Sealing mechanism

Static tightness on the outer surface

The primary task of the outer surface of the rotary shaft seal is to ensure static tightness in the housing bore, i.e. the passage of the medium where the rotary shaft seal sits in the housing bore must be prevented in all possible operating conditions.

The outer surface of the rotary shaft seal must also perform other tasks:

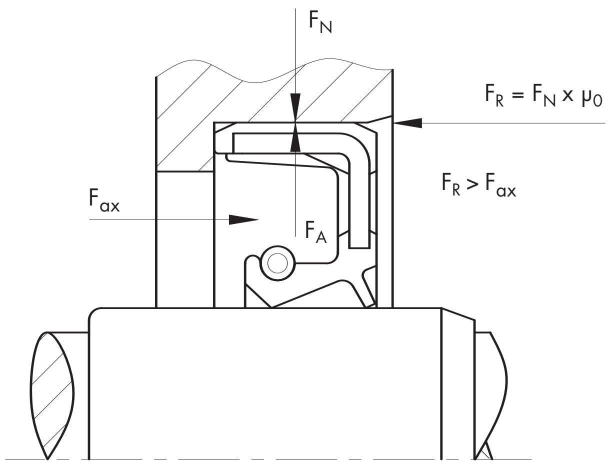
– Guidance and firm fit of the rotary shaft seal in the bore. A secure seating is guaranteed when the frictional force F_R is greater than all the axial forces F_{ax} that are exerted on the rotary shaft seal, e.g. the force resulting from the difference in pressure. The frictional force is the product of the static friction coefficient μ_0 and the radial normal force F_N. The normal force F_N is equal to the radial force on the outer surface F_A.

Different press fit allowances have to be made to the nominal diameter, depending on the composition of the outer surface (see table "Press fit allowances" page 14).

– Simple and easy installation, requiring chamfers and roundings.

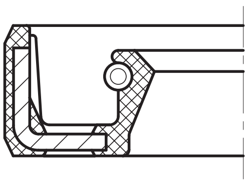
– Compensation of the resulting gap by means of different coefficients of thermal expansion.

The selection of the correct outer surface for a rotary shaft seal depends on the specific application and prevailing operating conditions.



Types of outer surface

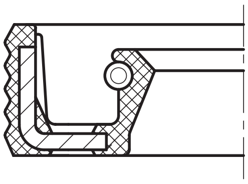
Rotary shaft seals are generally supplied with an elastomer outer sheath and metal outer surface. Combinations of both or special versions are no problem for Dichtomatik. The various types of outer surface are described in the following:



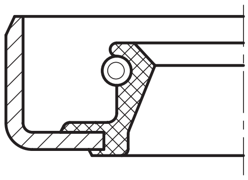
Rubber-encased outer surface: type WA, WAS

Type WA rotary shaft seals have a smooth outer surface made of elastomer material, ensuring good static sealing in the housing bore, even in difficult cases. This type is also supplied with a protective lip (WAS).

– Excellent static sealing
– For use in split housings, possibly with edge breakage and/or joint offset
– For use in light-metal housing with high thermal expansion (in all housings with a higher coefficient of thermal expansion than steel)
– For use in thin fluid or gaseous media
– For use in pressure applications (within the application limits)
– Capable of sealing larger surface roughnesses
– No fretting corrosion
– The housing bore is not damaged during installation and removal



Grooved, rubber-encased outer surface: Type WAK
To reduce the press-in force and improve static sealing, the elastomer outer surface is grooved along its circumference.
– Easier installation because less press-in force is required
– Secure static sealing, especially in housings with high thermal expansion, as the grooved, rubber-encased outer surface is made with a higher press-fit allowance
– Avoidance of a permanent skew of the rotary shaft seal

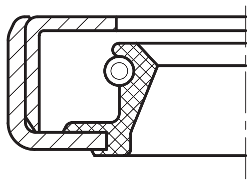


Metal outer surface, type WB, WBS
In the type WB rotary shaft seals the smooth metal outer surface of the metal insert is not encased, but ground, drawn or turned.
– A particularly exact (centrical) and firm fit in the bore is ensured
– More cost-effective due to the lower elastomer content
– The outer surface is made with a tighter press-fit allowance
– Good surface quality of the housing bore is required
– Not for use in split housings (also only limited use in split housings with paint coating)

In the case of large thermal expansion of the housing, rough bore surfaces, pressure applications or thin fluid, creeping media an additional sealant should be applied to the outer surface (see "Additional sealants" page 14).

