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Experimental and Numerical Investigation of Hydraulic Losses in Rolling Bearings

TRACK OR CATEGORY

Rolling Element Bearings

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1. INTRODUCTION

The optimization of components and processes has a great importance because even a small development of the efficiency could save a huge amount of energy and material in long term. An essential part of the optimization is the identification of the sources and the influencing factors of the losses. This is the same in our current topic, in the case of rolling bearings. During the operation of an oil-lubricated rolling bearing, losses also occur which can be divided into two groups. The first group is the load-dependent losses or contact losses which are resulted from mechanical friction due to contact forces. For the determination of these losses, there are suitable calculation methods and Multi Body Dynamics Simulation techniques [1]. The second group is the load-independent losses caused by lubricant displacement and lubricant shearing on the surfaces of the components. The aim of our project is to investigate this group, which is generally referred to as hydraulic losses. In contrast to contact losses, the number of the available calculation approaches for determination of hydraulic losses is limited. There are only same empirical models or numeric methods with high power and computing demand. Therefore, experimental and numerical investigations were carried out in the frame of a cooperation project in order to get know about the load-independent hydraulic losses in more detail. The experimental part was performed at the Institute of Machine Elements, Gears & Transmissions (MEGT), and the simulations at the Institute of Tribology and Energy Conversion Machinery (ITR). The project focuses on fully- and half-flooded lubrication with tapered roller bearings where the influence of the environment close to the bearing is also taken into account as an influencing factor.

2. EXPERIMENTAL APPROACH

For the investigation of hydraulic losses, a test rig was developed at the MEGT [2, 3], which has a modular design and it can be used to measure the total friction torque of axially loaded rolling bearings of different design, size, lubrication and axial bearing position (Figure 1). The test unit contains an angular ball bearing 7208 as support bearing and a tapered roller bearing 32208 as test bearing. The rolling bearings are mounted in X arrangement and are preloaded by a load unit consisting of a load cell, disk springs and a load bolt. Due to separate oil chambers, the oil level can be adjusted independently at the bearings, and the developing flows in the chambers are not disturbed from each other. Furthermore, it makes possible the investigation of environmental influences for the hydraulic losses with different axial positions of the test bearing in the second oil chamber. The presented test unit is driven by a DC motor thought a drive belt with a maximum of 10,000 revolutions per minute. Between the drive and test units there is a shaft torque sensor, which can measure the loss torque generated in the test unit until 5 Nm.

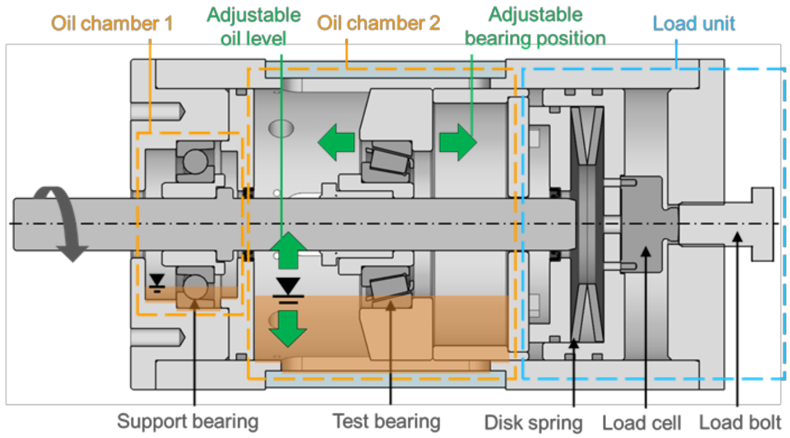

Figure 1: Test bench for the experimental investigation of hydraulic losses in horizontal bearing arrangements [2].

