*32nd Electric Vehicle Symposium (EVS32)*
*Lyon, France, May 19 - 22, 2019*

# Modular Solution for Rotary Shaft Cooling Seals for Electric Engines

Matthias Podeswa[1], Joachim Reichert[2], Cornelius Fehrenbacher[3],

[1]*KACO GmbH + Co. KG - Team Leader Water Management - matthias.podeswa@kaco.de*

[2]*KACO GmbH + Co. KG - Manager Product Development - joachim.reichert@kaco.de*

[3]*KACO GmbH + Co. KG - Development Engineer Water Management - Cornelius.Fehrenbacher@kaco.de*

**Summary**

Besides the power electronics and the stator, the cooling of the rotor as the central component of the electric motor is sometimes crucial. Compared to conventional air and oil cooling, a water-glycol mixture has proven to be a cost-effective alternative with a high specific heat capacity. For that a mechanical face seal is predestined. As a worldwide specialist for dynamic sealing technology KACO has developed a modular concept that provides our customers with the necessary flexibility, regarding the design of the cooling concept and in the dimensioning of the cooling capacity.

*Keywords: cooling, water cooling, thermal management, efficiency, standardization*

## 1 Introduction

New electric motors specially developed for use in vehicle require sophisticated thermal management due to their compact design in combination with high performance. Effective cooling systems dissipate heat, where it is generated. Besides the power electronics and the stator it is necessary to cool the rotor as the central component of an electric motor. The coolant used has a significant impact on cooling performance. Compared to conventional air or oil cooling, a water-glycol mixture has proven to be an effective alternative with a high specific heat capacity. Because of this, a water-glycol mixture is used for a rotor shaft cooling system. In such cooling systems, overpressure and high circumferential speeds must be sealed. Due to the existing boundary conditions, the water-glycol mixture and the high temperature range which leads to a thermal expansion a mechanical face seal is predestined. As a specialist for mechanical face seals with millions parts in the field for water pump application, KACO has developed a modular concept. This concept provides the customers necessary flexibility regarding the design of cooling concept and in dimensioning of the cooling capacity. In addition to flexibility, the modular design allows reduced development times and cost to be saved while maintaining high quality. The **E**lectic **M**otor **R**otors-shaft **S**eal (EMRS) is currently available in three different diameters with two different types of rotor adaptations.

## 1.1 Why shaft cooling is basically needed?

It is generally known that electric motors can only operate efficiently in a certain temperature range. The high requirements of the automotive industry for compact electric motors with high performance and efficiency cause the energy density to rise. The high energy density and efficiency can only be permanently guaranteed by targeted cooling. To meet the high continuous power requirements it is no longer sufficient to cool the stator from the outside by convection cooling, as it is usual with conventional electric motors, but requires cooling from the inside via the rotor by transferring the heat generated in the rotor directly to the cooling fluid via heat conduction. [1]

Water-glycols are the preferred choice for effective cooling due to its double specific heat capacity compared to oil. In the area of combustion engines, such cooling is used as standard in water pumps. Now also finds its advantages in the electric variant. Although water cooling is more demanding in handling and sealing. Therefore it is more cost-intensive. Nevertheless the advantages clearly outweigh the disadvantages. As a consequence a more uniform and reduced temperature level will be achieved this is resulting in a preferred battery cooling. It allows the use of cheaper permanent magnets, which cost considerably less and do not require rare earths

# 2 Cooling Concepts

For the implementation of an internally cooled rotor there are two possibilities for the coolant flow through the rotor.

Concept 1 - Axial cooling : A through cooling in which the coolant is supplied from one side to the other.

Concept 2 - Return cooling: A recirculating cooling system in which the coolant enters from the same side as it exits through a lance.

The advantages of concept 1 are the simple design of the rotor and the possibility of a very small diameter. However, the rotor must be sealed on both sides of the coolant supply to the stator. Concept 2, on the other hand, requires only one seal between rotor and stator, but a lance has to ensure the distribution and fluid flow of the cooling medium in the rotor. The arrangement of lance and rotor leads to correspondingly larger diameter than it is with concept 1. Nevertheless, the advantages of concept 2 dominate because every additional sealing point can cause friction and leakage, which can have an unfavourable effect on the power consumption of the motor.

