Sealing Systems under Starved Lubrication Conditions

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Various operating conditions can cause sealing systems to be insufficiently supplied with oil, resulting in starved lubrication. This paper deals with the experimental investigation of starved lubrication operating conditions. For this purpose, the test rig configuration used is introduced. The influence of starved lubrication on 3 different sealing systems was investigated. In addition to a standard elastomeric rotary shaft seal, a multi-lip initially grease-filled elastomeric rotary shaft seal and a PTFE sleeve with circumferential grooves were employed. The results show that the standard rotary shaft seal is unsuitable for the investigated starved lubrication conditions. The other two sealing systems performed better in comparison and are suitable for operation with a starved oil supply, at least for short durations.

1 Introduction

Rotary shaft seals are used to seal shaft interfaces in many industrial applications and especially in the automotive sector. They are available at the market in different sizes and designs, as well as in different materials. In addition to elastomeric rotary shaft seals made of FKM (fluoro rubber) or NBR (nitrile rubber), different PTFE sleeve seals are available for various applications [1]. Sealing systems form complex tribological systems [2] consisting of the sealing ring itself, the sealing counterface (shaft), the fluid to be sealed, as well as the ambient and operating conditions. To ensure the function of a sealing system over a long service life, the dynamic sealing area must always be sufficiently lubricated. Insufficient lubrication results in excessive abrasive wear and thermal overload of the tribological system.

The initial situation is a gearbox drive shaft application as shown in Figure 1. The sealing system is cooled and lubricated using the transmission oil. The lubricant supply to the sealing area is dependent on the shaft speed. At low speeds of the drive shaft, hardly any transmission oil reaches the sealing contact. Only at higher speeds the transmission oil reaches the sealing edge. A complete lubrication with flooded sealing edge still cannot be ensured. Only a limited amount of oil splashes the sealing contact. The available oil volume flow rate is very low in this application.

Starved lubrication is problematic for every sealing system. The friction and wear rate in the sealing contact increases and the generated heat cannot be dissipated by the fluid. The aim of this study is to develop a method for simulating starved lubrication conditions on the test rig. Different sealing concepts are to be tested and evaluated in parallel.

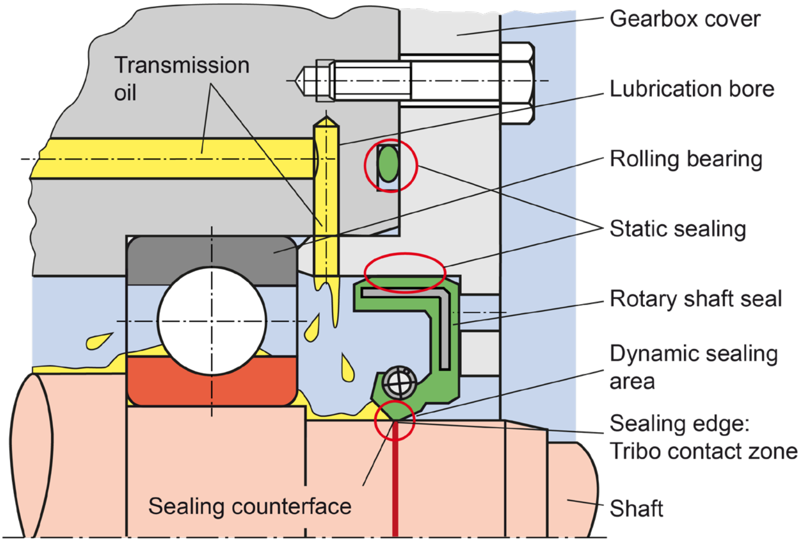

Figure 1: Gearbox sealing system under starved lubrication conditions (Illustration based on [1])

2 Test Rig and Sealing Systems

The test rig setup introduced in [3, 7] was modified for the investigation of sealing systems under starved lubrication conditions. The test rig configuration and the tested sealing systems are introduced in the following.