During the measurements, the outer ring- and oil temperature, the rotational speed, the axial load and the shaft torque were observed and measured. With the help of the measured torque, the hydraulic losses can be determined with the variation of the oil level (Figure 2). It means that we need two measurements with the same boundary conditions except the oil quantity. One, with the investigated oil quantity and one with minimum quantity of lubrication. The difference between the measured loss torques is the pure hydraulic losses at the adjusted boundary conditions.

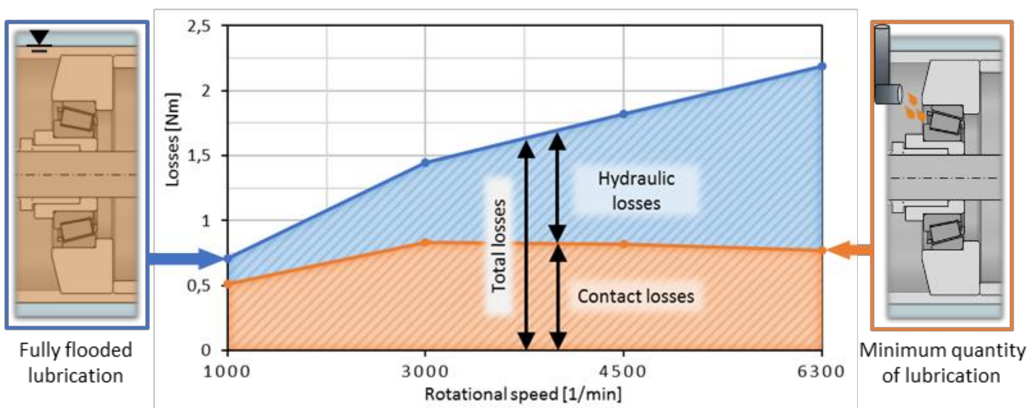

Figure 2: Example for the determination of the hydraulic losses with the variation of the oil level at a fully-flooded tapered roller bearing 32208

3. NUMERICAL APPROACH

Next to the experiments, CFD fluid simulations were carried out for the determination of hydraulic losses at the Institute of Tribology and Energy Conversion Machinery (ITR). These three dimensional, transient simulations were performed with ANSYS CFX and models complex flow distribution inside the test chamber. For the calculations, the oil properties and the rotational speed were set according to the measurements. The computational grid covers the oil chamber of the test bearing and contains approximately 5.5 million hexahedral cells. This block-structured mesh is divided into three parts and it has finer resolution near the walls.

4. RESULTS

The first step of the evaluation was a reproducibility test. This means that the measurements were carried out several times with the same boundary conditions, but with different test bearing samples. At this test, the examined conditions were the followings: the test bearing was in the middle axial position; the test chamber was fully flooded; the rotational speed was varied between 1000 and 6300 rpm; there were two investigated oil temperature (50 and 60°C) respectively two oil viscosity (58,3 and 38 mm²/s). With these conditions the first simulations were performed, as well. The result of the reproducibility test and the first numerical calculation can be seen on Figure 3. The indicated hydraulic loss values refer to the test chamber, it means that it contains not only the hydraulic bearing losses but also the hydraulic losses of the test chamber (for example the losses caused by the shearing of the lubricant on the shaft or on the walls).

