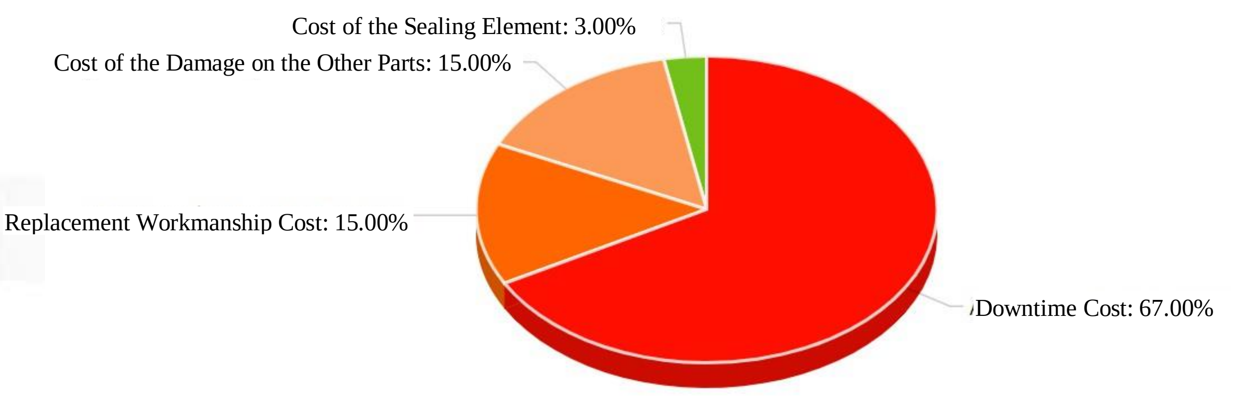
SEALING ELEMENTS

Sealing elements are known by different names such as rotary shaft seal, O-Ring, tool ring, bellows seal. They are generally elements that prevent all kinds of substances from leaking between moving or fixed machine parts. The prices of the sealing elements are too low to be compared with the prices of machines and tools.

Since the life of bearings, gears and other valuable machined parts depends on the quality of the sealing element, sealing elements are at least as important as other parts among machine elements. A truck leaking wheel seal oil may have to spend a working day at repair service or the engine of a vehicle leaking crank seal oil might need to be dismantled. Due to this well-known importance, sealing elements require advanced research, advanced technology and quality safety in production. Parts that are very similar to each other in terms of appearance may create unexpected and undesirable bad results in practice due to properties such as size tolerance, cross-sectional difference, and difference in material quality.

Although sealing elements may seem relatively simpler and cheaper than other machine elements, they can cause great damage in terms of cost in case of breakdown or failure.

Figure 1: Graph for possible financial loss of the vehicle in case of seal failure.



Regional Terms of Seals

Although a wide variety of seals are produced today, the areas of use of these seals can also vary considerably. The seal elements that should be present in almost every seal are shown in Figure 2.

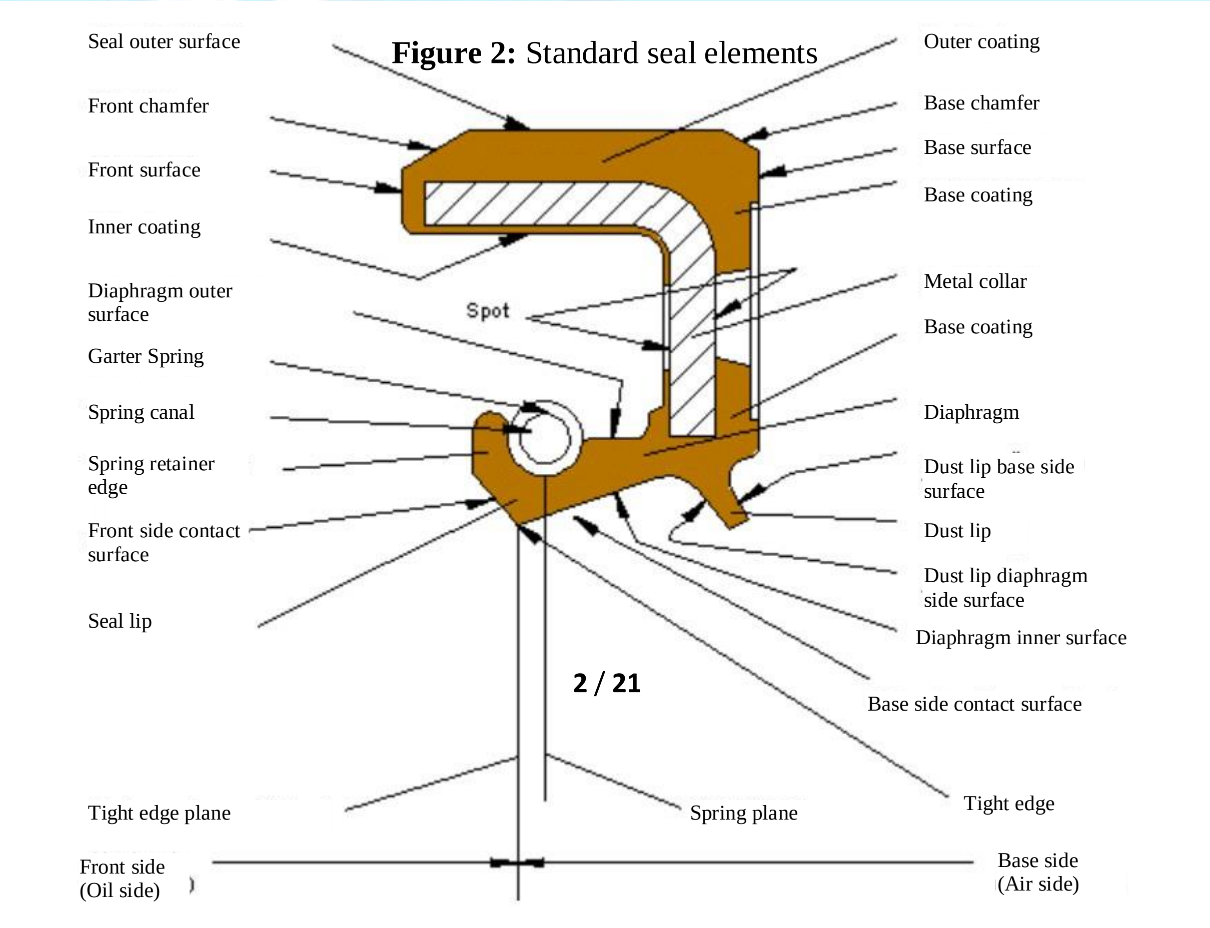


Figure 2: Standard seal elements

Coding and General Type Definition in Seals

Seals have different physical and chemical properties and shapes according to their places of use, conditions and dimensions. These properties are also used in the selection and classification of the seal. Seals are defined and classified according to their nominal dimensions, seal types and material varieties. Each seal is named by numbers and letters, which also indicate the lip material.