To prevent corrosion, the metal outer surface is coated with corrosion protection oil or a thin layer of wax following final processing.

This type is also supplied with the protective lip (WBS).

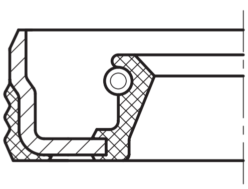


Metal outer surface with metal insert: Type WC, WCS
Type WC rotary shaft seals have a smooth metal outer surface like type WB and an additional metal insert. These seals are used successfully in particularly difficult installation conditions, hostile operating conditions and for large dimensions.

Type WC rotary shaft seals have greater rigidity than type WB rotary shaft seals.

Due to the additional metal insert the type WC is highly insensitive to installation errors.

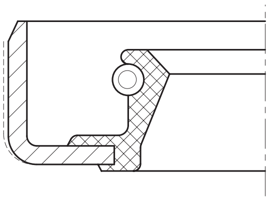
This type is also supplied with the protective lip (WCS).



Partially rubber-encased outer surface: Type WA/B
The so-called "half-shoulder" type is a special design of the outer surface of the rotary shaft seal which is not stocked as standard at Dichtomatik.

This type combines the advantages of the type WA rubber-encased outer surface and WB metal outer surface, the secure static sealing and firm seating and exact fit in the bore. Due to the influence of the metal outer surface, good centring is ensured during installation.

The rubber-encased part of the outer surface is grooved, enabling this type to be used successfully in housings with high thermal expansion and in split housings.



Additional sealants

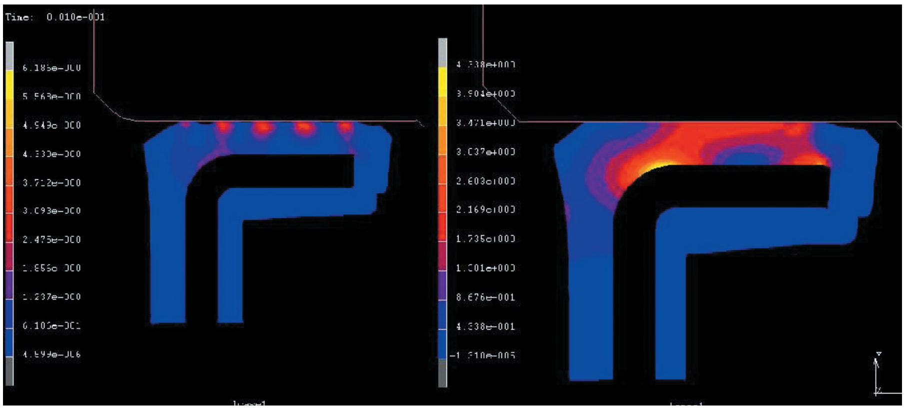
In order to attain high static sealing in the housing bore, rotary shaft seals with a metal outer surface are often coated with paint or sealing compounds. Wax or paint is also applied to protect against corrosion.

The paint should compensate processing marks on the outer surface of the rotary shaft seal, any roughness in the housing bore and more pronounced thermal expansion. It also protects against damage to the housing bore during installation or removal.

The thickness of the paint coating is usually approx. 30 µm. When it comes into contact with a medium, volume swell frequently occurs in the paint which provides additional static sealing.

When applying paint to the outer surface, somewhat higher press-in force is required as the paints have a certain adhesive effect.

Paints are supplied in different colours, namely blue, dark red, orange, dark green and light green.



Simulation of static sealing in the housing bore using the finite-element method

Press-fit allowance

The rotary shaft seals are manufactured with press-fit allowances at the outer diameter depending on the type. The press-fit allowances are attuned to the ISO tolerance H8 of the housing bore. This ensures a firm fit, moderate press-in and press-out forces and higher static sealing in the housing bore without the need for further measures.