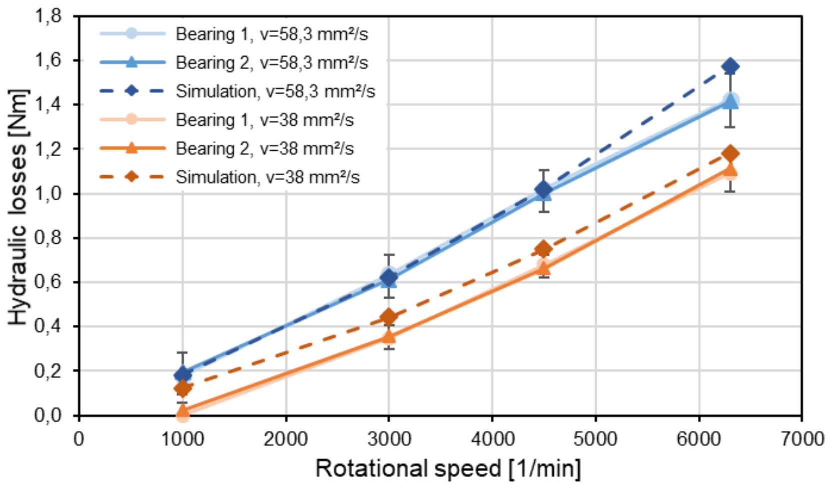

Figure 3: The results of the reproducibility test and the first numerical calculations

Since the difference in every measured point in the reproducibility test less than 5 percent, we can say that the measurements have good reproducibility. The comparison shows a good correlation between the experimental and numerical results, there is only a small deviation in the case of higher viscosity. In general, we can say that the lower oil viscosity (so higher oil temperature) leads to lower hydraulic losses, which increasing almost linearly with the rotational speed. After the reproducibility test, further measurements were carried out, with different oil level and different axial position of the test bearing. The results show the influence of the oil quantity, oil temperature (i.e. oil viscosity), rotational speed, and the bearing position (i.e. the presence of the wall near to the test bearing) for the hydraulic loss values. Furthermore, the so-called pumping effect of the tapered roller bearing and the foaming of the oil is also observable in the measurement results which are presented at the 74th STLE Annual Meeting & Exhibition.

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KEYWORDS

Rolling Bearings, Tapered Roller Bearings, Lubricant, Oil Bath Lubrication, Bearing losses, Hydraulic losses

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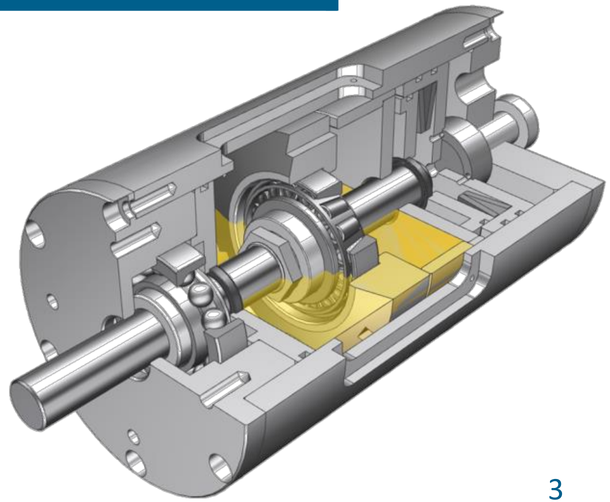
Introduction

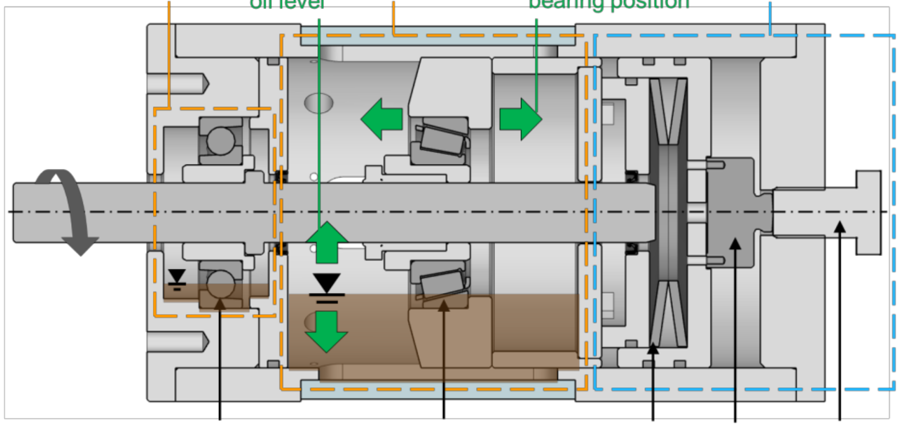
- **Optimization**
- **Bearing losses**
  - Load-dependent losses due to contact forces
  - Load-independent losses due to the displacement of lubricant → HYDRAULIC LOSSES
- **Limited number of calculation approaches** ← HYDRAULIC LOSSES
- **Cooperation:**
  - TU Kaiserslautern – MEGT → Experimental
  - TU Claustahl – ITR → Simulative
- **Focus:**
  - Fully- and half-flooded lubrication
  - Influence of the environment
  - Tapered roller bearings - 32208
  - Grooved ball bearing - 6208