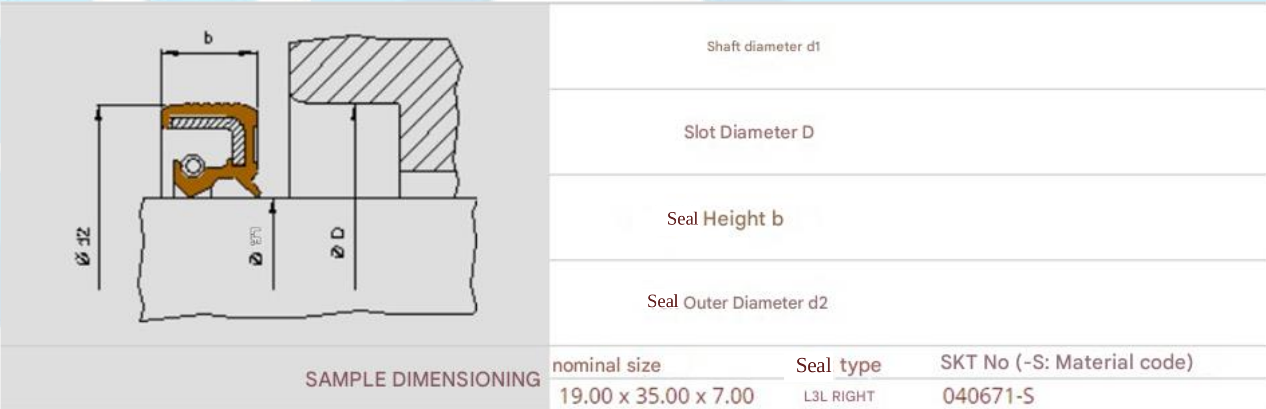


Figure 3: Identification of nominal seal dimensions

d1	x	D	x	b
30.00	x	45.00	x	8.00
Operating diameter of the seal.		Diameter of the housing on which the seal is driven. (Seal outer diameter is produced as large as to ensure required tightness on this housing.)		Total height of the seal.

Figure 4: Nominal dimensions in metric seals with three sizes

d1	x	D	-	D'	x	b	-	b'
45.00	x	72.00	-	86.00	x	8.00	-	12.00
Operating diameter of the seal.		Diameter of the housing on which the seal is driven. (Seal outer diameter is produced as large as to ensure required tightness on this housing.)		The second largest dimension after the outer diameter of the seal.		Driving height of the seal.		Total height of the seal.

Figure 5: Nominal dimensions in metric seals with more than three sizes

In our company, the most common types of seal that should be used depending on the shaft movement are radial rotational seals. These seals can be grouped as right, left or bi-directional according to the direction of rotation.

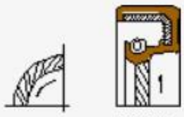
For Shafts Rotating to Right	For Shafts Rotating to Left	For Shafts Rotating to Right and Left
 L3 SAG	 L3 SOL	 L3 SS

Figure 6: Explanation of the knurls of the rotary seals according to the direction of rotation of the shafts

Sealing Mechanism and Seal Life

Oil seal (rotary shaft seal) is a machine element used to prevent fluids in two separate environments with rotational movement or, in some special cases, linear (tidal) movement from mixing with each other, in other words, to ensure that the oil in an environment remains in that environment.

Sealing functions depend on many factors such as seal profile, seal rubber material, rotating shaft surface, speed, ambient temperature, ambient pressure, vibration, amount of axial movement and their variations over time.

An oil seal performs two basic tasks where it operates and during operation.

- **Static Sealing:** To provide static (non-moving) sealing between the outer diameter of the seal and the seat surface.
- **Dynamic Sealing:** To provide dynamic (moving) sealing between the seal oil lip and the rotating shaft.

The main sealing principle of the oil seals is shown in Figure 7.

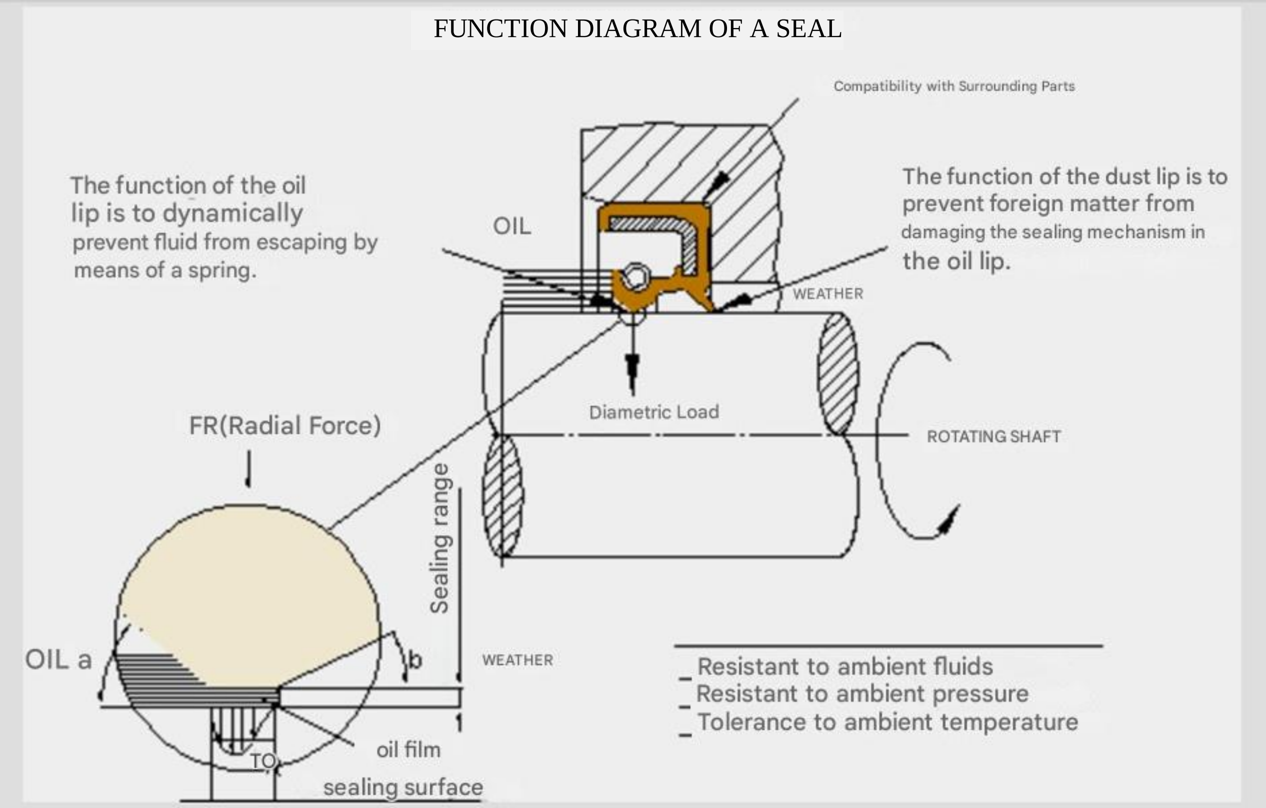


Figure 7: Seal working principle

Seal Life

The lifespan of the actively working seal depends on the area where they are used, the way they are used, the environmental conditions, etc. One of the important issues to be considered when selecting the seal is the circumferential rotation speed of the shaft where the rotary seals are driven, the frequency of the seal's drive, etc. are factors that should not be overlooked.

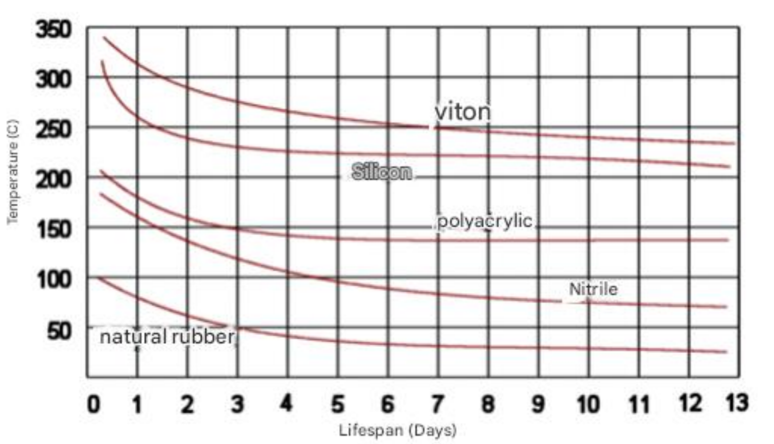


Figure 8: Material selection of seal lips subjected to dynamic wear according to the temperature reached

While selecting the seal, the diameter, radial and circumferential velocity of the shaft on which the seal rotates together with the temperature and the diameter of the shaft used are also important factors.

