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New Method for Estimating the Sealing Quality of Rotating Seals

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Besides the classical application of radial shaft seals with a stationary sealing ring and a rotating shaft, there are various applications where the sealing ring itself is rotating. The best known examples are hub units for vehicles or centrifuges. Especially at high speeds, the rubber-elastic sealing lips may deform because of the centrifugal force, resulting in sealing problems. To estimate the application limits of rotating standard radial shaft seals and to ensure reliable sealing, a method was developed that, on the basis of static radial force studies, determines the critical speeds of rotating radial shaft seals.
This offers the possibility to reduce friction losses without impairing sealing performance.

1. Introduction

Due to continuous improvements and specializations, elastomeric radial shaft seals provide reliable sealing for different applications in various operating conditions. In the majority of cases, the radial shaft seal is mounted into a non-rotating housing, while the shaft is turning (Fig. 1, left).

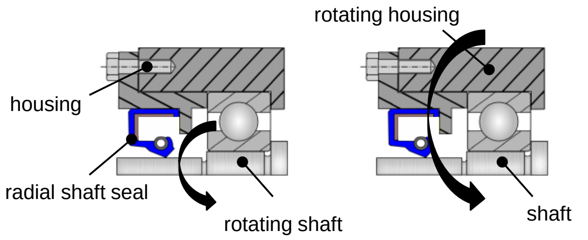

Fig. 1: Radial shaft seal in standard application and in a rotating housing

However, although the standard application is comprehensively investigated, the use of radial shaft seals in applications with inverted kinematics is barely described (Fig. 1, right). Of course, there are special designs for sealing in rotating housings. But these seals are mostly designed as cartridge seals and therefore, they are relatively expensive, or insufficiently tested and do not go beyond a patent stadium.

To avoid problems in the selection and procurement of seals, it would be advantageous to use standard radial shaft seals for rotating housings, too. Therefore, it is necessary to know the application limits of standard radial shaft seals under influence of the centrifugal force.

In a fast rotating housing, the fluid can form a static oil ring along the housing wall (Fig. 2). At the time of the lift off, the hydrostatic pressurized oil can splash out through the sealing contact and cause massive leakage.

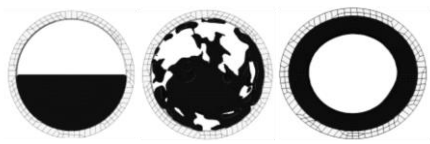

Fig. 2: Phases of the formation of a static oil ring in a fast rotating housing

To prevent this, an analytical calculation method was developed and the results were compared with dynamic radial force measurements and friction tests.

2. Setup

To get basic information about the operational behavior of radial lip seals under influence of centrifugal force, static radial force measurements has to be conducted and the lip design has to be analyzed.

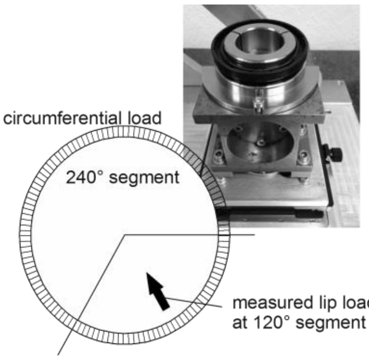

Fig. 3: Static radial force measurement with a divided mandrel

With the knowledge about the two radial force components “elastomer” and “garter spring” in combination with the lip mass, critical speeds for rotating radial shaft seals can be calculated.

$$F_{\mathrm{cent}} = F_{\mathrm{radial}} \qquad (1)$$

with $$F_{cent} = m \cdot r \cdot \omega^2 \qquad (2)$$

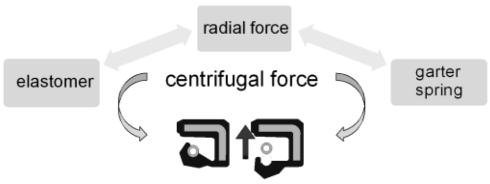

Fig. 4: Effect of centrifugal force on the lip seal

To evaluate the calculated critical speeds, a second test rig was built to measure the radial force at different rotating speeds of the lip seal (Fig. 5).

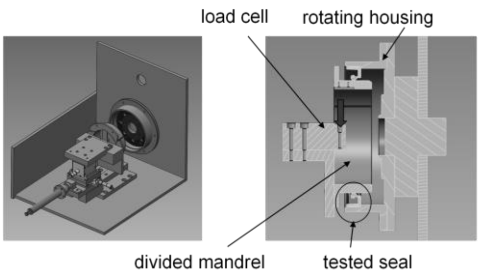

Fig. 5: Dynamic radial force test rig

The dynamic radial force test rig can be easily modified to a device for friction torque measurements. Instead of the load cell and the divided mandrel, a torque device with a standard seal counterface is installed (Fig. 6).

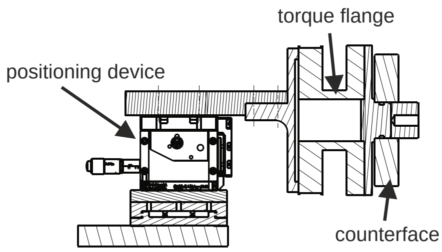

Fig. 6: Device for friction torque measurements at the dynamic radial force test set up

Thereby friction torque measurements with different fluid levels inside the rotating housing are possible and the effect of the hydrostatic oil pressure on the sealing lip as a additional radial force component can be examined (Fig. 7).