Experimental approach

Test unit

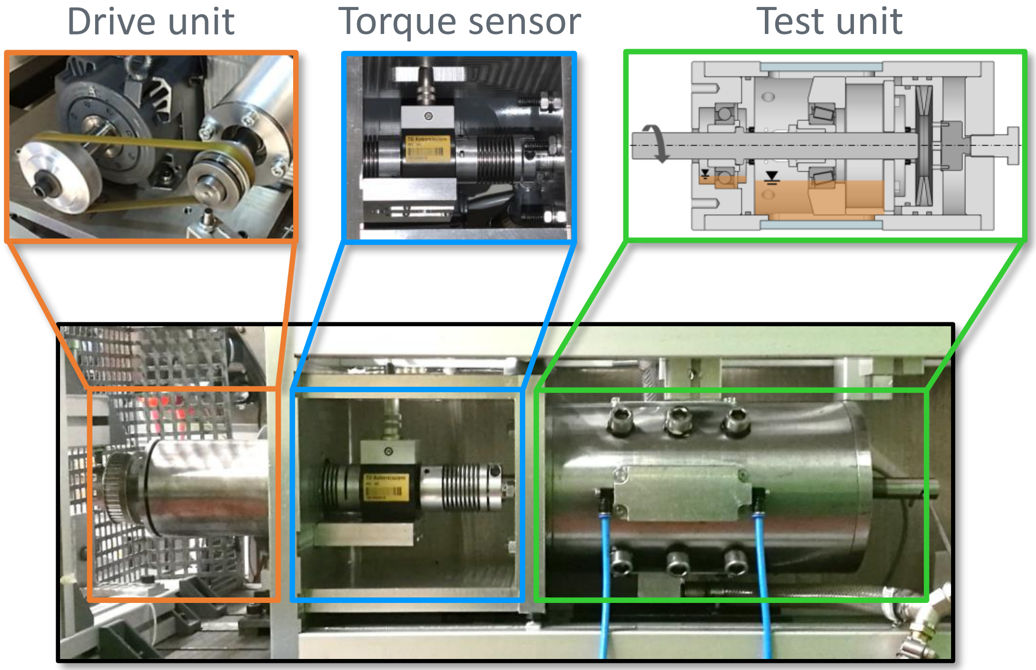
- **Horizontally orientated shaft with X-bearing arrangement**
  - Test bearing: Tapered roller bearing 32208
  - Support bearing: Angular ball bearing 7208
- **Axial load unit**
  - Axial load F ≤ 10 kN
- **Separate oil chambers**
  - Independent oil levels in chambers
    Test bearing investigated independently
  - Adjustable bearing position
    Investigation of environmental influences



Experimental approach

Test rig

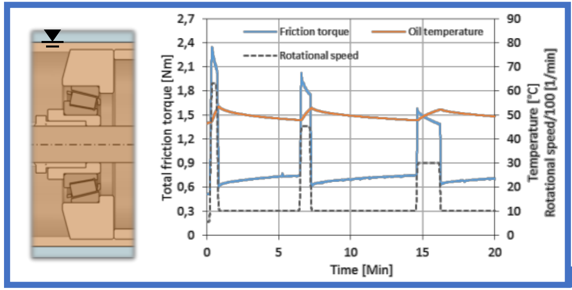
- **Drive unit**
  - DC Motor with drive belt
  - n ≤ 10.000 rpm
- **Measurement of the torque**
  - Shaft torque sensor
  - M ≤ 5 Nm
- **Measured parameters**
  - Temperature (Outer ring, Oil)
  - Rotational speed
  - Axial load
  - Torque ⟶ Losses