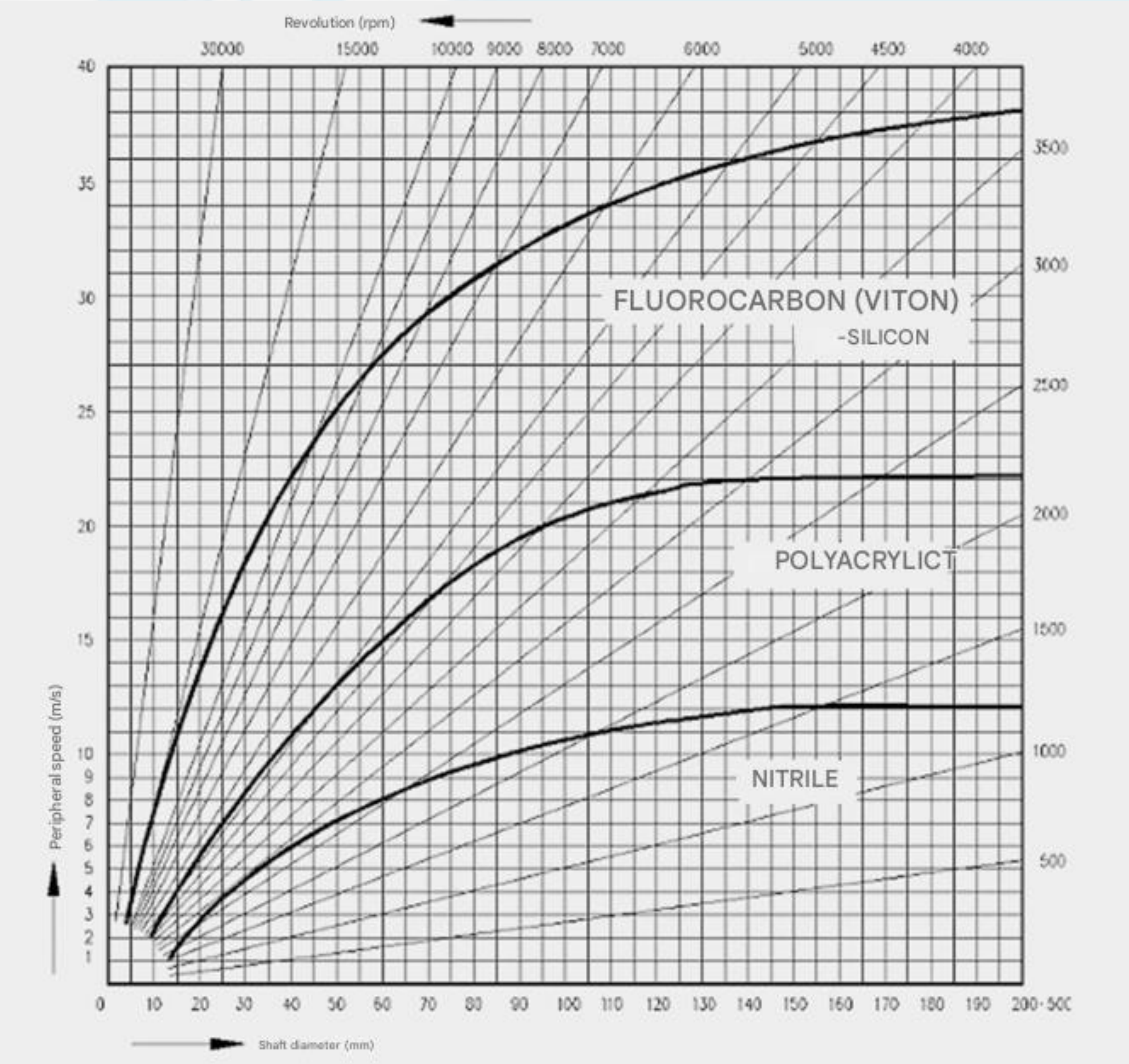


Figure 9: Parameters to be considered for lip material selection in rotary shaft seals

Other Factors Affecting Seal Lip Temperature;

- Oil Temperature
- Mechanical Factors
- Possible Errors in Diameters (Incorrect seal use, incorrect assembly, incorrect spring, design error, etc.)

Shaft/Slot Specifications to Place the Seal

As well as the selection of the seal, the slot and shaft where the seal will be placed are also important. Otherwise, the leakage problem is no longer caused by the seal, and the arrangement should be made in the production department.

Shaft Diameter Value: The shaft on which the seal operates must be machined to h11 tolerances.

Shaft diameter (d1)	Tolerance	Shaft diameter (d1)	Tolerance
1-3 included	0.00 -0.06	50-80 incl.	0.00 -0.19
3-6 included	0.00 0.075	80-120 incl.	0.00 -0.22
6-10 included	0.00 -0.09	120-180 incl.	0.00 -0.25
10-18 incl.	0.00 -0.11	180-250 incl.	0.00 -0.29
18-30 incl.	0.00 -0.13	250-315 incl.	0.00 -0.32
30-50 incl.	0.00 -0.16	315-400 incl.	0.00 -0.36

Figure 10: Shaft machining tolerance chart

Shaft Surface Hardness: The hardness of the shaft surface where the seal will work must be between 45-55 HRC. In cases where the environment is dirty and the environmental speed is more than 4 m/s, this hardness should be at least 55 HRC.

Quality and Treatment of Shaft Surface: Surface roughness should be Ra= 0.2 - 0.8 µm , Rz= 1 - 5 µm , Rmax= 6.3 µm in rotating shafts (Rz= 1 - 2 µm in silicone seals is recommended) and Rz < 1 µm in reciprocating shafts.

If Rz = 1 µm is processed in rotating shafts, there may be a problem in the formation of oil film at high speeds between the lip and shaft. This causes the lip to burn due to overheating and the seal to become unable to operate. If Rz is processed larger than 6.3 µm, the seal may start to leak oil in a short time, as it will cause increased wear on the lips.

Roughness quality values Ra=um 1 µm = (0.001 mm)		Surface treatment marks according to DIN 140	Work benches where surface quality values are obtained
Most	Least		
50	25		Cutting with a torch, chiseling, grinding by
25	12.5	Ñ	hand Sawing, rough filing Rough
12.5	6.3		lathe, freze, planer, disc grinder Lathe,
6.2	3.2		milling, planer, boring with drill Lathe, milling,
3.2	1.6	ÑÑ	planer, grinding, reamer Lathe,
1.6	0.8		milling, planer, grinding, reamer
0.8	0.4		Cylindrical grinding, surface grinding
0.4	0.2	ÑÑÑ	Cylindrical grinding, honing, lapping, polishing
0.2	0.1		Honing, lapping, copper disc polishing
0.1	0.05		Honing, lapping, super finishing
0.05	0.025	ÑÑÑÑ	Special precision machining, polishing finishing
0.025	0		Special precision machining, polishing finishing

Figure 11: Roughness quality and operations required in surface quality

Plunge grinding systems should be used in the machining of the shaft so that spiral marks are not left on the shaft surface. Machines that leave spiral marks on the shaft surface (axial surface grinding or turning, etc.) may cause oil leakage during operation. If the shaft has to be processed by a method that leaves spiral marks, these marks should be towards the oil side according to the direction of rotation of the shaft.

