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A Dual-Lip Radial Shaft Seal Design for E-Mobility

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Compared to legacy ICE applications, e axles and e drive units feature higher shaft surface speeds, tighter assembly envelopes, new lubricants and dielectric coolants, and stricter efficiency and durability targets. These changes stress convention-al elastomeric seals in few principal ways: Such as chemical degradation or swelling driven by novel base oils and additive packages that differ from traditional ATF or gear oils, second elevated lip rise temperature under frictional torque at high circumferential speeds and increased sensitivity to shaft alignment, including coaxially tolerances and dynamic runout that affect contact pressure distribution and hydrodynamic pumping effect. In some seal configurations, concentric shafts rotate at different speeds within a shared space of static seal seat, creating a requirement to seal with two interfaces in one compact component. This work presents a step-by-step development of a single seal integrating two distinct radial lips to meet demands in e mobility applications.

1 Introduction

Radial oil seals with elastomeric radial lips, as described in research article from researcher Bauer [1] have been widely used for several decades in automotive and general mechanical engineering applications. The basic configuration of a radial lip seal is illustrated in Figure 1. Such seals are designed to seal fully flooded, partially flooded, or splash-lubricated rotating shaft outlets in machine housings. Their primary function is to prevent leakage of the working fluid to the environment (air side) while simultaneously inhibiting the ingress of dust and contaminants from the external environment into the sealed region (fluid side). Under static conditions, the sealing edge is elastically pressed against the shaft surface, effectively preventing fluid leakage. During dynamic operation, shaft rotation entrains a small amount of fluid into the sealing interface, leading to the formation of a thin lubricating film within the sealing gap. Moreover, hydrodynamic pumping effects occur, whereby fluid entering the sealing gap is transported back from the air side toward the fluid side, thereby maintaining the sealing function

In recent years, several theoretical models have been proposed to describe the lubrication and sealing mechanisms of radial lip seals. Among these, the sealing edge distortion principle originally proposed by Kammüller [2] is regarded as one of the most influential approaches. Building on the experimental investigations of Kammüller [2] and Kawahara [3], established a correlation between the pressure distribution within the contact zone and the tangential distortion of the sealing edge. It was demonstrated that radial lip seals exhibiting back-pumping capability are characterized by an asymmetric pressure distribution, whereas seals with a symmetric pressure distribution show neither back-pumping behaviour nor effective sealing, resulting in leakage.

The pressure distribution is governed primarily by the contact surface angles α and β. Based on these observations, Kammüller [2] formulated the sealing edge distortion principle, as schematically illustrated in figure 1. During assembly, asperities of the rough sealing surface are elastically compressed (a). Subsequent shaft rotation induces shear stresses at the contact interface (b), which lead to tangential distortion of the asperities (c). As a result, microvanes structures are formed, which deflect the tangential fluid flow into the axial direction (d). This mechanism generates two opposing axial flow components: a back-pumping flow $\dot{m}_{bp}$directed toward the fluid side and a leakage flow $\dot{m}_{lk}$ directed toward the air side.

Owing to the asymmetric pressure distribution, the asperity distortion is likewise asymmetric, with a maximum occurring on the fluid side $\dot{m}_{bp}$ is higher than the leakage flow to the air side$\dot{m}_{lk}$ The resulting pumping rate flow $\dot{m}_{pr}$ is therefore directed towards the fluid side, which means that the radial lip seal is leak-proof Consequently, the net pumping rate is directed toward the fluid side, ensuring leak-free operation of the radial lip seal.

These findings have provided the foundation for numerous numerical investigations, including elastohydrodynamic lubrication (EHL) models developed by Salant [4], Despite differences in formulation and numerical implementation, these models consistently identify the asymmetric distortion of surface asperities and the associated formation of microvanes as key factors governing the sealing and pumping behaviour of radial lip seals [5].

