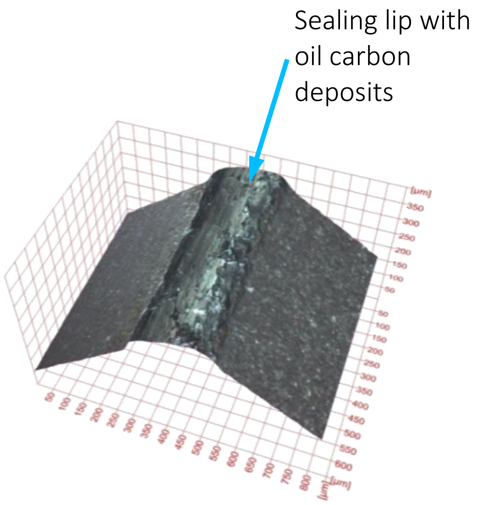
Possibilities to Reduce the Contact Temperature of Rotary Shaft Seals

University of Stuttgart
Institute of Machine Components

IMA-TechSheet #104180

This TechSheet provides a brief introduction to the importance of the contact temperature and the mechanisms behind heat generation and transfer for rotary shaft lip-type seals. A catalog of recommendations lists all the key factors influencing the contact temperature and options for its reduction.

Contact temperature



The sealing edge of rotary shaft lip-type seals touches the shaft. As the shaft rotates during operation, frictional heat is generated in the contact area. The limited heat transfer to the environment causes the temperature in the contact area to rise. This temperature is called contact temperature. It is used to evaluate the risk of thermal damage.

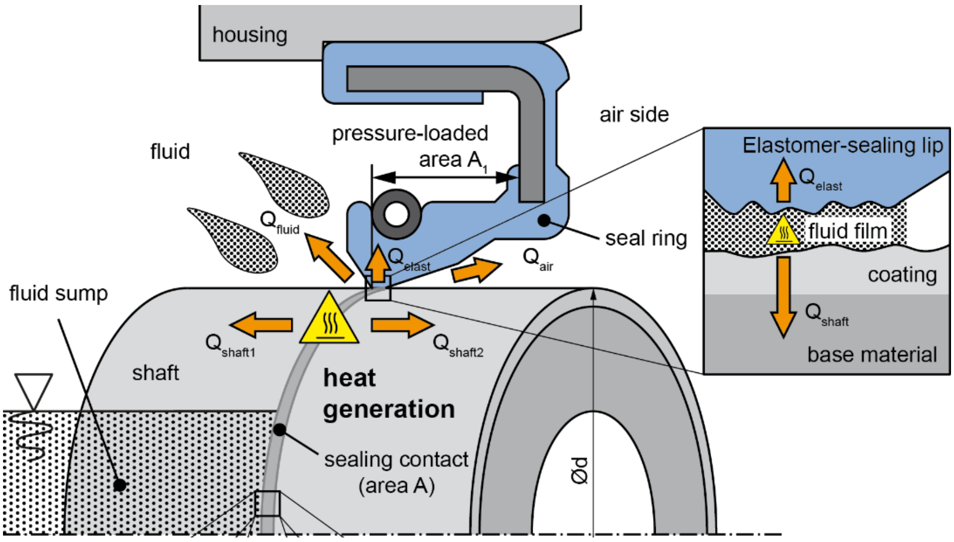
High contact temperatures can lead to hardening of the elastomer sealing lip and / or to the formation of oil carbon deposits, as shown in the image on the right. Both effects can disrupt the dynamic sealing mechanism and ultimately lead to the failure of the sealing system. Such failures can lead to major ecological and economic consequences. High contact temperatures should therefore be avoided.

Ways to determine the contact temperature

The contact temperature can be determined using complex measurements or sophisticated simulations. Alternatively, the contact temperature can be approximately calculated using the InsECT web app. It was developed by the IMA and is available online free of charge (https://insect.ima.uni-stuttgart.de/en).

Heat generation and transfer

Frictional heat is generated through the shearing of the thin fluid film in the contact area between the shaft surface and the sealing lip during rotation. As shown in the figure below, it is transferred to the environment by heat conduction, convection (and radiation).