The area where the oil lip works on the shaft surface is defined as the “working surface” of the seal, and when calculating the width, the axial movements of the shaft and the new surface where the seal lip can work during repairs should also be taken into account.

Shaft Surface Coating: Materials used in general machine construction are used as shaft material. Casting materials that can be poured without gaps can also be used. Coating the shaft surfaces with hard chrome provides good results. Plastic shaft surfaces are not recommended as they do not conduct the temperature between the lip and shaft well; they can be used at very low speeds and after trials.

Contact Surfaces: During installation, care should be taken to ensure that the surfaces to which the seal lip will come into contact and the surface on which the seal will operate are clean and rust-free.

Radius and Chamfers: Radius and chamfers at the inlet of the shaft are important during assembly. If the seal is to be placed on the shaft from the front side, the chamfer should be beveled to the end of the shaft in the specified dimensions as shown in Figure 12 and care should be taken to ensure that the corners are smooth. If the shaft is to be mounted by the base, the end of the shaft should be given a radius as shown in Figure 12.

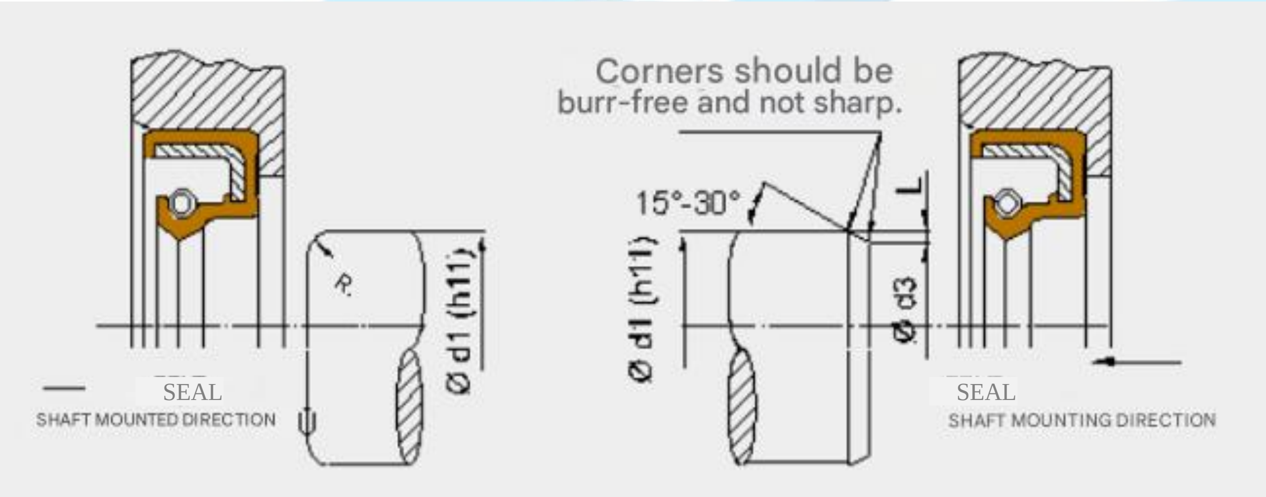


Figure 12: Dimensioning of radius and chamfer according to the assembly direction of the seal

Shaft diameter	Difference between diameters half	Shaft diameter	Difference between diameters half
d1 (h11)	L=(d1-d3)/2 (*)	d1 (h11)	L=(d1-d3)/2 (*)
£10	0.75	>50-70	2.00
>10-20	1.00	>70-95	2.25
>20-30	1.25	>95-130	2.75
>30-40	1.50	>130-240	3.50
>40-50	1.75	>240-500	5.50

Figure 13: Dimensions to be considered in beveling the chamfer

Seal type	R at least (mm)
Without dust lip (like L3, L1, SL)	0.6
With dust lip (such as L31, L1L, SLL)	1.0
REF: DIN 3760	

Figure 14: Dimensions to be considered in radius opening

If the radius is to be beveled instead of the chamfer, the size must be smaller than L. If the ends of the shaft cannot be machined as prescribed or if there is a groove or groove wedge structure at the end of the shaft, the ferrule or sleeve that has been machined and deburred by giving the desired chamfer or radius should be used.

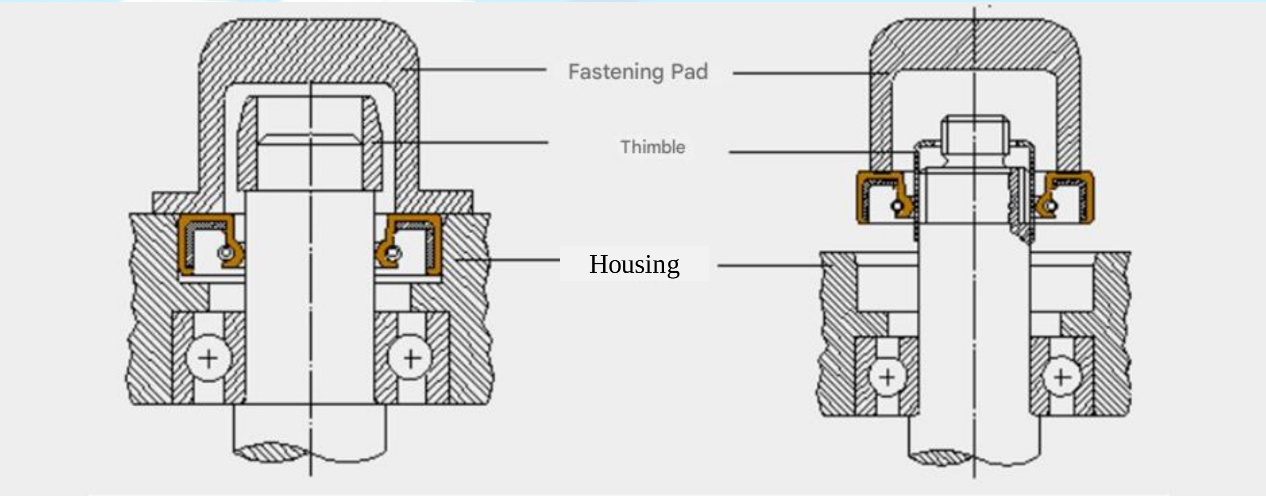


Figure 15: Ferrule use

Axis Offset Tolerance: The offset tolerances between the seat axis and the shaft axis are shown in Figure 16. In some types of rubber, on long fat lips (flexible lips), this tolerance can be increased. In the opposite cases (short oil lips), the tolerance should be narrowed.

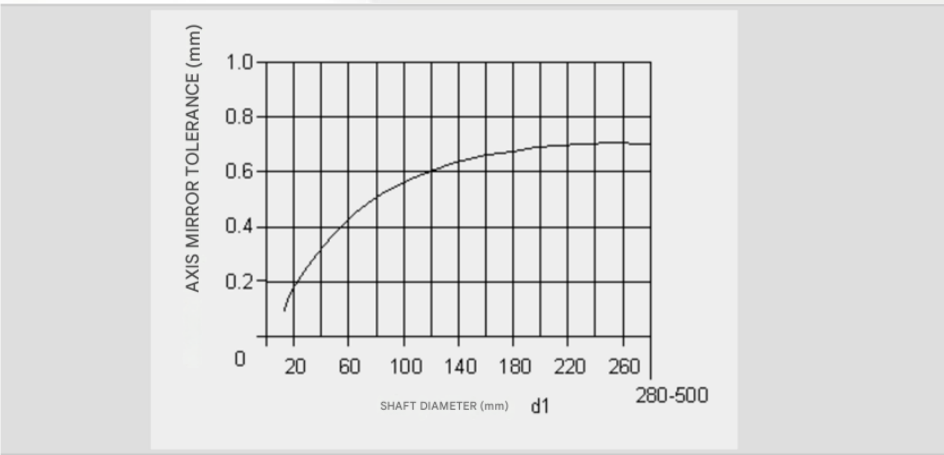


Figure 16: Axis offset tolerance/shaft diameter table

Runout Tolerance: The runout tolerance according to the axis of the shaft is shown in Figure 17. Especially at high speeds, there is a danger that the oil lip will not be able to follow the runout in the shaft due to its own inertia. If the distance between the lip and the shaft becomes greater than sufficient for hydrodynamic lubrication due to runout, the liquid to be sealed begins to flow out. Therefore, it is necessary to put the seal as close to the housing as possible and keep the housing tolerance narrow.