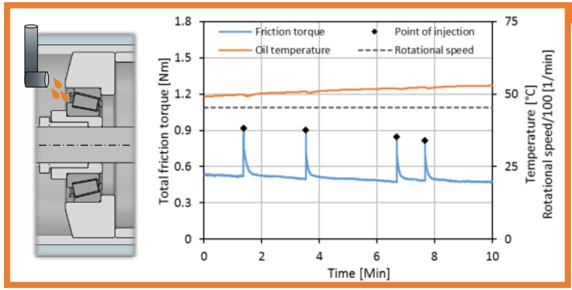
Experimental approach

Measurement Process

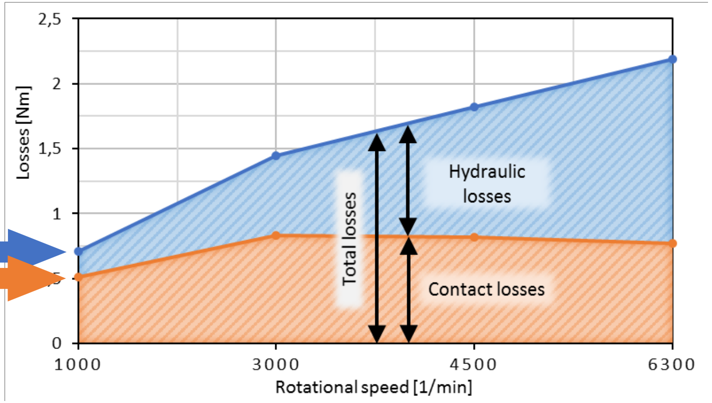
- **Determination of hydraulic losses by variation of oil level**