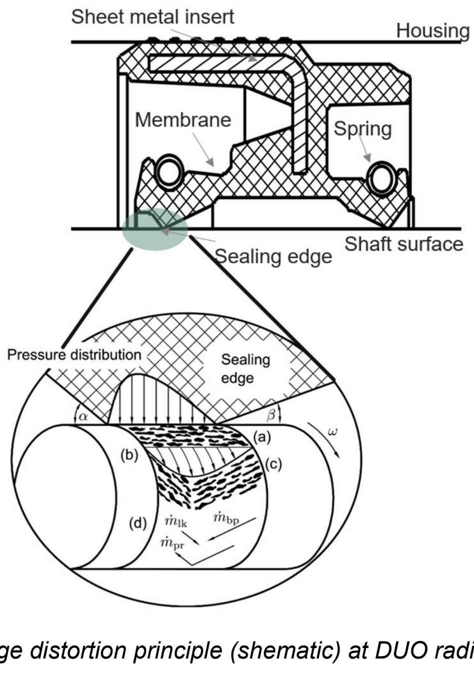


Figure 1. Edge distortion principle (shematic) at DUO radial oil shaft seal

2 Dynamic eccentricity of radial shaft oil seal

Geometrical tolerances within a sealing system have a significant influence on seal performance and leak-tightness. Deviations in form, orientation, location, and run-out of the shaft–seal assembly determine the magnitude of both static and dynamic misalignment.

In the present study, particular attention is given to dynamic eccentricity. Dynamic misalignment, also referred to as dynamic run-out (DRO), is defined as the time-dependent variation of coaxiality between the geometrical axis of the shaft and its rotational axis during operation, as illustrated in figure 2. Such misalignment typically arises from manufacturing tolerances, assembly inaccuracies, bearing clearance, or elastic deformations under load [1].

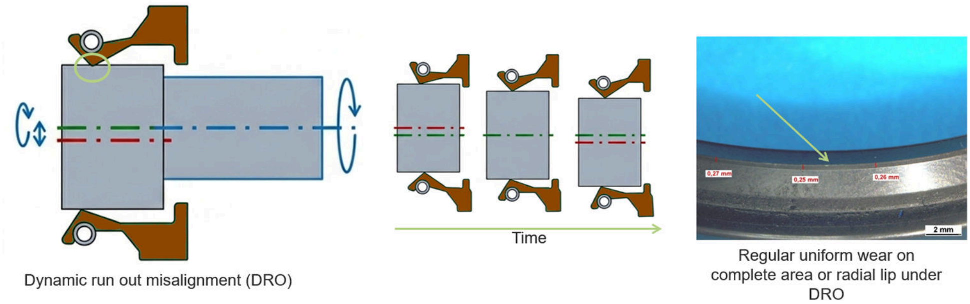


Figure 2. Dynamic run out DRO

Dynamic eccentricity leads to a periodic variation of the contact conditions between the sealing lip and the shaft surface, resulting in locally varying contact pressures and film thicknesses over one shaft revolution. These variations can significantly affect lubrication conditions, pumping behaviour, and ultimately the leakage performance of radial lip seals. Consequently, a detailed consideration of dynamic eccentricity is essential for an accurate assessment of sealing performance under realistic operating conditions.

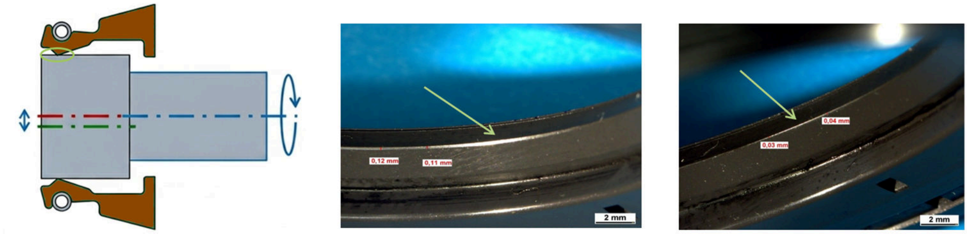
In the presence of dynamic eccentricity, the shaft exhibits a periodic radial reciprocating motion superimposed on its rotational motion. The peak-to-peak amplitude of this radial displacement corresponds to twice the dynamic eccentricity in literature [1] named as total indicator reading (TIR), while the frequency of the motion is directly governed by the shaft rotational speed. Consequently, the sealing lip is cyclically forced to follow the radial displacement of the shaft surface during operation.

We can very often see that an elastomer radial lip under DRO have a uniform wear like we can see on figure 2.

At elevated shaft speeds and in the presence of dynamic eccentricity, the viscoelastic behaviour of the elastomeric sealing lip may prevent it from faithfully following the shaft motion. As reported in [1] and [5], this can lead to a temporary loss of contact between the sealing lip and the shaft surface. Such lift-off phenomena impair the local contact pressure and lubrication conditions and may ultimately result in increased leakage.