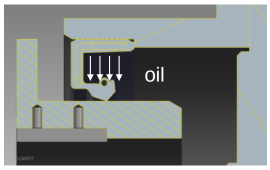

Fig. 7: Oil inside a rotating housing can induce an additional radial force component

3. Results

The static measurements with and without garter springs give information about the size of the different radial force components (Fig. 8).

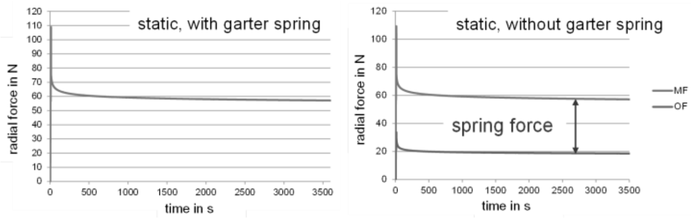

Fig. 8: Example of static radial force measurements with and without a garter spring

With these results and the knowledge about the seal geometry and mass, the required rotating speed to eliminate the measured radial force can be calculated (equation (1)). To evaluate this analytical estimation, measurements with the dynamic radial force test rig were conducted. A typical radial force development as a function of the rotational speed is shown in Fig. 9.

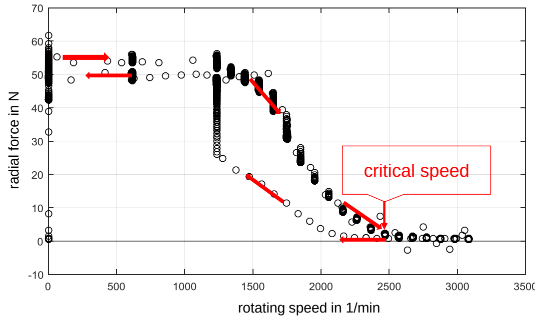

Fig. 9: Result of a dyn. radial force test

In comparison with the calculated radial force, the analytical estimation approximates the measured critical speeds very well (Fig. 10).

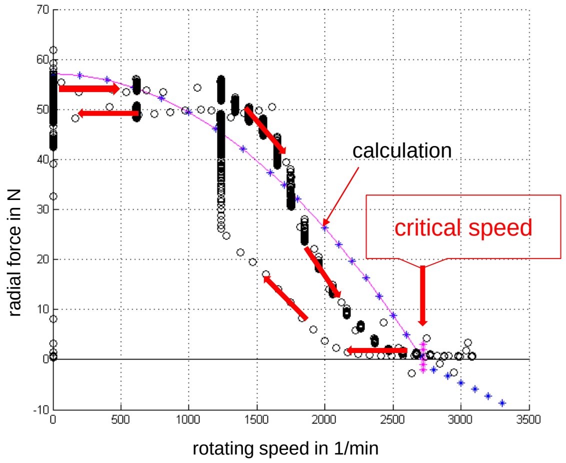

Fig. 10: Comparison of measured and calculated critical speeds of a rotating radial shaft seal

The tests and calculations revealed that small seals with short and rigid sealing lips are more suitable for the sealing of rotating housings than seals with large diameters and long lips. The calculation in Fig. 10 includes the influence of hydrostatic pressure on the sealing lip.

Further experimental studies with the friction torque device showed, that the higher the oil level in the rotating housing gets, the further the critical speed is moved to higher rotational speeds. However, a high filling quantity also risk heavy leakage in case of a lift off and increases the friction torque (Fig. 11).

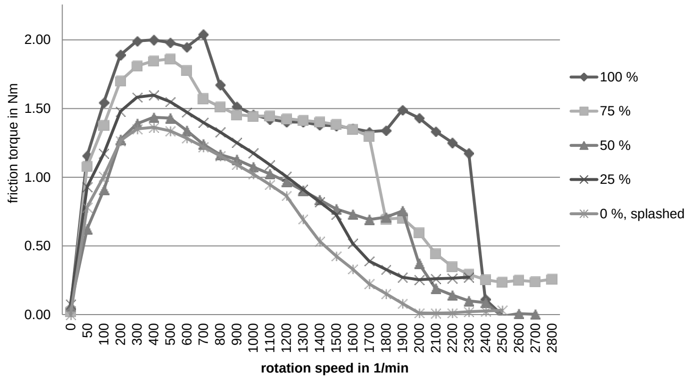

Fig. 11: Measured friction torques with different oil levels inside the rotating housing

4. Summary

A new method for estimating the critical speeds of standard radial shaft seals in rotating housings is described. Based on static radial force measurements, the analytical approach showed good results for estimating the rotational speed at which the sealing lips lift off. With this information, standard radial lip seals can be used in applications with rotating housings appreciably reducing the risk of heavy leakage. The contribution of the centrifugal force can be used to decrease the friction torque without impairing sealing performance.

Furthermore, the effect of different oil levels inside the rotating housing is shown. Higher oil levels lead to a higher friction torque because of the additional radial force component due to the oil pressure exerted on the sealing lip.

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