The following equation represents the state of a thermal balance. The individual terms of this equation vary considerably depending on the design of the sealing system and its immediate surroundings. The most significant influencing factors are included in the following balance equation:

$$\overbrace{F_c \cdot v_c = F_r \cdot \mu \cdot v_c}^{heat\ generation} = \overbrace{\dot{Q}_{\text{shaft1}} + \dot{Q}_{\text{shaft2}} + \dot{Q}_{elast} + \dot{Q}_{fluid} + \dot{Q}_{air}}^{heat\ transfer}$$

The individual parameters of the balance equation and their dependencies are listed below.

- Radial load $F_r = f$ (pressure),
- Frictional force in circumferential direction $F_c = F_r \cdot \mu$,
- Circumferential speed $v_c = f$ (rotational speed, diameter),
- Coefficient of friction $\mu = f$ (viscosity, lubrication, surface topography)
- Heat transfer in the shaft to the oil side (1) and air side (2) $\dot{Q}_{shaft1,2} = f$ (geometry, thermal conductivity, coating),
- Heat transfer into the sealed fluid $\dot{Q}_{fluid} = f$ (fluid properties, fluid level, flow, environment),
- Heat transfer into the surrounding air $\dot{Q}_{air} = f$ (environment),
- Heat transfer into the elastomer of the seal $\dot{Q}_{elast} \approx 0$ (very low thermal conductivity of the elastomer!)

Catalog of recommendations

All factors that are considered to have a significant influence on the contact temperature are discussed below. These influencing factors can be used to optimize the application of rotary shaft seals. The contact temperature is influenced on the one hand by the heat transfer and on the other hand by the frictional power in the contact area. These two fundamental impact categories are discussed separately below.

Frictional power

Reducing the frictional power in the sealing system results in a lower contact temperature and can also contribute to improved efficiency, less wear and a longer product lifespan. The frictional power P is equal to the thermal power $\dot{Q}_{\mathrm{fric}}$ generated in the contact area. It is calculated from the friction torque M_{fric} and the rotational speed n,

$$P = \dot{Q}_{\mathrm{fric}} = M_{\mathrm{fric}} \cdot 2\pi \cdot n$$

The rotational speed has a significant influence on the frictional power in the sealing system. A reduction in speed leads to a decrease in frictional power. In addition to the rotational speed, the frictional power is influenced by the friction torque, which in itself depends on several other factors,

$$M_{\mathrm{fric}} = F_{\mathrm{fric}} \cdot \frac{d}{2} = F_r \cdot \mu \cdot \frac{d}{2}$$

The diameter d of the shaft directly influences the friction torque. A reduction of the diameter therefore leads directly to a reduction in frictional power. The frictional force F_{fric} is determined by the radial load F_r and the coefficient of friction μ. The coefficient of friction μ is not constant, but depends on various parameters such as the rotational speed, the temperature and the components of the sealing system (fluid to be sealed, shaft and seal ring). By using a fluid that ensures good lubrication and low friction, the friction torque and thus the frictional power can be reduced. A suitable surface of the sealing ring and the shaft can also reduce friction and thereby the contact temperature. Finally, the friction torque is also influenced by the radial load F_r. A reduction in the radial load also reduces the frictional power. The radial load can be reduced by lowering the preload of the tension spring or by removing the tension spring. Alternatively, a sealing lip with lower stiffness can be used or the overlap between the sealing ring and shaft can be lowered.

Additional contacting elements on the sealing ring, such as contacting protection lips or nonwovens, also increase the friction torque. Avoiding these additional elements or reducing the radial load of the additional elements reduces the frictional power introduced into the system. In the case of contacting protection lips, the formation of negative pressure in the space between the sealing lip and the protection lip should be prevented by design. Otherwise, the pumping effects of the two individual lips create a partial vacuum in the space between the lips, which increases the contact pressure of both lips and thus the frictional power. Other components of the technical system also contribute to the heating of the contact area. A reduction in the frictional power introduced into the system, for example at a bearing location close to the seal, therefore has a positive effect on the contact temperature.

The previously discussed influencing factors are outlined below in Table 1. Further optimization opportunities to reduce the contact temperature are specified and their effectiveness is evaluated. The qualitative assessment ranges from 0 for low effect to +++ for a very high effect. It should be noted that the effect of individual measures may be stronger or weaker depending on the specific application and the other system parameters.