2.1 Test Rig Configuration

To test different sealing systems under starved lubrication conditions, the modular endurance test rig at the institute was equipped with an additional fluid circulation system (see Figure 2). This enables the situation in the field to be simulated very accurately. The oil is preheated and pumped to the test chambers. It is supplied to the test chamber directly above the sealing system. The oil pump supplies 12 sealing systems from the same oil reservoir. The oil quantity is adjusted via the delivery rate of a gear pump and via oil flow restrictors in each seal housing. Consequently, the flow rate for each sealing system is very low and the starved lubrication conditions can be simulated realistically. The oil runs down on the inside of the seal housing and drips directly into the sealing contact. After that, the oil collects at the bottom of the test chamber and returns to oil reservoir following gravity.

Each test rig module is equipped double sided with two test chambers driven by a central drive shaft. In this test series, 12 individual test runs on 6 modules are carried out simultaneously. The test rig during operation is shown in Figure 3.

The leakage, as well as the temperature at the airside of the sealing edges were measured during the test. The test chambers are vented, which prevents a pressure difference in the sealing contact.

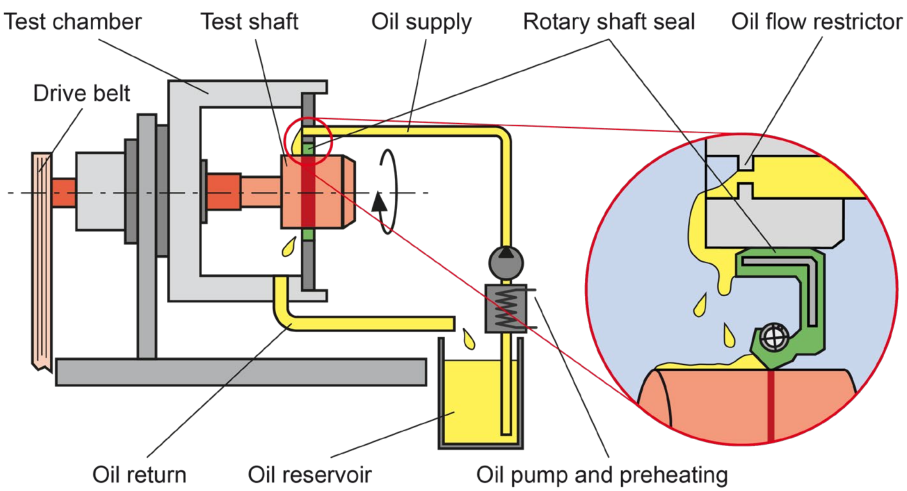

Figure 2: Configuration of a single test chamber with fluid circulation system

Figure 3: Modular endurance test rig during the starved lubrication test runs

The load collective is based on the operating conditions of the field application. There are several circumferential velocity levels between 3 m/s and 15 m/s, as well as a longer standstill duration. The oil is supplied to the sealing edges during the higher velocity levels at the typical operating temperature of the transmission oil. At lower velocities, the sealing systems are running without any external oil supply. The air in the test chamber is heated during the running period slightly above oil temperature.

During the standstill, the test chambers are cooling down passively to ambient conditions. The duration of the test run is less than 200 h resulting in a sliding distance of approx. 3500 km for each sealing edge.

2.2 Tested Sealing Systems

A total of 3 different types of sealing systems are tested with 4 individual seals each. The sealing systems tested are shown in Figure 4.

① is the standard seal type in the application. The elastomeric rotary shaft seal made of FKM has a pressure stable geometry. It has a shortened membrane area to withstand pressure differentials up to 10 bar and pulsating pressures up to max. 25 bar.

② is also an elastomeric rotary shaft seal made of FKM with a protective lip and an additional oilside sealing lip. Between the sealing edges, an initial grease lubrication is added (see investigations with this seal type in [3]). In contrast to ①, this seal is not specially developed to seal overpressure.

③ is a PTFE sleeve with circumferential grooves in the contact area.

All seals are tested on identical shafts. The shaft surfaces are plunge ground lead free with rotating grinding wheel. The fluid is transmission oil according the API category GL-5 [4, 5].