In case of static misalignment, such as shaft-to-bore misalignment (STBM), the force varies over the seal circumference but does not vary in time during shaft rotation like we can see in figure 3

In case of STBM we have a wear or radial lip only on one side due higher contact shaft force on these side like we can see on figure 3



Shaft to bore misalignment (STBM) | Unregular wear on one side of radial lip under STBM | Regular wear on other area or radial lip under STBM

Figure 3. Shaft to bore misalignment (STBM) and wear on radial lip

3 Standard radial shaft seal and Performance benchmark

The initial investigations were conducted using a standard radial oil seal (RWDR) with nominal dimensions of 40 × 52 × 7 mm. The seal was manufactured from an FKM elastomer with a hardness of 75 Shore A (material code FKM 585). Bench tests performed under controlled conditions with a dynamic runout (DRO) of 0.5 mm and an oil temperature of 80 °C demonstrated stable sealing behaviour and acceptable wear characteristics.Under these laboratory conditions, the elastomer maintained sufficient flexibility to generate a stable radial force, ensuring an adequate and uniform contact pressure along the sealing edge. Consequently, no abnormal wear or leakage was detected during short-term testing of 240 working hours according to test standard DIN 3761 [6].

4 Low-Temperature Effects and Wear-Relevant Material Behaviour

In contrast, field testing in cold climate regions revealed early leakage at ambient temperatures approaching −20 °C. This behaviour is directly linked to the temperature-dependent viscoelastic properties of the FKM elastomer [1]. With a glass transition temperature of approximately −14 °C, FKM exhibits a pronounced increase in storage modulus and a corresponding loss of elastic recovery below T_g [1].

From a tribological perspective higher T_g increased stiffness reduces the ability of the sealing lip to conform to shaft micro-roughness and dynamic shaft movements. The resulting reduction in effective contact area leads to locally elevated contact pressures and unstable lubrication conditions at the sealing interface. Such conditions promote boundary lubrication and significantly increase abrasive and adhesive wear of the sealing lip, ultimately enabling leakage initiation [1]. In comparison with ACM elastomer with a glass transition temperature T_g -33°C where we have significant seal performance at sub zero working conditions.

5 Influence of Increased Dynamic Runout DRO on radial oil shaft seal

A further challenge was introduced with the revised gearbox design, which resulted in increased shaft misalignment and a dynamic runout of up to 1 mm. Elevated DRO causes cyclic deformation of the sealing lip membrane, leading to alternating stress states and non-uniform contact pressure distribution along the circumferential contact line.

These effects accelerate wear through several mechanisms:

- Increased frictional energy input due to fluctuating contact pressures,
- Micro-sliding at the lip–shaft interface,
- Fatigue-induced crack initiation at the sealing edge.

To mitigate these effects, a new seal design incorporating an extended radial lip geometry was developed. The longer lip improves compliance to shaft eccentricities and reduces peak contact stresses, thereby stabilizing the tribological system.

6 Chemical Aging and Its Impact on elastomer radial lip force

In addition to mechanical loads, e-mobility gearbox oils pose a significant chemical challenge. Compatibility testing conducted according to customer-defined specifications revealed that FKM (material code FKM 585) undergoes more pronounced chemical aging in the specified working fluid (Schaeffler OIL TYPE 1) compared to an ACM elastomer with a hardness of 75 Shore A (material code ACM 380DF). The specifications lubricant for e-mobility gearbox application is summarized in table 1, with particular emphasis on properties relevant to wear mechanisms at the seal–shaft interface.

Table 1.Oil test specification

Oil-Type	Schaeffler OIL TYPE 1
Oil-Specification	Hydrocrack + Ester
Kinematic viscosity [mm2/s] at 40 °C at 100 °C	14,5 4,5
Dynamic viscosity at -40 °C [MPa]	2400
Density at 15°C [kg/m3]	835,0
Flash point [°C]	≥180

A increase in radial force may result in insufficient sealing and micro-leakage, whereas an increase can lead to excessive friction, thermal degradation, and accelerated lip wear [7]. The observed radial force instability in aged FKM seals therefore represents a key factor contributing to increased wear rates and reduced service life [7]. The complete results of the lubricating oil aging tests conducted in Schaeffler OIL TYPE 1 are summarized in Table 2. The investigations were performed on FKM 585 and ACM 380 DF elastomer materials after an aging duration of 168 h at a test temperature of 150 °C. The presented data allow a direct comparison of oil-induced changes in mechanical and tribologically relevant properties of both elastomer systems under severe thermal and chemical loading conditions representative of e-mobility gearbox operation.