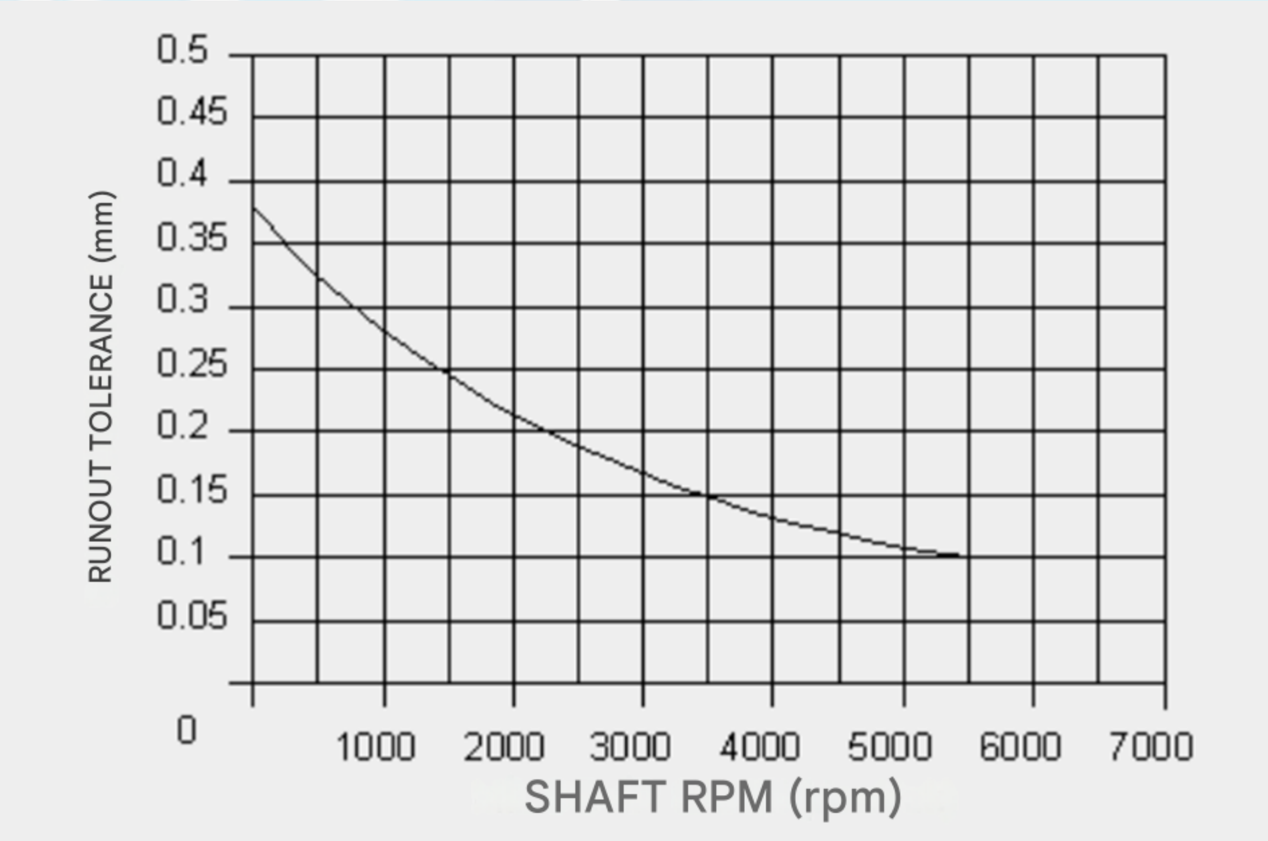


Figure 17: Chart for runout tolerance/number of shaft revolutions

Diameter Value of the Slot: Diameter measurement tolerances for slot dimensions should be made by considering H8 tolerances.

Slot diameter (D)	Tolerance	Slot diameter (D)	Tolerance
1-3 included	+0.014 -0.000	50-80 incl.	+0.046 -0.000
3-6 included	+0.018 -0.000	80-120 incl.	+0.054 -0.000
6-10 included	+0.022 -0.000	120-180 incl.	+0.063 -0.000
10-18 incl.	+0.027 -0.000	180-250 incl.	+0.072 -0.000
18-30 incl.	+0.033 -0.000	250-315 incl.	+0.081 -0.000
30-50 incl.	+0.039 -0.000	315-400 incl.	+0.081 -0.000

Figure 18: Slot diameter H8 tolerant chart

Seat Roughness: Seal seat surface roughness should be Ra = 1.6 - 6.3 µm, Rz = 10 - 20 µm, Rmax = 25 µm. The slot should be machined to the dimensions given in Figure 19. Burrs should not be left on the edges. For this, it is recommended to process the chamfer first, then the hole.

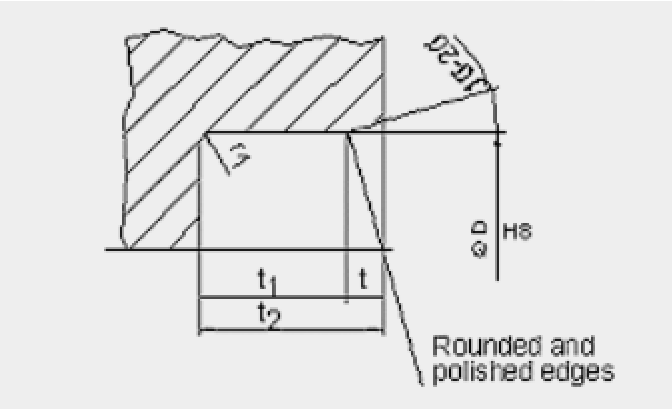


Figure 19: Dimensions to be considered when opening the slot

Seal high.b	t1 (0.85*b) min.	t2 (b+0.3) min.	t (t2-t1) min.	r1 max.
7	5.95	7.3	1.35	0.5
8	6.8	8.3	1.5	
10	8.5	10.3	1.8	
12	10.3	12.3	2	0.7
15	12.75	15.3	2.55	
20	17	20.3	3.3	