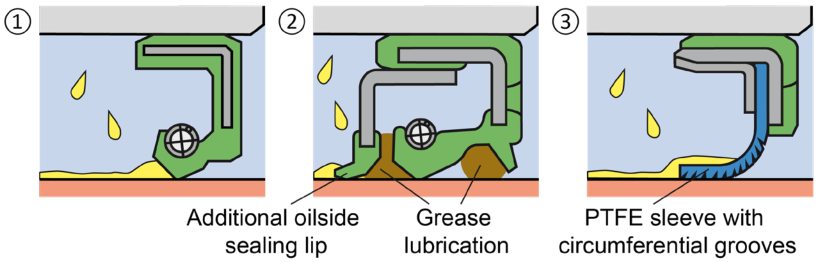

Figure 4: Tested sealing systems: ① elastomeric rotary shaft seal with pressure stable geometry. ② elastomeric rotary shaft seal with protective lip and additional oilside lip with initial grease lubrication. ③ PTFE sleeve with circumferential grooves.

3 Results

All sealing systems were analyzed comprehensively [1, 6, 7] after the test run. An excerpt of the test results is summarized in Figure 5 and Table 1.

The rotary shaft seal with pressure stable geometry ① has no additional lubrication during the dry running sections. The sealing edges show heavy wear, circumferential grooves, as well as sticking oil carbon deposits in the contact area of the sealing edge and on the fluid side of the sealing edge. The shaft surface also shows sticking oil carbon deposits.

The rotary shaft seal with additional oilside lip and initial grease lubrication ② is capable to lubricate itself during the dry run sections. In the contact area of the sealing edges there are no sticking oil carbon deposits and there are significantly less oil carbon deposits at the fluid side of the sealing edge compared to ①. The shaft surfaces also show sticking oil carbon deposits comparable to ①. All shafts of ① and ② show dark blue surface color after test run because of the heavy heat input [8].

In comparison to the elastomeric rotary shaft seals, the PTFE sleeve ③ has design related a wider contact area. This distributes the heat input into the shaft over a larger area. The shaft surface only shows yellow to brown color. There are no visible oil carbon deposits at the contact area of the sleeve or on the shaft surface. Only the original circumferential grooves in the contact area are clogged with wear debris or oil carbon deposits.

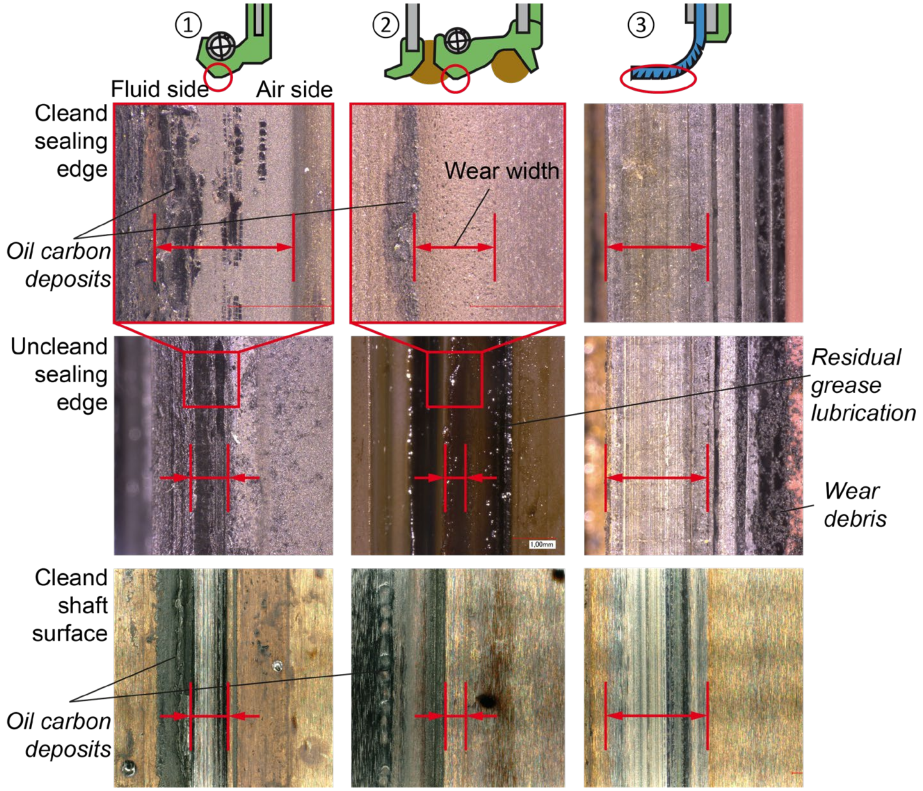

Figure 5: Cleaned sealing edges (top), uncleaned sealing edges (middle) and associated shaft surface (bottom) after the test run. Remark: each test run carried out with 4 individual sealing systems, only one representative result is shown in this figure.