Table 2. Elastomers corrosion test in Shaeffler OIL TYPE 1

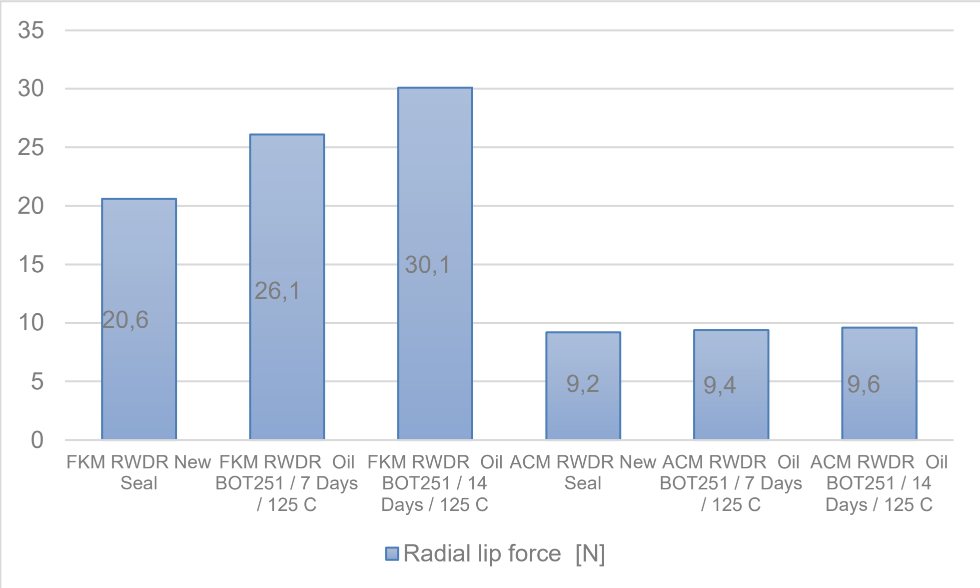
Material	Beafore test ACM 380 DF	Change after test ACM 380 DF	Beafore test FKM 585	Change after test FKM 858
Hardness Shore A (DIN ISO 7619-1, S2, 23°C)	74	75	75	77
Tensile strength [MPa] (DIN 53504, S2, 23°C)	8,3	8,6	11,3	4,7
Elongation at break [%] (DIN 53504, S2, 23°C)	132	110	252	94
Elongation at break [%] (DIN 53504, S2, 23°C)		4,3		3,2

As shown in Table 2, FKM 585 exhibits a pronounced change in both tensile strength and elongation at break after aging in Schaeffler OIL TYPE 1. These mechanical property alterations indicate significant oil-induced material degradation. From a tribological perspective, such changes are highly relevant, as tensile strength and elongation at break are directly related to the elastic and viscoelastic response of the sealing lip [8]. A reduction in these properties can lead to a measurable change in radial lip force, thereby modifying the contact pressure distribution at the seal–shaft interface. Consequently, altered radial lip force may promote unfavourable lubrication conditions and accelerate wear of the sealing lip, ultimately reducing sealing performance and service life [9].

These changes are expected to accelerate wear of the sealing lip, ultimately leading to reduced sealing performance and shortened service life. Radial lip force measurements carried out in accordance with DIN 3761 [6] are presented in Table 3. For FKM 585, the radial force increased markedly from 20 N to 30.1 N after a 14-day aging period. Such a substantial rise in radial force results in elevated contact pressure at the lip–shaft interface, which typically increases frictional loading and promotes accelerated wear of the sealing lip [10].

In contrast, the ACM 380 DF material exhibited only a minor change in radial force, increasing from 9.2 N to 9.6 N over the same test period. This variation is considered insignificant from a tribological standpoint and is therefore expected to have a negligible influence on wear behaviour and overall seal service life. The results indicate that the radial force stability of ACM 380 DF after oil aging provides more favourable conditions for long-term wear performance compared to FKM 585 under the investigated operating conditions.