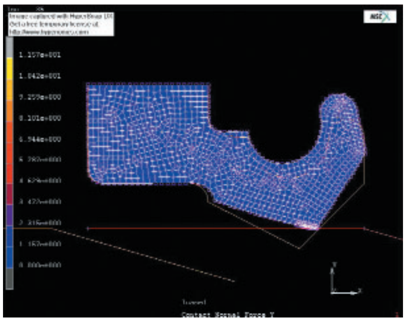
Outer diameter d2 [mm]	Type WA	Type WAK	Type WB, WC
≤ 50	+ 0.3	+ 0.4	+ 0.2
	+ 0.15	+ 0.2	+ 0.1
> 50 - 80	+ 0.35	+ 0.45	+ 0.23
	+ 0.2	+ 0.25	+ 0.13
> 80 - 120	+ 0.35	+ 0.5	+ 0.25
	+ 0.2	+ 0.3	+ 0.15
> 120 - 180	+ 0.45	+ 0.65	+ 0.28
	+ 0.25	+ 0.4	+ 0.18
> 180 - 300	+ 0.45	+ 0.65	+ 0.3
	+ 0.25	+ 0.4	+ 0.2
> 300 - 500	+ 0.55	+ 0.75	+ 0.35
	+ 0.33	+ 0.45	+ 0.23

Out-of-roundness

The out-of-roundness tolerance (d2max - d2min) results from three or more measurements distributed evenly on the periphery. The values given must not be exceeded. Within the tolerances, roundness is of secondary importance because the rotary shaft seal adapts to the location bore when it is installed.

Outer diameter d2 [mm]	Out-of-roundness tolerance [mm]
≤ 50	0.25
> 50 - 80	0.35
> 80 - 120	0.5
> 120 - 180	0.65
> 180 - 300	0.8
> 300 - 500	1

Dynamic sealing mechanism

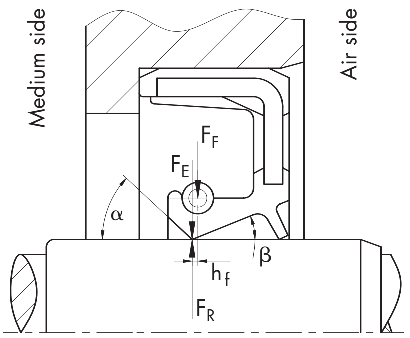


The functional principle of the rotary shaft seal is that the elastomer sealing edge slides on the rotating shaft surface. The sealing edge is pressed in the radial direction against the shaft surface as the inner diameter of the sealing lip is smaller in its non-tensioned condition than the shaft diameter. The difference in diameter is called prestressing.

The resulting radial force on the linear contact zone is additionally supported by a metal screw tension spring to counteract the gradual decrease in radial force as a result of the ageing of the elastomer material (stress relaxation).

The sealing action at the elastomer sealing edge is achieved for two functional states:
– for the stationary shaft
– for the rotating shaft

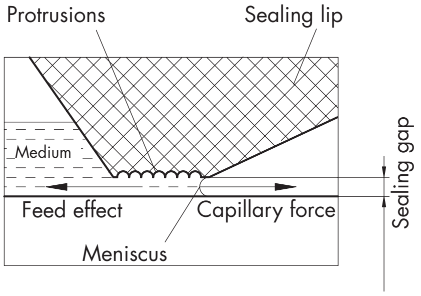
It is dependent on the following parameters:
– geometry of the sealing lip
– properties of the elastomer material
– alignment of the screw tension spring
– finish of the shaft surface
– lubrication condition



Sealing action with stationary shaft

When the shaft is stationary the sealing action is based on the radial contact pressure of the sealing lip on the spiral-free ground shaft surface, so that the deformation of the elastomer sealing edge compensates for the surface roughnesses of the shaft and closes the gap. A radial force is exerted on the shaft. The contact pressure of the sealing lip is attained by prestressing and supported by the screw tension spring. The lessening of the elastomer prestress during operation is dependent on the application parameters.

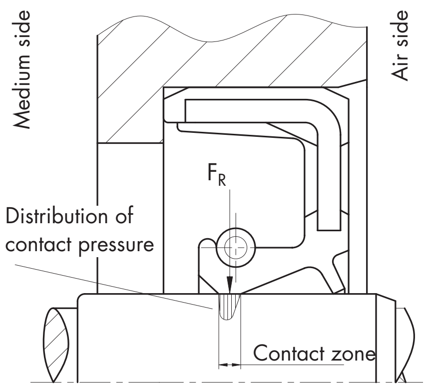
The radial force F_R is thus composed of the elastomer component F_E and the spring component F_F .



Sealing action with rotating shaft

When the shaft is rotating a hydro-dynamic effect occurs which causes the sealing lip to float on the lubricating film formed by the medium to be sealed. This prevents the premature wear and thermal destruction of the sealing lip.