Figure 20: Sample values of the parameters shown in Figure 19

The Most Common Types of Faults in Seals

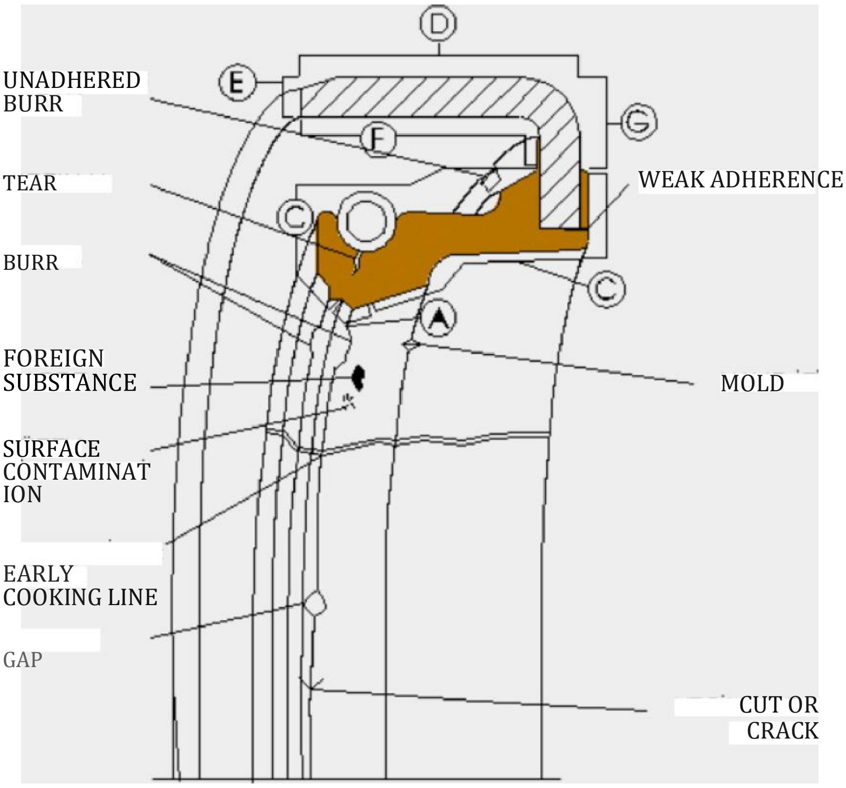


Figure 21: Fault types in self-cutting oil lip seals

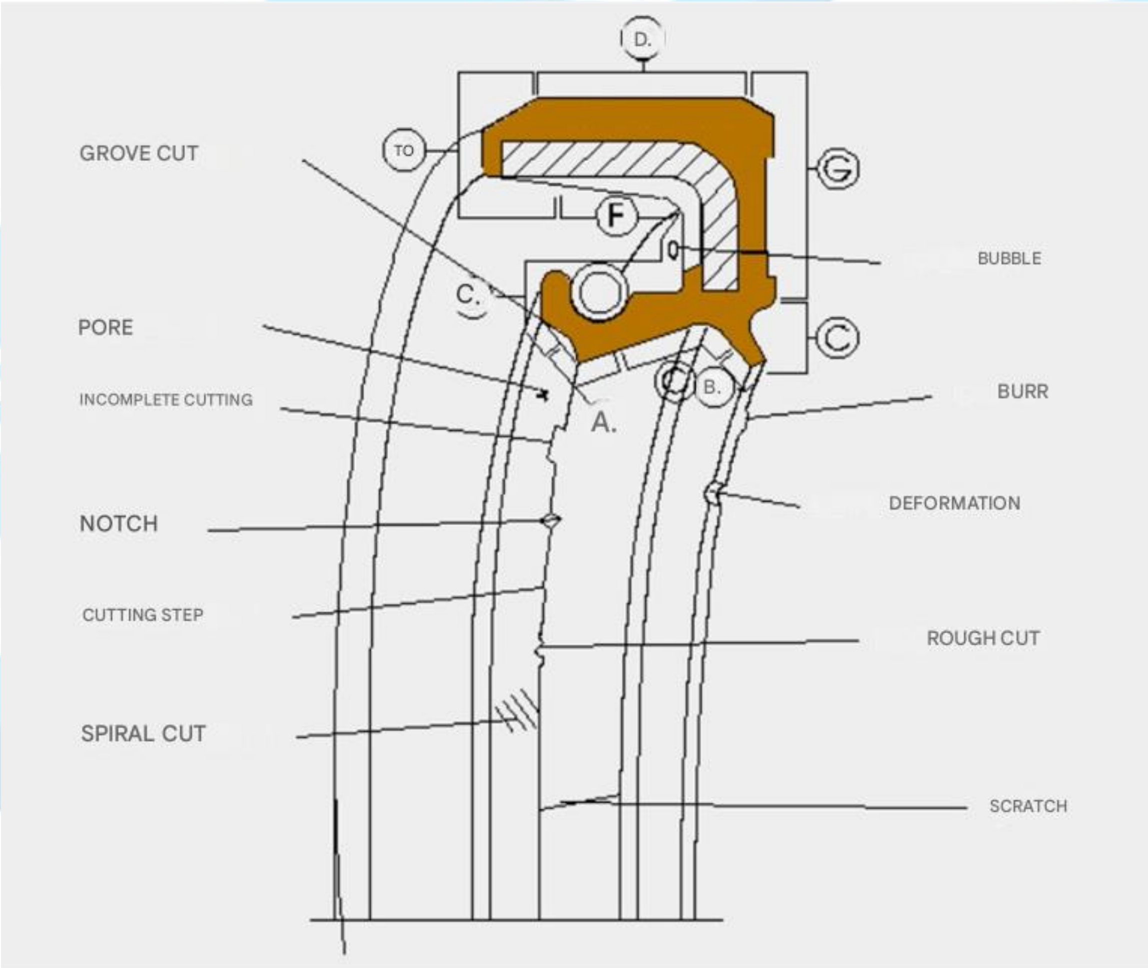


Figure 22: Fault types in powder lip seals

Storage of Seals

The physical properties of rubber products may deteriorate due to improper use and storage conditions. Since the life of bearings and other valuable machined parts depends on the seal sealing, rotary shaft seals must be stored carefully. Possible hazards are listed below.

Temperature: The storage area should be cool (below 30°C). Temperatures exceeding 30°C shorten the life of the seal. Seals that have been left in the environment below 10°C for a long time should be used after being brought to the ambient temperature. The seals should be at least 1 meter away from the heating cores in the storage areas or the cores should be screened. No problem is observed in our company in this regard. It is recommended to check the temperature of the part where the seals are stored only during cold winter months or on days when high temperatures are reached. If an extreme situation is observed, necessary measures should be taken.

Ozone: Ozone exposure causes aging in rubbers. To prevent this, mercury vapor lamps that can produce ozone (for example, known fluorescent lamps) should not be used, normal bulbs should be preferred. Electrical tools that might cause arc (for example, electric motor) should not be in the storage environment. Seals should be protected from direct or indirect sunlight: The windows of the warehouses should be covered with red or orange paint, never with blue paint. In our company, there is no problem such as exposure to ozone since the seals are stored in an environment that is not exposed to light.

Humidity: The relative humidity in the storage area should be between 40% and 70% as it can cause condensation. If it is to be stored for a long time, it should be protected in sealed, airtight packages in a dry environment. Excessive humidity can affect the rubber and cause rusting of the ring and spring.

Physical Damage, Dust, Deposition: Seals should be stored away from operating environments to prevent physical damage. A closed container will protect the seal from physical damage, dust, sand and deposits. Products should never be threaded into ropes, nails or wire for storage; it will damage the sealing areas. If necessary, warm water and soap should be used for cleaning and maintenance, the cleaned product should be dried at room temperature and precautions should be taken against rust. Solvents such as gasoline or thinner should never be used for cleaning. Mechanical cleaning should not be performed. Rubber parts should not be stored under load. The seals should be stacked properly, never stockpiled or transported in piles where the seals can damage each other’s seal lips. When cardboard seal boxes are placed on top of each other, excessive weight should be avoided on the underlying seal.

Radioactive Materials, Odors, Fumes: Seals should be stored away from radioactive materials and chemical fumes. Some metals (such as copper-containing metals and manganese) can damage rubber. Parts should not be stored in contact with them. In this case, it should be separated from each other by paper or polyethylene.

First In First Out (Fi-Fo) Application: It should be noted that the first product to enter the warehouse should be the first out (first used). Even under ideal storage conditions, the rubbers of seals that have been stored for too long can be damaged.