Table 3. Radial lip seal force measurement



7 Design changes and rest result at test rig

The new gearbox design imposes unique operating requirements, as two radial shafts with fundamentally different working conditions must be sealed simultaneously. The first shaft operates at high rotational speed, up to 16,000 rpm, with low dynamic eccentricity not exceeding 0.15 mm. In comparison, the second shaft is characterized by a significantly higher dynamic eccentricity of up to 1 mm, while operating at a comparatively low rotational speed of approximately 2,300 rpm. These strongly differing kinematic conditions pose substantial challenges for seal design and wear control.

The initial sealing solution implemented in the prototype gearbox consisted of a standard radial shaft seal (RWDR) manufactured from FKM 585 with dimensions 40 × 52 × 7 mm like We can see on figure 4. The performance of this seal design and material has been described and evaluated in previous sections. While FKM 585 showed satisfactory performance in preliminary bench tests, its chemical compatibility with the specified working lubricant was found to be insufficient for long-term serial application. Oil aging resulted in pronounced changes in mechanical properties and radial lip force, which are expected to negatively affect wear behaviour and service life.

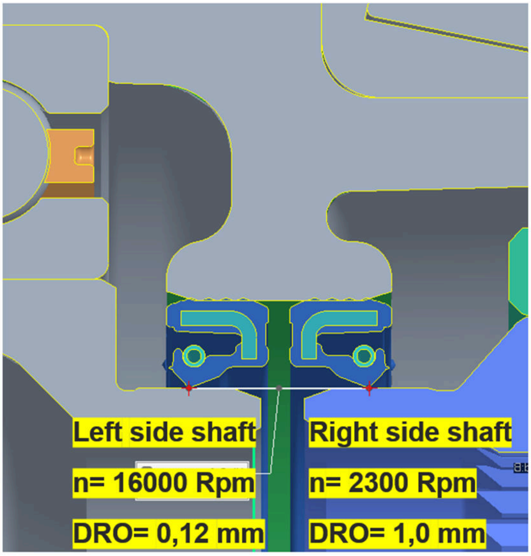


Figure 4. Standard radial oil shaft seal configuration

To address these limitations, a new sealing concept was developed in the form of a dual-lip radial shaft seal (duo-RWDR). The design incorporates two spring-loaded radial sealing lips manufactured from ACM 380 DF, a material exhibiting improved chemical stability and more stable mechanical properties after oil aging. Although dual-lip seals are commonly used to separate two different working media, in the present application both lips are exposed to the same lubricant. However, the shafts differ significantly in rotational speed and dynamic coaxiality, making a differentiated sealing approach necessary.

During operation, the shaft rotation between the two sealing lips can lead to pressure build-up in the inter-lip volume. Such pressure conditions are known to influence radial lip force and may result in increased contact pressure, friction, and wear at the seal–shaft interface. To eliminate this effect, air venting was implemented between the two shafts, ensuring pressure equalization between the sealing lips and preventing undesirable changes in radial force.

An additional motivation for the development of the duo-RWDR concept was related to assembly and durability considerations like we can see of figure 5. Compared to the use of two separate radial shaft seals, the integrated dual-lip design allows easier assembly within the housing groove and simplifies maintenance procedures.

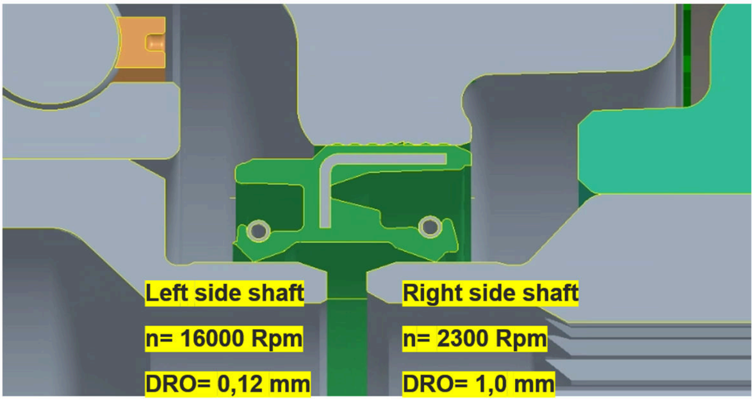


Figure 5. Duo-Radial oil Shaft seal configuration

Furthermore, the extended static sealing length enhances axial stability within the housing, reducing the risk of seal misalignment and associated uneven wear during operation.Overall, the dual-lip sealing concept combining optimized geometry, controlled venting, and an ACM-based elastomer provides improved robustness against wear mechanisms arising from chemical aging, pressure effects, and highly dissimilar shaft operating conditions.