On the one hand, the wear-inhibiting lubricating film within the contact zone is to be retained and on the other hand, the medium to be sealed is to be prevented from escaping on the air side and resulting in leakage.

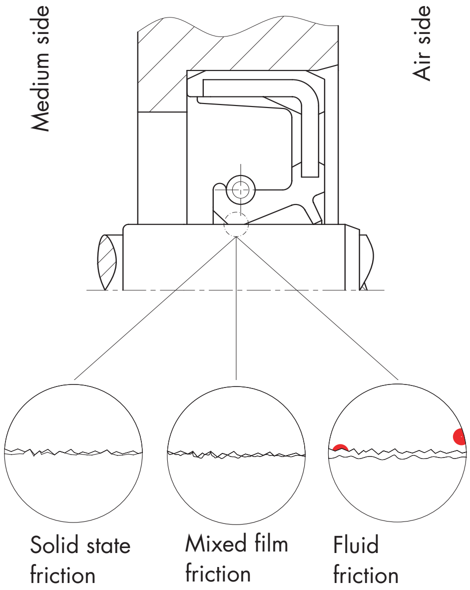


Shortly after the start-up of a new rotary shaft seal, micro-protrusions form in the elastomer contact zone in an axial direction. These are deformed as a result of the relative motion between the sealing edge and the shaft. The alignment of these deformed protrusions is dependent on the distribution of contact pressure in the contact zone and the rotation direction of the shaft.

They create a feed effect (drag flow) from the air side to the medium side of the contact zone that is similar to a micro-threaded shaft pump. The required "feed effect" of the rotary shaft seal is obtained only if the distribution of the contact pressure of the axial track width is asymmetrical. Only then does the "micro-threaded shaft pump" feed in the right direction.

The asymmetrical distribution of the contact pressure is attained partly by the different contact surface angles (α>ß) of the sealing lip to the shaft surface and partly by the shifting of the screw tension spring to the air side (spring distance).

Due to the skew of the protrusions the medium in the contact area is fed not only peripherally, but also axially. In addition, with wetting media such as lubricants, the influence of the surface tensions has an effect in the leakage direction. As a result of capillary forces, these media are drawn into the sealing gap and form a cambered interface on the air side known as a "meniscus". In the case of a "tight" rotary shaft seal there is a balance between the forces causing the leakage (pressure difference and capillary force) on the one side and the pumping effect of the elastomer protrusions on the other side.



Friction conditions in the contact zone

Friction conditions and lubrication

The interplay of the machine elements shaft, rotary shaft seal and lubricant is to be seen as a tribological system, i.e. three components / materials meet. At a friction point the lubricant is equal to the solid components and has a decisive influence on the operational reliability and service life of the system.

Even at low rotational speeds the medium intrudes into the contact zone due to the capillary forces. The feed of fluid by the capillary forces in the direction of the leakage is essential for the lubrication of the contact zone which is subjected to extreme thermal stress.

Probably the most common condition is mixed film friction between the shaft and sealing lip. Here too, the materials of the two contact surfaces are extremely important.

At higher shaft rotational speeds the friction condition changes from solid state friction through mixed film friction to hydrodynamic fluid friction. The higher rotational speed and the hydrodynamic effect cause the sealing lip to float on the lubricating film formed by the medium to be sealed.

This hydrodynamic lubricating film protects the elastomer sealing edge from premature wear and thermal destruction caused by the existing friction condition. To ensure a long service life it is important to supply the sealing edge with sufficient and continuous lubricating medium. Friction and friction loss are influenced decisively by the radial force, the rotary shaft seal material, the lubricating condition, the peripheral speed, the temperature, the pressurisation and the surface condition of the shaft.

Frictional energy:

$$P_{REIB} = F_R \cdot \mu \cdot d/2 \cdot 2 \cdot \pi \cdot n$$

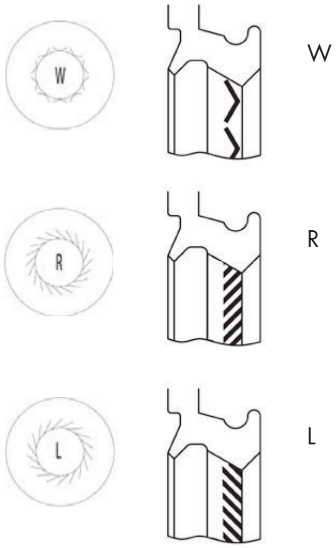
P_{REIB} = frictional energy [Watt]
F_R = radial force [N]
μ = coefficient of friction
d = shaft diameter [mm]
n = rotational speed [1/min]

This calculation can only serve as an estimate as the coefficient of friction for the individual operating conditions cannot be sufficiently determined.