Insects and Rodents: Because some insects and rodents can eat rubber, seals should be protected against insects and rodents.

Packaging: Products should be protected from foreign matter and damage until the place of use and should not be removed from their packages until the assembly line. This will ensure that products are protected and identified. The products must be brought to the assembly line in such a way that it ends in the short term (one shift / one day, etc.) and must also be well protected on the assembly line. The seals are kept open along with the semi-finished products that are kept ready for any product to be assembled. This may take more than a week. In this regard, this situation, which should be avoided, will prevent the seals from wearing out.

Points to be Considered Before and During Assembly

Visual Check: There should be no defects in the seals, especially in the lip area. Waste may occur in the seals due to improper applications that may occur due to their arrival from the manufacturer, stocking or use. Waste seals should never be used.

Direction of Rotation Check: During repair, if there is a knurl on the lip of the new seal to be removed or replaced, the direction of shaft rotation and how long this rotation continues is very important. If the shaft rotates in both directions at the place of use, the seals to be used in these places must be either bi-directional (Sergeant) knurl or seals without knurls. Very short-term reverse rotations can be neglected.

Pressure Check: Standard seals can maintain their functions and provide the desired efficiency in environments with a maximum pressure of 0.5 bar. In cases where the ambient pressure is more than 0.5 bar, it is essential to use a pressure seal.

Lip Material Check: There may be very significant differences in rubber materials according to the environment in which the seal operates (such as ambient temperature, type of fluid in the environment) and operating conditions.

Attention to Silicone Seals: Silicone rubber is a sensitive material due to its structure. It can be damaged quickly with the smallest impacts. Therefore, more attention should be paid to the storage and assembly of silicone seals, and the risks of damage and tearing should be reduced.

Removal from Packaging: The rotary shaft seal must be removed from its packaging by hand and no sharp tools such as knives or screwdrivers must be used. It should be noted that a scratch on any part of the seal may cause leakage.

Label Check: The label on the packaging should be protected as much as possible until the final product in the packaging.

Seal Direction Control: Seals are normally mounted facing the oil to be sealed on the lip side (spring in spring seals). Attention should be paid to the direction.

Seal Lip and Shaft Lubrication: Depending on the oil level in the environment, it often takes time for the oil to reach the seal lip. The shaft work surface or seal lip must be thoroughly lubricated with a clean oil (ambient oil) just before installation, as this may cause dry friction during operation at the beginning of the first movement. However, this amount of oil should not flow from the base of the seal. Otherwise, it can be assumed that the seal is leaking oil. Appropriate grease should be applied between both lips in the case of seals rubbing the powder lip on the shaft, and between the two powder lips in the case of seals with double powder lips.

Correct Assembly Technique: For a correct assembly, a suitable lever (mechanical) or hydraulic press is recommended. To prevent the seal from retracting, it should be waited for a while after the driving process. Although this time can be defined as a few seconds, the actual value should be determined by trial. The hammer should never be used during the driving process or when first driving the seal into the slot in order to avoid damage when driving the rotary shaft seal, which is a sensitive machine element, into its slot. Hitting the seal with a hammer will cause deformations in the seal and the seal will lose its functions. In compulsory cases, the force to be created by the hammer should be transmitted to the seal through a buffer. This system should not be preferred as there is a risk that the force cannot be transmitted perpendicular to the surface.

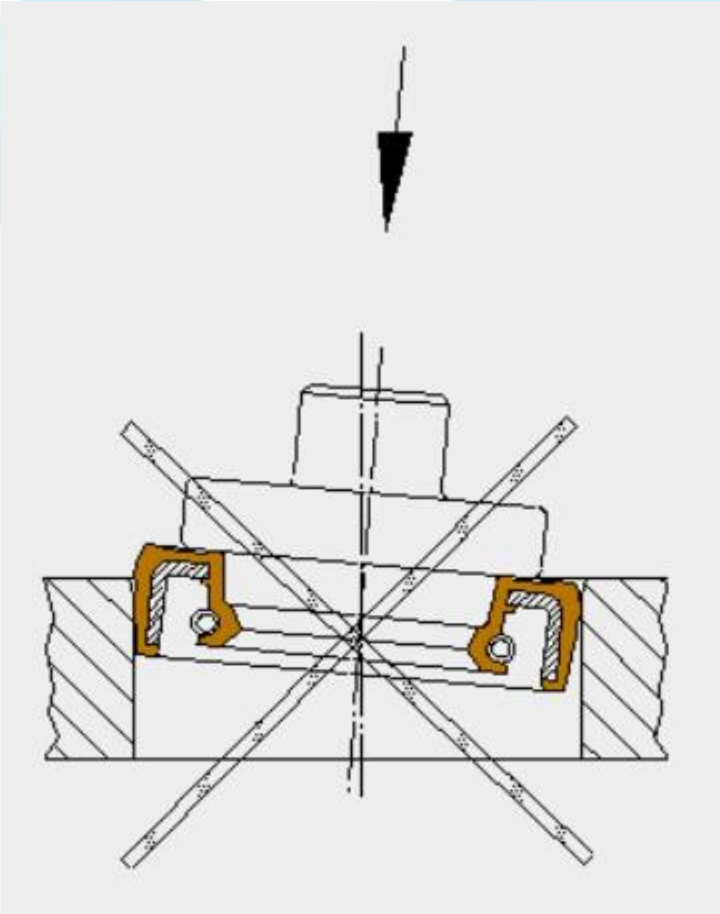


Figure 23: Incorrect Seal Assembly Method and Application

When the seal is driven into its slot, care must be taken to apply peripheral equal force to the seal base and not to subject it to pressure when the seal is seated on the tab. To achieve this, the auxiliary apparatus shown in the following figures should be used. It is recommended that the center of the apparatus be empty and rested so that the outer diameter of the apparatus is smaller than 0.5 mm from the slot diameter and does not cause deformity.

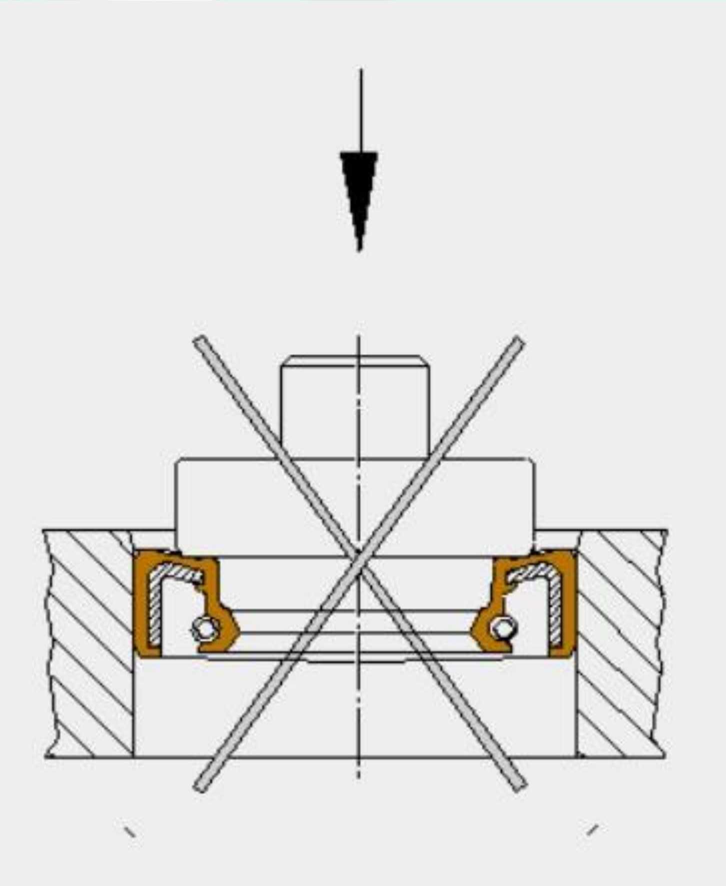


Figure 24: Improper Buffer Use

Spring Length: The length of the spring is determined by the seal manufacturer company, foreseeing that the seal lip will ideally tighten the shaft, and the production is carried out accordingly. The length of the spring should never be cut and reduced. This process gives rise to the misconception that the problem is solved in a short time, but due to the high radial force, the lip wears too much in a very short time, causing oil leakage.