7.1 A test rig working conditions

The pumping behavior of the radial shaft seals was investigated using a laboratory test rig designed in accordance with DIN 3761 [6]. Figure 6 presents the test rig configured for pumping rate measurements under controlled temperature and shaft speed conditions.

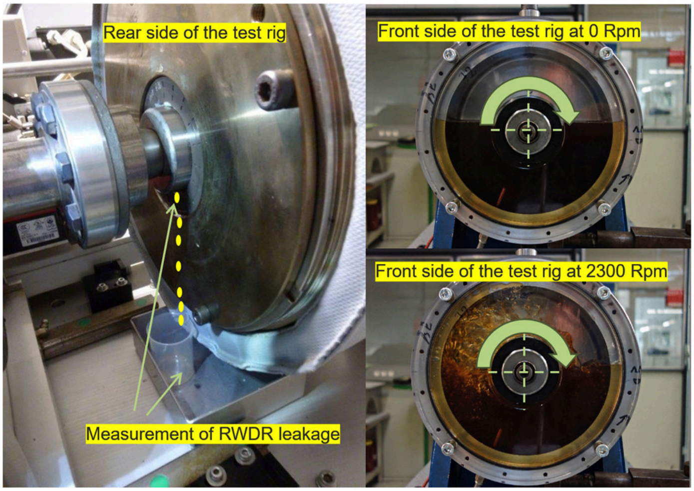


Figure 6. Radial oil shaft seal test rig

A computer-based control unit was used to set and monitor all test parameters. The test shaft sleeve, exhibiting a surface roughness compliant with DIN 3761 [6] specifications, was mounted on a shaft adapter and driven by an electric motor through a belt drive system, ensuring stable and reproducible rotational speeds.

The seal ring under investigation was press-fitted into a dedicated holder mounted in the oil chamber. The chamber housing, made of aluminium, incorporated heating cartridges to regulate the lubricant temperature. The lubricant was filled to approximately half the seal height. The oil sump temperature was continuously recorded using an integrated temperature sensor.

To quantify the pumping performance, the radial shaft seal was installed in an inverse orientation (Fig. 7), producing a continuous pumping action toward the fluid side. The pumped lubricant was collected in a beaker over a predefined test duration and subsequently weighed, allowing determination of the pumping rate.

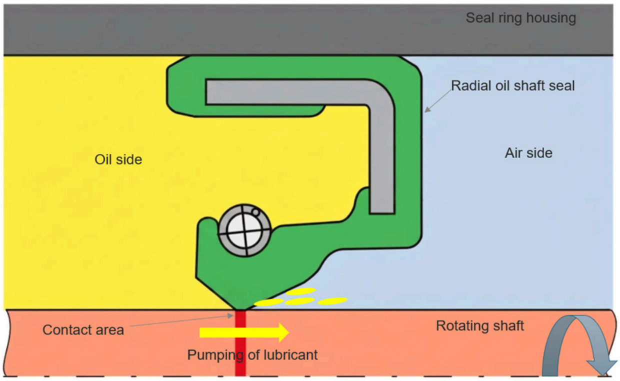


Figure 7. Pumping rate measurement

7.2 Test results analyse

Standard seal designs and commonly used elastomer materials may reach their performance limits under such demanding boundary conditions. Therefore, systematic experimental evaluation under realistic misalignment loads is required to establish performance limits and to provide a reference for advanced seal concepts.

The objective of this study is to characterize the sealing and wear behavior of a standard FKM-based RWDR seal, serving as a baseline for comparison with a newly developed RWDR design.

The overall test program was divided into two stages:

1. **Preliminary tests** with standard radial shaft seals used in prototype gearboxes test results we can see in table 5
2. **Evaluation tests** with a newly developed RWDR seal concept test result we can see in table 6 and table 8

The tested specimen was a standard FKM 585 RWDR seal, part type BA UM3 X7 40-52-7, representing a commonly applied sealing solution in prototype gearbox applications. Our test result we will divide into two stages pre results with standard seals used in prototype gearboxes and test results with new developed RWDR.