To keep friction loss to a minimum the lowest possible radial force is applied. However, the radial force must be sufficient to perform the sealing function.

If the required lubricating film under the sealing edge is disturbed, e.g. due to contamination of the medium, damage to the contact surface or too much surface roughness on the shaft, leakage occurs.

Some machine elements, e.g. taper roller bearings, angular contact ball bearings and some types of gearwheel, exert a feed effect that can impair the supply of lubricant to the sealing point. Appropriate measures to feed the lubricant, e.g. lubricating ducts and flingers, should therefore be taken in the design stage.



Various designs of hydrodynamic sealing aids “spiral”

Dry run
Under no circumstances must the shaft rotate without lubrication on the rotary shaft seal as premature wear to the sealing edge will otherwise occur and the temperature at the sealing edge rises too high as a result of non-functioning heat dissipation.

The sealing edge of the rotary shaft seal should therefore be lightly lubricated prior to installation. Besides acting as a lubricant, the medium to be sealed also has the function of ensuring the continuous dissipation of the frictional heat that occurs.

For dry run application, special types and materials are to be selected, e.g. rotary shaft seal seals with a PTFE sealing lip.

Grease lubrication
With pure grease lubrication, frictional heat is dissipated to a considerably lesser degree than with oil lubrication. It should only be applied to slowly rotating shafts with a peripheral speed not exceeding the permissible values for oil lubrication (see rotational speed table on page 20).

For the sealing of slowly rotating shafts we recommend filling the space between the rotary shaft seal and the bearing almost completely with grease. If no suitable lubricating grease can be applied, a rotary shaft seal with a PTFE sealing lip can be used.

Sealing against poorly lubricating media
When sealing against poorly lubricating media, e.g. water or suds, a maximum of 2/3 of the space between the sealing lip and the protective lip must be filled with grease to ensure sufficient lubrication of the sealing edge. Two rotary shaft seals aligned in tandem with a max. 2/3 grease filling between them and the possibility of relubrication are even more effective.

Hydrodynamic sealing aids "spiral"
If the normal feed effect of the rotary shaft seal is not sufficient, so-called spiral grooves can be used as additional, hydrodynamic sealing aids to increase the functionality of the rotary shaft seal. Spiral grooves are raised return feed grooves that run at a slanting angle from the air side to the sealing edge.

Depending on the rotation direction of the shaft, rotary shaft seals with right or left spiral or with alternating spiral are used. The purpose of the spiral grooves is, in the event of impairment of the normal feed effect, to prevent the medium running to the air side from flowing off as leakage and to bring it back to the sealing edge. Rotary shaft seals with hydrodynamic sealing aids therefore provide double protection against leakage.

The mode of action of the spiral grooves is the same as that of a simple threaded shaft seal. The feed value of single-spiral rotary shaft seal is considerably greater than that of a standard type.

Rotary shaft seals with hydrodynamic sealing aids have improved functionality, particularly in difficult operating conditions, e.g. true running deviations, centricity deviation between shaft and bore and minor damage to the shaft surface.

Operating parameters

Pressure

Unpressurised operation
Rotary shaft seals are generally designed for unpressurised operation, i.e. there is no difference in pressure between the spaces to be sealed.

The rotational speed table on page 20 shows the maximum permissible rotational speeds in unpressurised operation with regard to the elastomer material.

Pressurised operation
The load combination of pressure p and peripheral speed V is decisive for the selection of the correct rotary shaft seal.

With pressurised rotary shaft seals the sealing lip is pressed hard against the shaft, thereby increasing the radial force in accordance with the pressure and the effective surface (self-strengthening effect) and thus the sealing action. The sealing capacity of the rotary shaft seal adapts, within certain limits, to the prevalent pressure difference.

However, this process also causes the thermal load and the frictional energy at the sealing edge to increase, which can result in premature wear and hardening. If pressures are too high, the sealing lip can turn over to the air side.