Fully flooded lubrication



Minimum quantity of lubrication

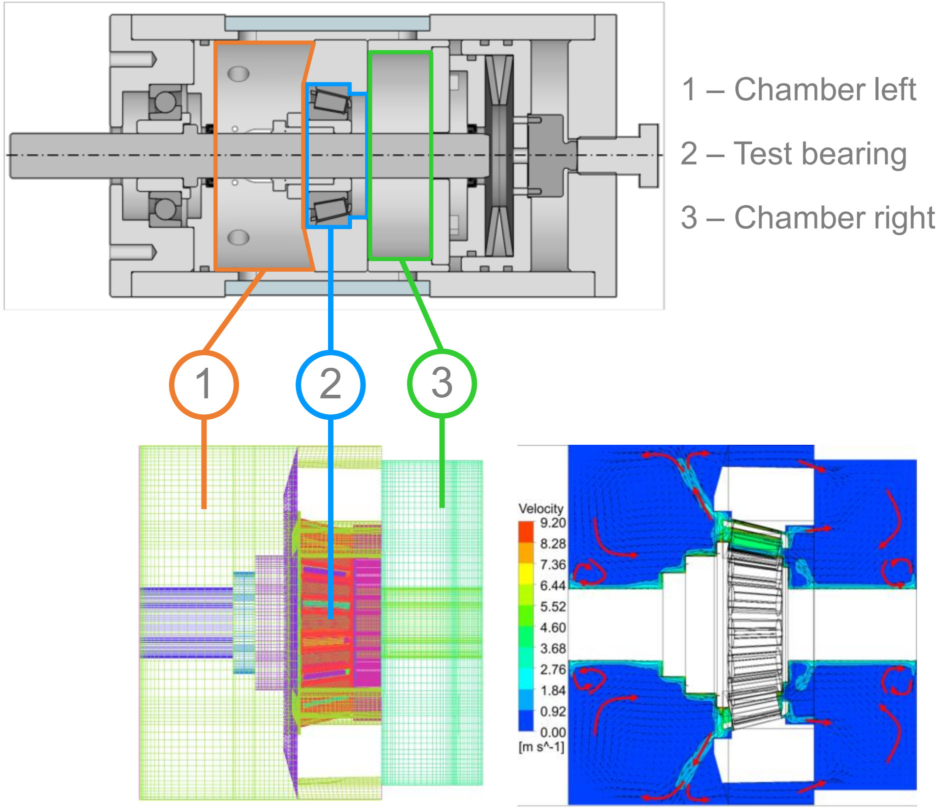


Fully flooded lubrication − Minimum quantity of lubrication = Hydraulic losses

Numerical approach

Fluid simulation

- **CFD-simulation with ANSYS CFX**
- **Complex flow distribution inside the bearing**
  - Three-dimensional
  - Transient
  - Oil properties and rotational speed corresponding to experiment
  - Component speed according to kinematic dependencies
- **Computational grid**
  - Block structured
  - Finer resolution near the walls



Results

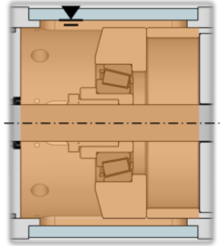
Comparison: Experimental & Numerical Results

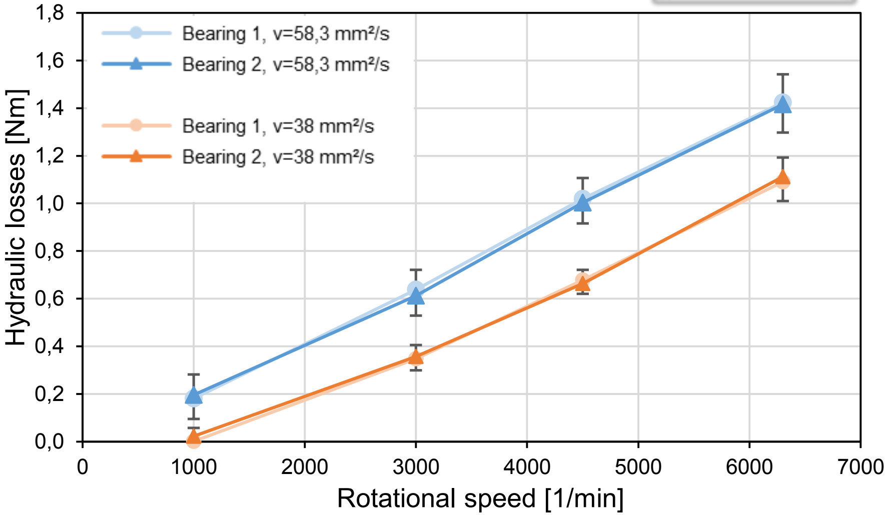
- **Reproducibility**
  - Test bearing 1 vs Test bearing 2
- **Conditions**
  - Middle test bearing position
  - Fully flooded lubrication
  - Rotational speed: 1000 - 6300 [rpm]
  - Oil: Temperature ⟷ Viscosity

Temperature	Viscosity
50 [°C]	58,3 [mm²/s]
60 [°C]	38 [mm²/s]