Tests were conducted according to DIN 3761 with a total test duration of 240 hours. The applied test program (Table 4) included elevated temperature levels and high shaft speeds representative of demanding gearbox operation.

To simulate realistic working conditions, the following parameters were imposed:

- Dynamic Radial Offset (DRO): 1.0 ± 0.1 mm
- Static Tilting and Bending Misalignment (STBM): 0.1 ± 0.1 mm

Table 4. Test program of test rig with DRO 1.0 mm

Step	Duration [h]	Temperature [°C]	Shaft Speed [rpm]	Rotational Direction	Comments
1	14	110	2300	cw	3 seals cw
2	6	120	2300	cw	
3	4	no heating	w/o	w/o	

Table 5. Test results of standard FKM RWDR

Test Number	Rotation	Test Duration [h]	Without Leakage [h]	DRO [mm]	Wear Track Width [mm]	Leakage mass [g]
146298	cw	240	48	0.92	0.34	0.2
146299	cw	240	216	0.90	0.36	3.2
146300	cw	96	24	1.06	0.38	25.6
Average		192	96	0.96	0.36	9.66

The test results obtained with the standard FKM RWDR seal are summarized in Table 5. The leakage-free operating time showed noticeable variation between individual test samples, indicating sensitivity of the sealing system to combined thermal and mechanical loading.

Post-test inspection revealed continuous circumferential wear tracks on the shaft surface. The measured wear track widths ranged between 0.34 mm and 0.38 mm, resulting in an average value of 0.36 mm after the applied test duration.

Several test specimens exhibited increasing leakage mass with test duration, suggesting a progressive loss of effective sealing capability.

These results define a clear performance baseline for standard seal designs and highlight the limitations of conventional FKM materials under demanding gearbox conditions. The findings form the technical basis for the subsequent evaluation of a newly developed RWDR concept with optimized design and elastomer material.

The wear and sealing performance of a standard ACM 380DF radial shaft seal, part type BS DUO DF 40-57-16, were evaluated as part of the baseline test program. The tests were conducted in accordance with DIN 3761 with a total test duration of 240 hours. A Dynamic Radial Offset (DRO) of 1.0 ± 0.1 mm was applied to represent realistic misalignment conditions typically encountered in prototype gearbox applications.

As shown in table 6, all three test specimens completed the full test duration without premature failure. The leakage-free operating time ranged from 192 h to 240 h, with an average value of 224 h. Two of the three specimens remained completely leakage-free throughout the entire test period, while only one sample exhibited minor leakage toward the end of the test.

The average leakage mass of 0.33 g is significantly low and indicates stable sealing behavior under sustained high-speed and misalignment loading. This result demonstrates a high tolerance of the ACM 380DF elastomer to combined mechanical and thermal stresses.

Table 6.Test Results of new developed DUO RWDR at DRO 1.0 mm

Test Number	Rotation	Test Duration [h]	Without Leakage [h]	DRO [mm]	Wear Track Width [mm]	Leakage mass [g]
146301	cw	240	192	0.97	0.43	1.0
146302	cw	240	240	1.04	0.49	0.0
146303	cw	240	240	1.03	0.41	0.0
Average		240	224	1.01	0.44	0.33

Post-test inspection revealed continuous circumferential wear tracks on all tested shafts. The measured wear track widths ranged from 0.41 mm to 0.49 mm, resulting in an average value of 0.44 mm.

Overall, the ACM 380DF DUO seal demonstrated superior sealing performance stability compared to standard single-lip FKM RWDR designs tested in earlier stages. The combination of advanced elastomer properties and optimized sealing geometry results in extended leakage-free operation and controlled wear development.

The wear and sealing performance test was done according to test program in table 7 of a Hi - speed side ACM 380DF radial shaft seal, part type BS DUO DF 40-57-16, were evaluated as part of the baseline test program. The tests were conducted in accordance with DIN 3761 with a total test duration of 240 hours. A dynamic radial offset (DRO) of 0.12 ± 0.1 mm was applied to represent realistic misalignment conditions typically encountered in prototype gearbox applications.