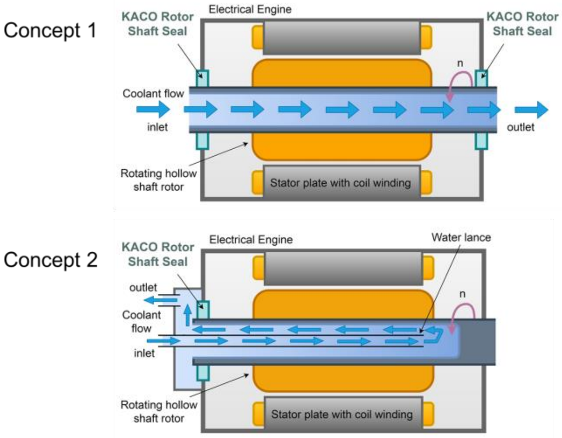


Figure1: Cooling concepts of electrical engines

## 3 Adaptation Rotary Shaft Cooling Seals to Electric Engines

There are two different kinds of adaptation holders for the rotor shaft, depending on the type of application and bearing size. Both of them have advantages and disadvantages. While the dynamic rotating part of the seal, the holder of variant 1 is mounted on the inner diameter of the rotor shaft. The holder of variant 2 can be pressed into the rotor shaft. Variant 1 offers the possibility of simple rotor shaft geometry with a small radial width. Due to the smaller radial width, a smaller bearing can be favoured. By mounting the holder on the rotor shaft, the axial installation space of the holder cannot easily be used for other purposes. Despite the more complex machining of the rotor shaft, variant 2 is much easier to assemble and handle due to the larger radial flange of the holder. The resulting axial space above the bracket can be used for other adjacent components, but may require the use of a larger bearing.

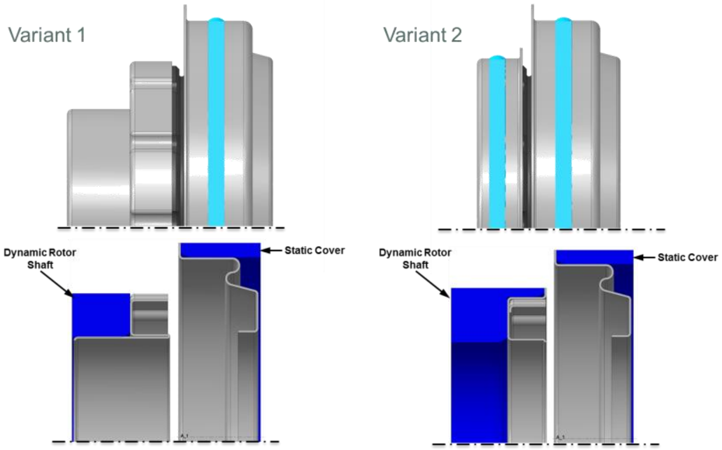


Figure2: Different holder types for rotor shaft

## 4 Customer requirements

There are many requirements for cooling systems. Typical are the temperature (-40°C to 150°C) or the pressure (-10mbar to 4bar) and a service life time of 8.000 hours. Furthermore there are many special requirements for cooling systems in electrical motors like

- the largest possible internal diameter and an axially compact design, depending on the variant of the cooling system
- the cooling medium is positioned on the inside of the sealing system (normally outside)
- a wide speed range from -6,000 rpm to 22,000 rpm
- the possible axial offset of the rotor shaft of up to 1 mm in both directions
- a radial misalignment of 0,1 mm and a inclination of one degree

In addition to the points mentioned above, the main focus of sealing systems is on the lowest possible friction and a minimal technical leakage.

# 5 Challenges for designing rotary shaft cooling seals

The challenge in designing such a sealing system lies in the high requirements. The large axial mobility with additional radial degrees of freedom and the high circumferential speed of up to 50 meters per second place high demands on the design and material of the seal. All these points had to be taken into account when designing a sealing system as well as when selecting the material.

In order to meet these requirements, the static part of the seal was designed so that the spring-loaded sliding ring together with the bellows and the ferrule can compensate this shape and positional deviation. In addition, the seal ring must be protected against over-torque by a mechanical drive lock without restricting its mobility too much. Particularly by designing the spring, it is important that it has as flat spring characteristic curve in the complete working range of +- 1 mm in order to keep the influence on the contact pressure of the seal and thus friction and leakage as low as possible.