  - Overall hydraulic losses of the chamber

Fully flooded
Middle position



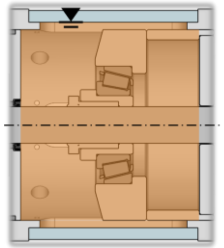


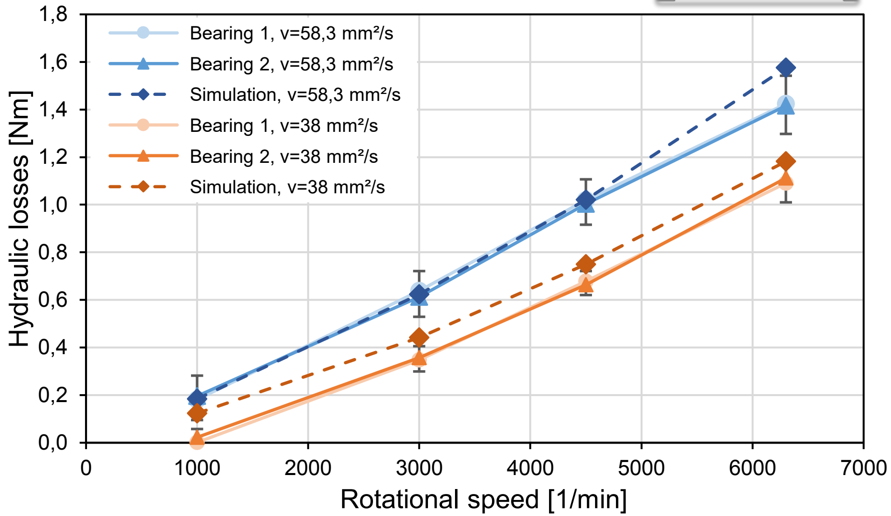
Results

Comparison: Experimental & Numerical Results

- Good reproducibility (Δ < 5 %)
- Good correlation between experimental and numerical results
- Only small deviations in case of higher viscosities
- Lower viscosities → Lower hydraulic losses
- Almost linear increase of hydraulic losses with the rotational speed

Fully flooded
Middle position





Results

Numerical Results

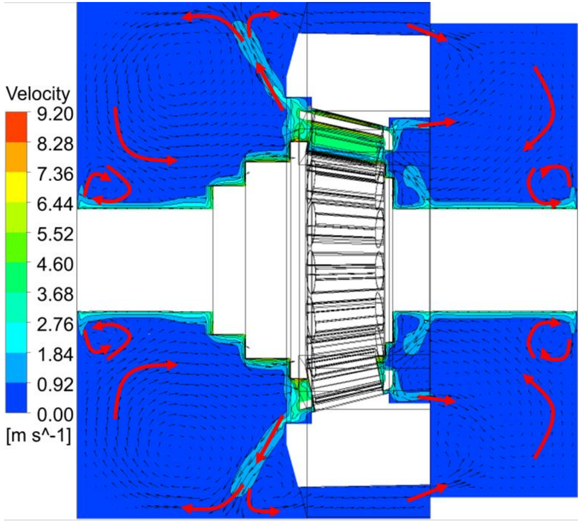
- **Highest velocity gradients near rotating components**
- **Pumping effect**
  - Oil transport from the right side to the left side of the chamber
- **Centrifugal force**
  - Oil transport from the shaft to the housing
- **Low influence of the bearing environment**
  - Oil flow close to the bearing is not disturbed due to the walls of the chamber

Middle bearing position

Oil velocity in stationary frame

T = 50 [°C] ⟷ ν = 58,3 [mm²/s]

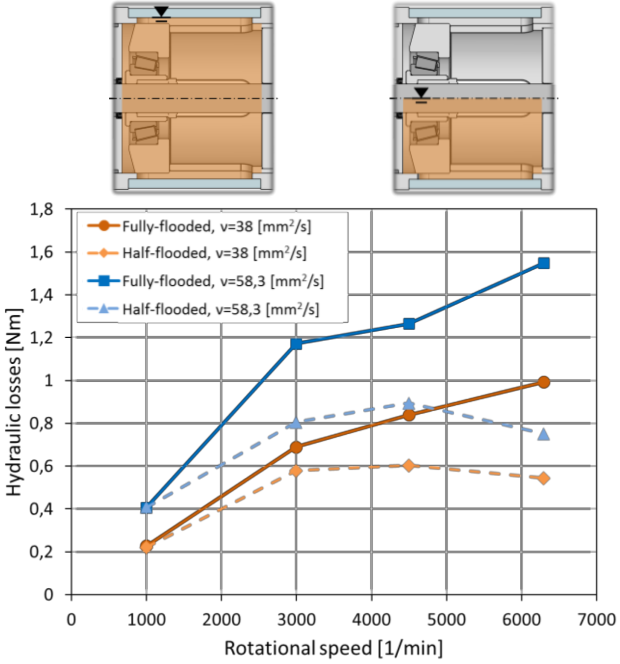
n = 3000 [rpm]