*Table 7.*Test program of hi-speed Lip side from duo RWDR

Step [-]	Duration [hh: mm: ss]	Temperature [°C]	Speed [min^{-1}]	Rotation Direction (CW / CCW)
1	01:00:00	90	1.000	5 seals CW / 5 seals CCW
2	01:00:00	90	2.000	5 seals CW / 5 seals CCW
3	01:00:00	90	3.000	5 seals CW / 5 seals CCW
4	01:00:00	90	4.000	5 seals CW / 5 seals CCW
5	01:00:00	90	5.000	5 seals CW / 5 seals CCW
6	01:00:00	90	6.000	5 seals CW / 5 seals CCW
7	01:00:00	90	7.000	5 seals CW / 5 seals CCW
8	01:00:00	90	8.000	5 seals CW / 5 seals CCW
9	01:00:00	90	9.000	5 seals CW / 5 seals CCW
10	01:00:00	90	10.000	5 seals CW / 5 seals CCW
11	01:00:00	90	11.000	5 seals CW / 5 seals CCW
12	01:00:00	90	12.000	5 seals CW / 5 seals CCW
13	01:00:00	90	13.000	5 seals CW / 5 seals CCW
14	01:00:00	90	14.000	5 seals CW / 5 seals CCW
15	03:00:00	120	15.000	5 seals CW / 5 seals CCW
16	03:00:00	120	16.000	5 seals CW / 5 seals CCW
17	04:00:00	no heating	0	without

As shown in table 8, all three test specimens completed the full test duration without premature failure. The leakage-free operating time ranged from 216 h to 240 h, with an average value of 321h. Two of the three specimens remained completely leakage-free throughout the entire test period, while only one sample exhibited minor leakage toward the end of the test.

The average leakage mass of 0.10 g is significantly low and indicates stable sealing behavior under sustained high-speed and misalignment loading. This result demonstrates a high tolerance of the ACM 380DF elastomer to combined mechanical and thermal stresses at hi speed working conditions.

Table 8. Test results hi-speed lip side of DUO-RWDR

Test Number	Rotation	Test Duration [h]	Without Leakage [h]	DRO [mm]	Wear Track Width [mm]	Leakage mass [g]
145916	cw	240	240	0.12	0.34	0.0
145917	cw	240	216	0.12	0.52	0.32
145918	cw	240	240	0.12	0.30	0.0
Average		240	231.33	0.12	0.38	0.10

Post-test inspection revealed continuous circumferential wear tracks on all tested shafts. The measured wear track widths ranged from 0.30 mm to 0.52 mm, resulting in an average value of 0.38 mm.

Overall, the ACM 380DF DUO seal demonstrated superior wear stability and sealing reliability at hi-speed working conditions.

8 Conclusion

The conducted investigations demonstrate that e-mobility drivetrain applications impose significantly increased mechanical, thermal, and chemical demands on radial shaft seals, which directly influence wear behaviour and sealing reliability. Standard single-lip RWDR seals manufactured from FKM elastomers exhibited limited robustness under elevated shaft speeds, increased dynamic runout, and chemically aggressive lubricants, leading to unstable radial lip forces, progressive wear, and reduced leakage-free operating time.

In contrast, seals manufactured from ACM 380 DF showed superior sealing stability and chemical resistance after oil aging, resulting in more stable radial forces and controlled tribological behaviour. Bench tests according to DIN 3761 confirmed extended leakage-free operation and low leakage mass under severe misalignment and high-speed conditions. Although larger wear track widths were observed for the dual-lip designs, these did not negatively affect sealing performance, indicating a stable and well-balanced seal–shaft contact system.

Overall, the results confirm that optimized seal geometry combined with chemically and mechanically stable elastomer materials is essential to control wear mechanisms in e-mobility applications. The developed dual-lip RWDR concept based on ACM 380 DF provides a robust solution to address high shaft speed, dynamic eccentricity, and lubricant compatibility requirements, offering significantly improved durability and wear performance for next-generation electric drive units.

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10 Nomenclature

Variable	***Description***	***Unit***
$\dot{m}_{bp}$	Back pumping flow	[ml]
$\dot{m}_{lk}$	Leakage flow	[ml]
$\dot{m}_{pr}$	Resulting pumping flow rate	[ml]
n	Shaft speed	[rpm]
T_g	Glass transition temperature	[°C]

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