When selecting materials in a cooling system, the first choice materials are that which have been proven in the field for many years. All deep-drawn parts are made out of corrosion-resistant stainless steel. The spring is also made of corrosion-resistant spring steel. In case of the elastomer components a special developed and optimised Sygumin® HNBR was chosen for this application. The HNBR used is essential for the function of the seal. As the bellows must not only provide a static seal, but also be capable to follow the spring and the sliding ring. The core components of the mechanical seal which form the sealing gap are the sliding and stationary ring. Both are made of a wear-free, non-porous ceramic. For a so-called hard hard pairing, KACO can rely on its many years of experience in the application of silicon carbide.

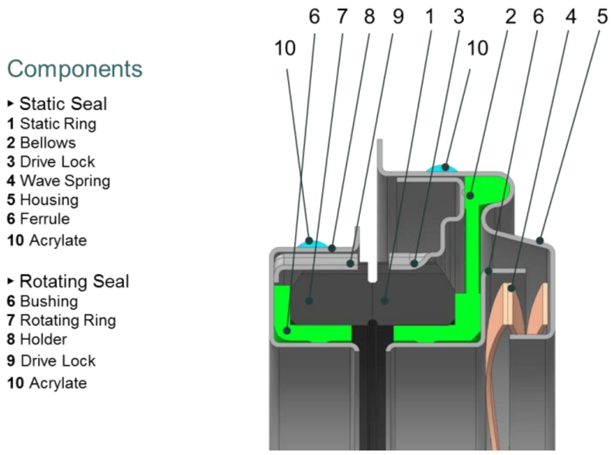


Figure3: Design of KACO **E**lectic **M**otor **R**otors-shaft **S**eal (EMRS)

## 5.1 Friction

Although friction and technical leakage are in conflict with each other when designing a sealing system, both must be within an acceptable range. Among other things, this is the biggest challenge to reduce friction as much as possible but not to lose the focus on the technically necessary leakage that is justifiable for the customer.

By designing the seal, the greatest influence on friction is the width of the sliding surface and the contact force of the spring. Both have been chosen as low as possible to ensure reliable static sealing under all operating conditions. Under the existing boundary conditions, KACO decided to further reduce friction by means of a suitable sliding surface structure. With structured SiC surfaces we have been able to achieve a friction reduction of up to 30 percent. Results are shown in figure 1.

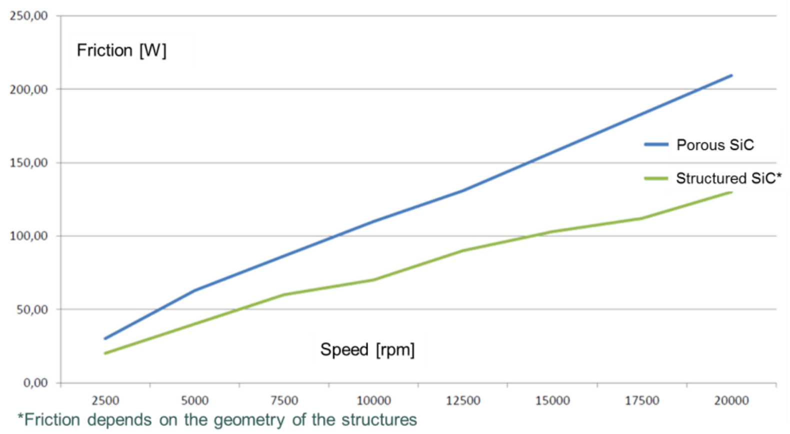


Figure4: Friction comparison between porous and structured SiC

## 5.2 Leakage

The hydrodynamic leakage flow for unstructured mechanical seal is described in the literature with the following equation formula [2]:

$$\dot{V} = \frac{\pi * h^3}{6 * \eta * \ln(\frac{r_a}{r_i})} * [\frac{3 * \rho * \omega^2}{20} * (r_a{}^2 - r_i{}^2) + (p_1 - p_2)] \quad (1)$$

$\dot{V}$ = Leakage volumetric flow
$h$ = Gap height
$\eta$ = Dynamic viscosity
$r_a$ = Sliding surface radius outside
$r_i$ = Sliding surface radius inside
$\rho$ = Density
$\omega$ = Angular velocity ($\omega = 2 * \pi * n$)
$p_1$ = Pressure inside (system)
$p_2$ = Pressure outside (environment)

The equation shows that the gap height is entered in the third potency and the speed is entered quadratic. After the pressure is set at up to 4 bar overpressure and the speed of the motors is set at up to 20,000 rpm, a decisive influence can only be exerted on the technically necessary leakage via the gap height. The gap height is influenced by the following parameters:

- Installation situation (overlaps, axial run-out of the stationary ring, working height, ...)
- Equilibrium of forces in the sealing gap (pressure inside ($p_1$ system), pressure outside ($p_2$ environment), spring force, bellows force, ...)
- Surface quality of the sliding partners (flatness, waviness, roughness, ...)
- Gap formation in operation (convergent, parallel, divergent)
- Circulation medium (mixing ratio, temperature, density, dynamic viscosity, ...)
- Operating conditions (speed, load spectrum, storage, vibrations in the system, ...)

- Structuring (geometry, arrangement, ...)
- part tolerances

In order to transfer the theoretical relationship between speed and gap height to the technical leakage that occurred, KACO carried out tests to determine the correct cause of leakage. Active influence was exerted on the gap height via the axial run-out of the rotating ring. This was achieved by specific underlay during assembly in the test specimen. This test used a speed profile provided by the OEM with speeds up to 18,000 rpm. The result showed in the following diagram (Figure 5) shows a clear influence on the leakage which is of decisive importance especially at high speeds above 15,000 rpm.

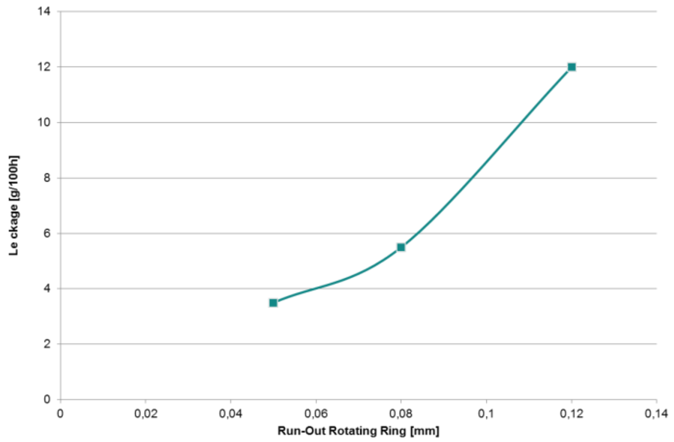


Figure5: Influence of sealing gap via axial run-out on technical leakage

# 6 Design verification and testing at KACO

KACO has rebuilt and expanded the test field. It is located on various locations in Germany and China to accommodate the new applications. There are many different types of test rigs. In the one hand model test rigs and in the other hand system test rigs, this represents the customer application. This enables us to offer our customers a high level of component testing.

Figure6: KACO model test rigs

# 7 Possibilities and outlook on integrated sub-assembly solutions

We are currently working on integrating various sub-assemblies, such as the static part of the mechanical face seal, a radial shaft seal, shaft grounding ring and multipole wheel. Furthermore we integrate various sensors into the cover of the electric motor or mounting them directly into the cover would offer a wide range of functionality. By mounting directly into the cover, the number of components can be reduced and costs for additional assembly and quality checks at the customer's site can be avoided. This also represents a great potential with regard to service friendliness, as it is possible to easily change sub-assemblies in a similar way to the water pump. Similar to the conventional aluminium cover, a realisation in high-performance plastics would also be considerable. For KACO and our customers, early cooperation can easily reduce the total cost of ownership. In summary we achieve a valuable contribution to the future of electrical mobility.

# Nomenclature

| | |
|---|---|
| EMRS | Electric Motor Rotors-shaft Seal |
| SIC | silicon carbide |
| HNBR | hydrogenated nitrile butadiene rubber |

# References


[1] MTZ - Motortechnische Zeitschrift, Release 6/2018, The new electric axle drives from Audi, cooling concept

[2] G. Jacobs, M. Plogmann: Tribology, Institute for Machine Elements and Machine Design, RWTH Aachen University, 6th edition, Aachen, Germany, 2015


# Authors


Matthias Podeswa

After three years of dual studies at KACO in mechanical engineering, specializing in plastics technology, I have been working as a development engineer for more than eight years now. At the moment I am working as a team leader in the field of water management. In addition to the classic development of the mechanical seal, this also includes various lip seals and rod seal packages.

Joachim Reichert

Since 1983 I have been working in research and development at KACO, being responsible for various areas such as pre-development, testing and product engineering. Currently, I am head of the product development for all KACO product groups.