Table 1: Influencing factors and optimization opportunities for the frictional power

Influencing factor	**Optimization opportunity**	**Effect**
Rotational speed	Reduction of rotational speed	+++
Sealing diameter	Reduction of diameter	+++
Friction of the fluid being sealed	Utilization of a fluid that ensures good lubrication and low friction	++
Shaft surface	Provide a surface that ensures good lubrication of the contact area	+
Radial load of the seal	Reduction of the radial load by using a weaker spring, no spring, a sealing lip with a lower stiffness or interference	++
Additional contacting elements	Reducing the radial load or removing additional elements such as contacting protection lips or nonwovens. In the case of contacting protection lips, prevent the formation of negative pressure in the space between the sealing lip and the protection lip	+++
Frictional power of other components	Reduction of the frictional power introduced into the system, for example at a bearing location close to the seal	++

Heat transfer

The heat transfer out of the sealing contact is influenced by various individual factors. Heat is transferred through the shaft, the seal ring, the sealed fluid and the surrounding environment. A better thermal conductivity of the individual components ensures better heat transfer from the sealing contact. The base material of the shaft has the greatest influence, as the thermal conductivity of the usually metallic shaft is significantly higher than that of the other components.

Another major influence is the temperature level at which the heat can be transferred. A cooler environment or a cooler fluid sump provide improved heat transfer. The fill level of the sealed fluid also has a significant influence on heat transfer. As the fluid to be sealed usually has a significantly greater thermal conductivity and thermal capacity compared to air, the heat can be transferred better at a higher fill level. In contrast, a lubrication of the seal with only grease (without fluid sump) leads to significantly worse heat transfer. The flow of the fluid in the area of the seal is also critical. Heat transfer is improved If the contact area is continuously provided with colder fluid. For example, such a flow can be generated by a dedicated fluid supply, but can also be an effect of a fluid-pumping bearing.

In addition, the geometric design of the shaft has a considerable influence on heat transfer. Any changes in cross-section due to shoulders or hollow shafts can affect heat transfer. Sleeves or coatings also have an influence on heat transfer through the shaft.

The previously discussed influencing factors are outlined below in Table 2. Further optimizations to reduce the contact temperature are listed and their effectiveness is evaluated. The qualitative assessment ranges from 0 for low effect to +++ for a very high effect. It should be noted that the effect of individual measures may be stronger or weaker depending on the specific application and the other system parameters.

Table 2: Influencing factors and optimization opportunities for the heat transfer

Influencing factor	Optimization opportunity	Effect
Thermal conductivity of the shaft	Material with higher thermal conductivity	+++
Thermal conductivity of the sealed fluid	Fluid with higher thermal conductivity	+
Thermal conductivity of the rotary shaft seal	Seal material with higher thermal conductivity	0
Ambient temperature	Reduction of the ambient temperature	++
Temperature of the sealed fluid	Reducing the temperature of the sealed fluid	+++
Fluid flow	Supply of cooler fluid near the seal	++
Fluid fill level	Increase the fluid level or convert from grease to oil lubrication; e.g. no bearings that pump oil away from the seal	++
Shaft shoulders	Shoulders at a greater distance	++
Hollow shafts	Reduction of the bore diameter	0
Shaft sleeves	Avoid very thin-walled sleeves in particular or increase the wall thickness	+
Shaft coatings	Usage of a more thermally conductive coating	0

Further information

Supported by: Federal Ministry for Economic Affairs and Climate Action on the basis of a decision by the German Bundestag
IGF Industrielle Gemeinschaftsforschung
FKM Forschung im VDMA

This catalog of measures with optimization recommendations for reducing the contact temperature of rotary shaft seals was developed as part of the "Temperature calculation" research project (IGF-Nr. 21587 N/1). This project of the Forschungskuratorium Maschinenbau e.V. (FKM) was funded by the AiF as a support of the Industrielle Gemeinschaftsforschung (IGF, Industrial Collective Research) by the Federal Ministry for Economic Affairs and Energy (BMWi) on the basis of a decision by the German Bundestag.

Further information, such as the entire measurement and simulation results of the extensive parameter analysis, is documented in the final report of the research project. This report is available from the VDMA store (https://www.vdmashop.de/en).