When selecting the elastomer material it is essential to take the higher thermal load of the sealing edge into consideration (overtemperature). The recommended values in the rotational speed table on page 20 for peripheral speed and rotational speed therefore do not apply to pressurised rotary shaft seals.

In pressurised rotary shaft seals (WASY) the capability of the sealing lip to absorb both the true running tolerance of the shaft and the centricity deviation between the shaft and the location bore is also reduced.

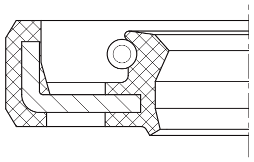
Pressurised rotary shaft seals must be secured axially on the non-pressure side by means of a housing shoulder, a distance ring or a retaining ring against being pressed out of the location bore.

Pressurising with standard types
Standard rotary shaft seals are still suitable for use in very low pressures. They have to seal spaces with small pressure difference against fluids, greases and even air. Pressure differences of max. 0.5 bar can be sealed, depending on the rotational speed.

The following table shows the limit values for pressure dependent on rotational speed and peripheral speed.

Maximum permissible shaft rotational speeds under pressurisation

max. pressure difference [bar]	permissible rotational speeds [1/min]	max.peripheral speed [m/s]
0.5	up to 1000	2.8
0.35	up to 2000	3.15
0.2	up to 3000	5.6



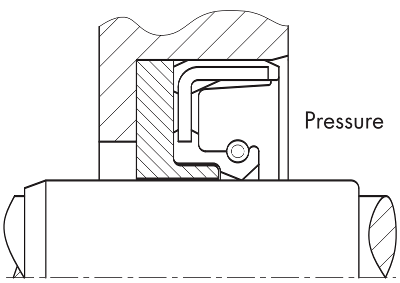
Pressure-loadable type WAY/WASY
For pressure differences greater than 0.5 bar, pulsating pressures and vacuum applications the type WASY is recommended.

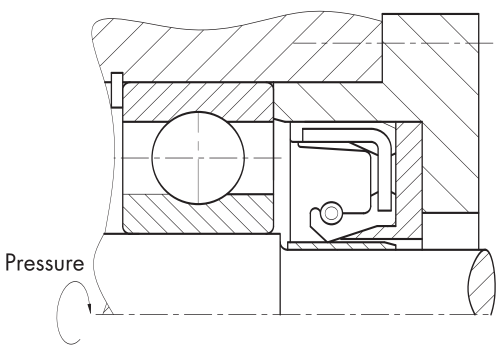
This type is fitted with a short, reinforced sealing lip and a drawn-down metal cage (stabilised membrane). This reduces the increase in contact pressure resulting from the pressure and thus also the increased frictional energy and, where applicable, premature wear.

Due to its reinforcement the sealing lip is also prevented, within certain limits, from turning over to the air side if the pressure is too high.

Depending on the rotational speed, the type WASY is pressure-loadable up to max. 10 bar (see table).

Pressure difference [bar]	Rotational speed [1/min]	max. peripheral speed [m/s]
up to 10	< 500	0.6
4.5	1.000	2.7
2.4	2.000	5.9
1.3	3.000	8.4
0.6	4.000	11.3





Backup rings
Pressure differences greater than 0.5 bar can also be sealed with standard rotary shaft seals and an additional backup ring. Such combinations permit pressures of up to approx. 10 bar, depending on the rotational speed.

Only types without protective lips can be used because the backup ring supports the sealing lip under the membrane. The backup ring must therefore be adapted exactly to the sealing lip profile in question. Dichtomatik can supply a drawing of the corresponding backup ring for every standard type (without protective lip) on request.

This kind of sealing system is ideal for applications where pressure-loadable types (WASY) are not available.

Permissible rotational and peripheral speeds

According to the following formula, the peripheral speed V of the shaft is the product of the rotational speed n and the shaft diameter d:

Peripheral speed
$v = (2\pi \cdot n) \cdot d/2$

v = peripheral speed [m/s]
n = rotational speed [1/min]
d = shaft diameter [mm]