The rotary shaft seals ① have lost almost the full amount of radial load. The decrease in radial load is up to – 99 %. This is clearly connected to the heavy wear, with measured wear widths wider than 1 mm. The manufacturer supplies the rotary shaft seals ② already with initial grease lubrication. Thus, there is no radial load measurement possible before the test run. The PTFE sleeves show a slight increase of radial load. The measured temperatures at the airside of the sealing edges are with up to 250 °C for ① way over the application limits of the elastomeric material [9]. With grease lubrication ② the temperatures are still high but less extreme. For the PTFE sleeves ③ the temperature up to 180 °C are in an acceptable range.

During the test runs, at some sealing systems small amounts of leakage occurred. Due to the starved lubrication, the leakage rate remained low.

Table 1: Test result after starved lubrication test runs

	① elastomeric rotary shaft seal	② with grease lubrication	③ PTFE sleeve
Change of radial load	-65 … -99 %	N/A	approx. + 10 %
Measured Temperature at the air side of the sealing edge	200 … 250 °C	180 … 200 °C	140 … 180 °C
Wear width	max. 1.1 mm	max. 0.6 mm	N/A

4 Summary and Conclusion

With the modified test rig setup, it is possible to investigate sealing systems under starved lubrication conditions. Real operating conditions can be reliably reproduced with tests at component level.

The elastomeric rotary shaft seal without grease lubrication has completely lost its sealing function. This sealing system is not suitable for sealing under starved lubrication conditions. The sealing system with additional grease lubrication performed as expected far better. The sealing function is nevertheless partially impaired by oil carbon deposits, and the additional oil side lip was heavily damaged. The PTFE sleeve has led to the lowest temperatures in the sealing contact therefore of the shaft. There are no oil carbon deposits at the sealing edge and the shaft. The sealing function only could be impaired by the clogged circumferential grooves in the contact area.

5 References

[1] Bauer, F.: *Federvorgespannte-Elastomer-Radial-Wellendichtungen. Grundlagen der Tribologie & Dichtungstechnik, Funktion und Schadensanalyse*, Springer Vieweg, Wiesbaden, 2021, ISBN 978-3-658-32921-1

[2] Bauer, F.: *Tribologie. Prägnant und praxisrelevant*, Springer Vieweg, Wiesbaden, 2021, ISBN 978-3-658-32919-8

[3] L. Merkle, M. Baumann, F. Bauer: *Improving a Gear Box Sealing System - Individual Test Design Based on Given Application Parameters and Failure Analysis*, ISGATEC JAHRBUCH Dichten. Kleben. Polymer., 2022, pp. 84–97, 2021.

[4] ASTM Standard D7450-19, 2019, *Standard Specification for Performance of Rear Axle Gear Lubricants Intended for API Category GL-5 Service*, ASTM International, West Conshohocken, PA, 2003, DOI: https://doi.org/10.1520/D7450-19

[5] American Petroleum Institute, *Lubricant Service Designations for Automotive Manual Transmissions, Manual Transaxles, and Axles*, API Publishing Services, Washington, D.C., 2013

[6] M. Baumann, F. Bauer, *Moderne visuelle Untersuchungsmethoden für die Verschleißanalyse am Beispiel Radial-Wellendichtring*, In: *20th International Sealing Conference*, 2018: pp. 93–104.

[7] L. Merkle, M. Baumann, F. Bauer, *Best Practice for Individual Test Design Based on Given Application Parameters and Failure Analysis on Radial Shaft Seals*, In: *61st German Tribology Conference*, 2020, pp. 50/1-50/7

[8] George E. Totten, *Steel Heat Treatment. Metallurgy and Technologies*, Taylor & Francis Inc, Portland, Oregon, 2007

[9] Freudenberg Sealing Technologies GmbH & Co. KG*, Technical Manual. Section 1*, 2015

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