type: _____

VI Index: _____

Sump Fill Level: _____

Application Description:

Usage **

Cycle Time: 1 2 3 4 5

Down Time: 1 2 3 4 5

See **Design Information chapter (page 18B) for parameters explanation.