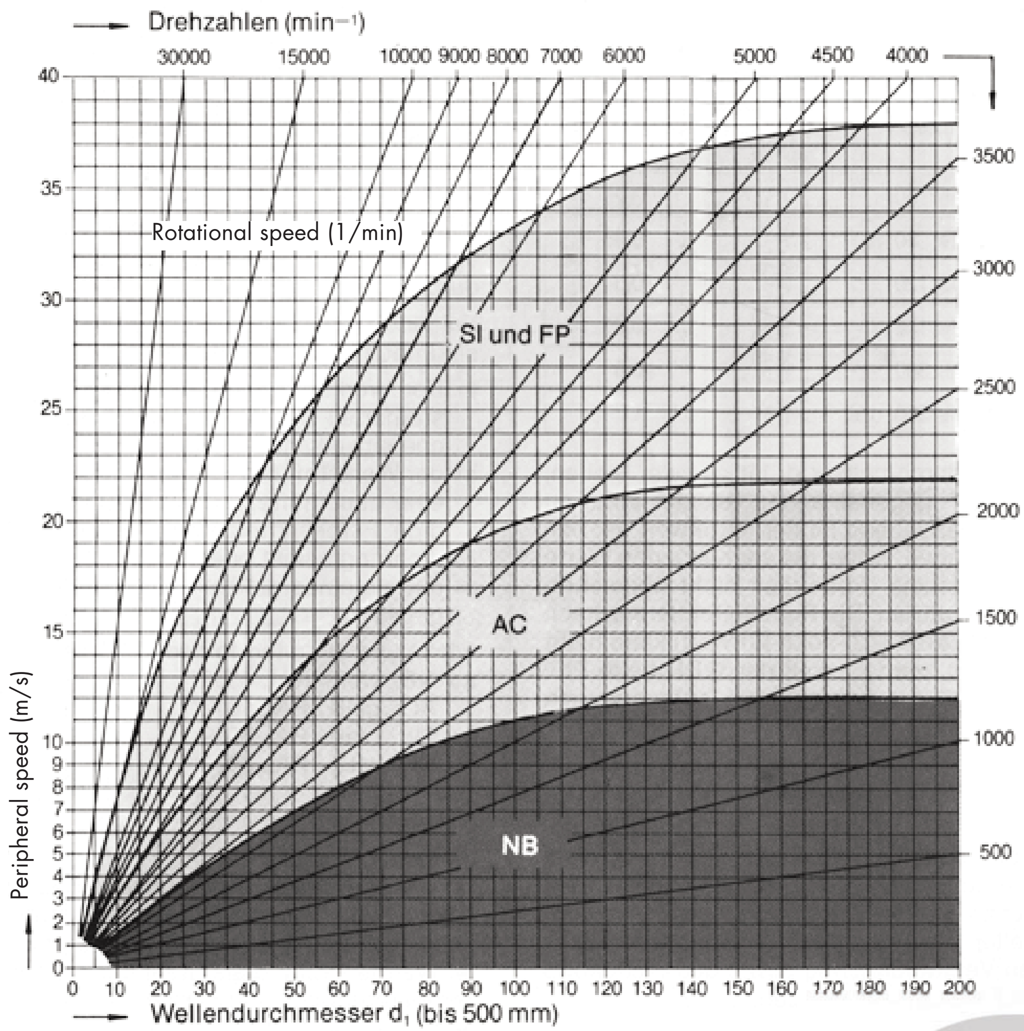
To prevent function-threatening over-temperatures at the sealing edge that can lead to the hardening of the elastomer or the formation of oil carbon, the peripheral speed must be limited.

The table shows recommended values for material selection, depending on the maximum permissible peripheral speed. The recommended values given are based on experience in accordance with DIN 3760.

Manufacturer-specific properties of the rotary shaft seals such as the geometry of the sealing lip or radial force are not taken into consideration.

These recommended values are valid only for unpressurised operation, adequate lubrication conditions with mineral oil and good heat dissipation at the point of sealing. In the case of insufficient lubrication or pure grease lubrication the limit values are to be halved. The recommended values are also to be reduced for pressurisation, poor surface quality in the contact area and large true running deviations.

For shafts with larger diameters, higher peripheral speeds are permissible than for shafts with smaller diameters as the cross-section of the shaft increases with the square of the diameter. This results in considerably better heat dissipation possibilities.



Shaft diameter d_1(up to 500mm)

Temperature

Due to the rotation of the shaft and the resulting friction at the sealing edge, the actual temperature at the sealing edge is higher than in the oil bath.

$$t_D = t_{Öl} + t_Ü$$

t_D = temperature at the sealing edge [°C]
$t_{Öl}$ = temperature in the oil bath [°C]
$t_Ü$ = overtemperature [°C]

The difference in temperature between oil bath and sealing edge is called over-temperature.