Centering: If there is a shaft at the place where the seal is mounted, that is, if the shaft is not put back in place later, the lip should be attached to the shaft and prevented from retracting. For this, although the shaft inlet chamfer is machined as described in the 'SHAFT' section, the seal must be fitted on the exact axis of the shaft. In stepped shafts, the step diameter should be smaller than the shaft diameter, so as not to damage the lip (up to 5%). If a risk is foreseen, thimbles should be used.

Bearing Factor: If it is necessary to drive a tight-fitting machine element over the shaft surface where the seal will operate, the shaft diameter in the region where the seal will operate should be reduced by 0.2 mm. Despite this decrease in diameter, it may be possible for the seal to fulfill its function without any loss of performance.

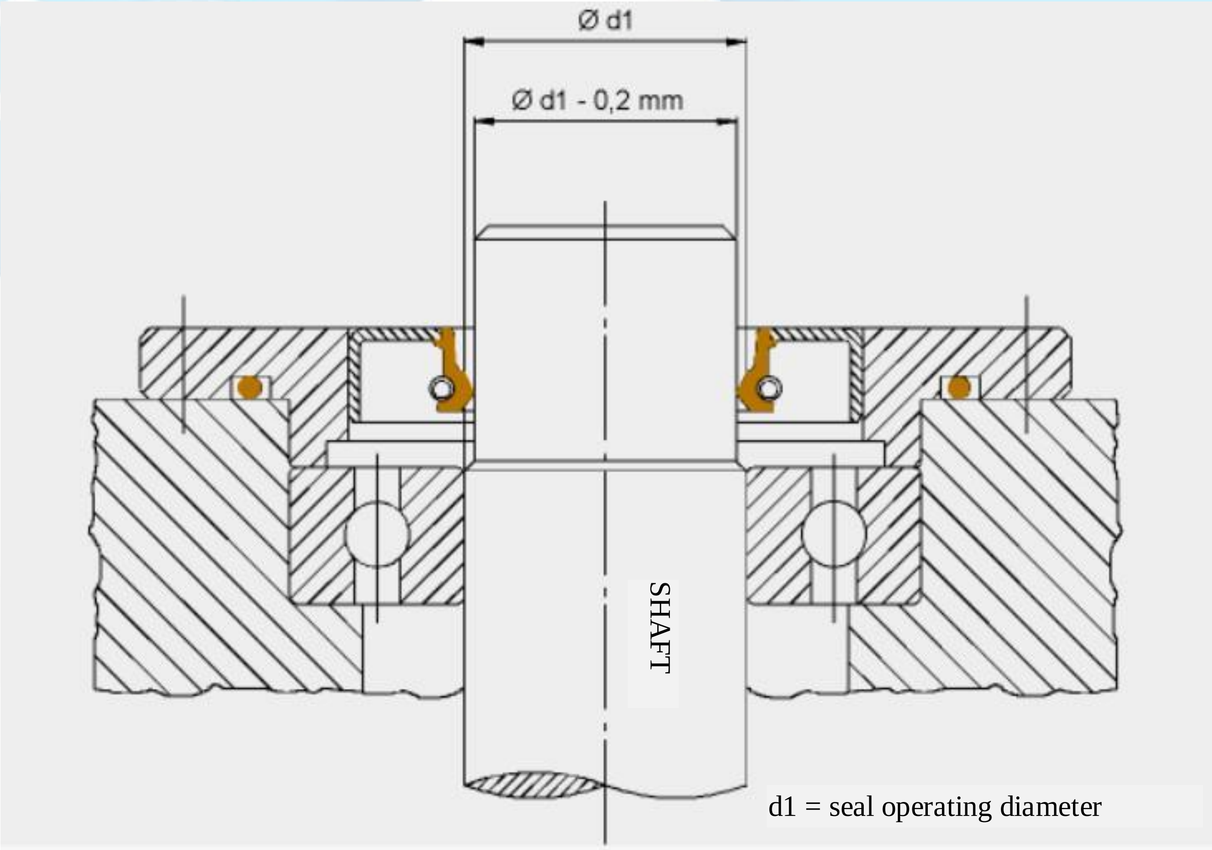


Figure 25: Seal shaft diameter that should be if the bearing is driven in the desired sealing area

Shaft Surface Cleaning: All surfaces that the seal lip will come into contact with during assembly must be rust-free, clean and flat (machined).

Seat Lubrication: For rubber coated seals with outer diameter, the outer diameter of the seal should be lightly lubricated to allow the seal to settle more comfortably in the seat. During assembly, the seal should be driven into the housing with a constant speed and a constant pressure in order to reduce the displacement effect by springing.

Seal Temperature: If the seals are stored in a cold environment, the seal can be kept in a clean suitable liquid with a temperature not exceeding 50°C for 10-15 minutes in order for the rubber to gain flexibility. Cracks or ruptures may occur due to loss of flexibility in the seals that are driven without being brought to room temperature.

Removed Seals: The seal removed from the slot should never be reassembled, a new seal should be used every time. Care should be taken that the trace of the new seal lip does not overlap with the track on which the old seal lip works on the shaft. The track on which the new seal lip operates should be shifted towards the oil side. This can be achieved by placing a washer on the base of the seal housing, replacing the existing washer with another washer of a different thickness, or by mounting the seal to a different depth in the housing without tab. If this is not possible due to the seat depth, the working surface of the shaft should be ground, and if the grinding depth exceeds 0.2 mm in diameter, a repair ring should be put on the shaft surface.

CONCLUSION

If all these processes are fulfilled, it is unlikely that the seals will leak oil as long as there are no user-induced errors. In order to inform the assembly personnel, it is necessary to provide a copy of the assembly checklist shown in Figure 26 and the necessary training regarding the assembly. In addition, it will be useful to check whether there is suitable equipment for assembly. Ensuring that the seals used in the completely designed products plays an essential role in preventing possible oil leaks in the future. All these processes should be taken into consideration in new designs and the seals to be used in these designs should be selected with appropriate care.

- Do not damage the housing when removing the old seal!
- Before assembling the seal, visually inspect it!
- Is there pressure in the environment? If so, use a pressure seal!
- Check that the lip material is suitable for the environmental conditions!
- Remove the seal from the packaging by hand, do not use a sharp tool!
- Preserve the label until the final product is in the package!
- Check the shaft's inlet opening in particular; there should be no sharp corners!
- Remember, every surface where the seal lip rubs against the shaft during assembly must be clean!
- Use a thimble on shafts with sharp corner ends, such as keyways!
- Check the housing and make sure its dimensions are up to standard!
- Pay attention to the seal direction, do not forget the spring oil duo!
- Lubricate the seal lip or shaft before assembly!
- Nail the seal vertically into the socket using the correct mounting tool!
- Do not hit the seal with a hammer!
- Do not shorten the spring length!
- Make sure the seal center is in the shaft center during assembly!
- Be careful when installing the seal in reverse, do not deform the seal!
- Lubricate the outer diameter and drive at a constant speed!
- Bring the seal to ambient temperature before hammering it!
- Do not reuse the removed seal!

Figure 26: Assembly checklist