Results

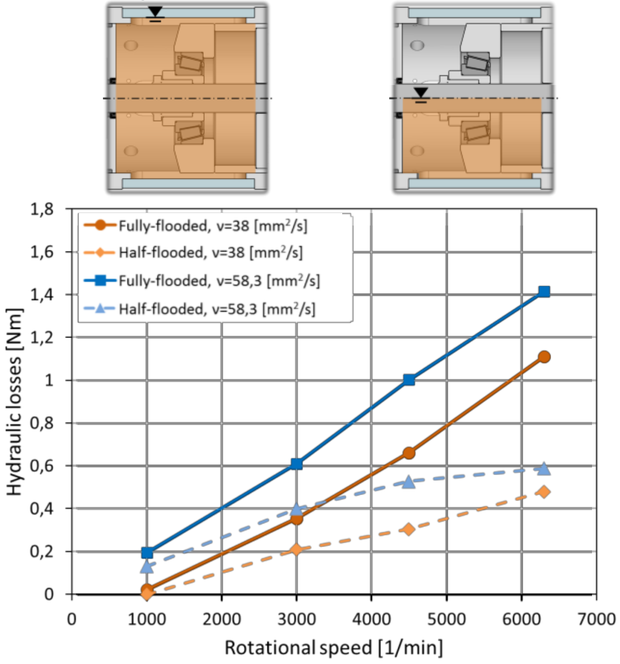
Left position

Fully-flooded Half-flooded



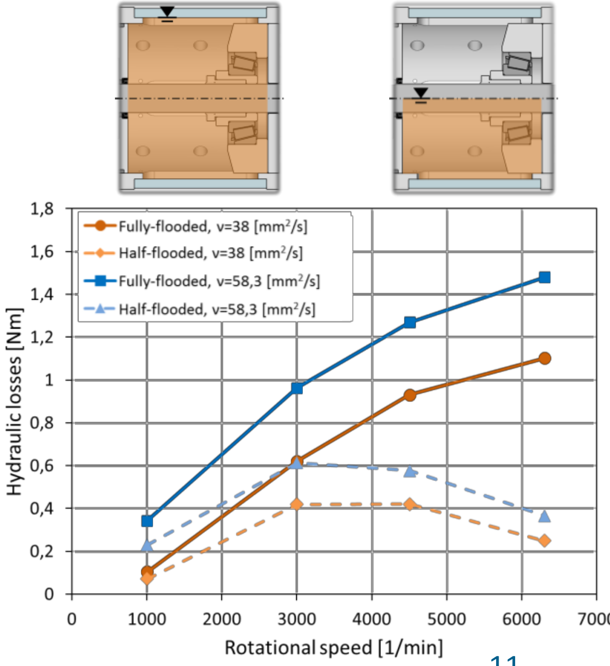
Middle position

Fully-flooded Half-flooded



Right position

Fully-flooded Half-flooded



Summary & Outlook

- **Summary**
  - Experimental examination method delivers reproducible results
  - Numerical simulations show a good correlation with the experimental results
  - Influence of the oil temperature i.e. viscosity for the hydraulic losses
  - Influence of the environment for the hydraulic losses
- **Outlook**
  - Numerical simulations with Left and Right test bearing position
  - Numerical simulations with partially flooded bearing → Two-phase (oil and air)
  - Reducing the “total hydraulic losses” to the “pure hydraulic bearing losses”
  - Investigation of grooved ball bearing - 6208

Thank you for your attention!

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