The level of overtemperature is dependent on the following parameters:

– peripheral speed
– lubrication condition / oil level
– heat dissipation
– pressure load
– surface condition of the shaft
– rotary shaft seal material

The higher the peripheral speed, the higher the overtemperature at the sealing edge. Depending on the peripheral speed, the overtemperature can be up to +40°C.

If the maximum permissible operating temperatures for the different elastomer materials are exceeded, this leads to premature hardening of the elastomer material and extreme wear.

The permissible operating temperatures for our elastomer materials are given in the tables in the chapter (see"Materials" page 7). The high temperatures given in the tables refer to the temperature at the sealing edge.

Media to be sealed

The selection of the correct rotary shaft seal and particularly of the correct material depends on the peripheral speed of the shaft, the pressure load and the friction-related rise in temperature, but most importantly on the medium to be sealed and its temperature. In particular, the chemical resistance of the rotary shaft seal to the medium used influences the lifespan of the seal to a decisive degree.

Chemical aggression by the medium can lead to
– softening of the material due to swelling
– or hardening and premature ageing, fostered by high temperatures.

The behaviour of the individual material groups to a variety of media is listed in the Dichtomatik resistance list. If new media are used, if there is any uncertainty or if maximum application parameters (e.g. temperature, pressure, peripheral speed) occur simultaneously, we recommend carrying out a test in advance. A practical test under standard conditions provides the best information on the suitability of a seal. A laboratory test and consultation with the medium manufacturer can also be helpful.

When sealing aggressive media, the types VIA/VIAS in FPM materials are more suitable for many applications than the types in NBR. Rotary shaft seals made of FPM have higher chemical and thermal resistance.

In addition, the types VIA/VIAS are already fitted as standard with tension springs made of 1.4301 (AISI 304) rust and acid-resistant steel and the metal insert is fully sheathed in elastomer.

For even higher requirements with regards to media resistance, two types with a PTFE sealing lip or made completely of PTFE are available, namely types WCP21 and WEPO.

Frequently used media: mineral oil-based oils and greases
Generally speaking, seals with NBR and FPM standard materials show good resistance to these media. With highly additivated media for which there are no values taken from experience, a test may be advisable.

Synthetic oils and greases
The composition of synthetic lubricants is characterised mainly by the base oil and a large number of additives. Depending on the type of base oil and additives, the NBR standard material can be used with less additivated lubricants. With more highly additivated oils, particularly at temperatures above +80°C, FPM is more suitable as a sealing material.

Due to the large number and the combination of additives in synthetic lubricants, however, resistance problems may arise. We therefore recommend verifying the suitability of the material in advance by means of testing.

Areas of application for rotary shaft seal materials

Material	NBR	FPM	HNBR	NBR High nitrile	NBR High temp.	NBR Low temp.	VMQ	ACM	PTFE
Low temperature [°C]	-40	-30	-40	-30	-30	-50	-50	-25	-80
High temperature [°C] (no media influence)	100	200	150	100	120	90	200	150	200
Wear resistance	2	1-2	1-2	2	2	2	3	3	3
Media to be sealed / permissible continuous temperatures [°C]									
Mineral oils									
Engine oils	100	150	100	100	120	90	130	130	150
Transmission oils	80	150	80	80	100	70	130	120	150
Hypoid transmission oils	80	140	80	80	100	70	-	120	150
ATF oils	100	150	100	100	110	80	□	130	150
Hydraulic fluids acc. to DIN 51524	90	130	90	90	100	80	□	120	150
Heating oils EL and L	90	150	80	90	90	□	□	□	150
Greases	90	150	90	90	100	80	□	120	150
Non-inflammable hydraulic fluids VDMA 24317 / 24320									
HFA oil in water emulsions	60	□	60	60	60	□	□	-	■
HFB water in oil emulsions	60	□	60	60	60	□	□	-	■
HFC aqueous polymer solutions	60	-	60	60	60	□	□	-	■
HFD non-aqueous synthetic fluids	-	150	-	-	-	-	□	-	150
Other media									
Water	80	80	90	80	80	□	□	-	■
Suds	80	80	90	80	80		□	□	■

The values given for the high temperatures refer to the maximum temperatures occurring under the sealing lip. Depending on the application, these can be up to +40°C above the medium temperature.

1 = excellent / 2 = good / 3 = moderate

■ = resistant, but not normally used
□ = resistant to a limited degree
- = not resistant