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The influence of external dynamic loads on the lifetime of rolling element bearings: Experimental analysis of the lubricant film and surface wear ☆

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ABSTRACT

Precise prediction of the lifetime of rolling element bearings is a crucial step towards a reliable design of many rotating machines. For bearings subjected to highly varying loads, recent research emphasises a strong reduction of the actual bearing lifetime w.r.t. the classically calculated bearing lifetime. This paper experimentally analyses the influence of external dynamic loads on the lifetime of rolling element bearings. A novel bearing test rig is introduced. The test rig is able to apply a fully controlled multi-axial static and dynamic load on a single test bearing. Also, different types and sizes of bearings can be tested. Two separate investigations are conducted. First, the behaviour of the lubricant film between the rolling elements and raceways is analysed. Increased metallic contact or breakdown of the film during dynamic excitation is investigated based on the measured electrical resistance through the bearing. The study shows that the lubricant film thickness follows the imposed variations of the load. Variations of the lubricant film thickness are similar to the variations when the magnitude of the static bearing load is changed. Second, wear of the raceway surfaces is analysed. Surface wear is investigated after a series of accelerated lifetime tests under high dynamic load. Due to sliding motion between asperities of the contacting surfaces in the bearing, polishing of the raceway honing structure occurs. This polishing is clearly observed on SEM images of the inner raceway after a test duration of only 0.5% of the calculated L_{10} life. Polishing wear of the surfaces, such as surface induced cracks and material delamination, is expected when the bearing is further exposed to the high dynamic load.

1. Introduction

The importance of research related to failure and damage detection of bearings is self-explanatory. Rolling element bearing failure is one of the foremost causes of breakdown in rotating machinery [1]. Bearings fail prematurely in service due to contamination, poor lubrication, poor fits, misalignments, etc. Motor bearing faults account for more than 40% of the induction motor's failure [2]. Gearbox bearing failure is the top contributor of the wind turbines downtime [3]. Bearings are

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Nomenclature

c_{AS}	Combined damping of the air springs
c_B	Combined damping of the bushings
c_{MS}	Damping of the mounting system
c_S	Equivalent damping of the spindle
c_{TB}	Damping of the test bearing
C_{TB}	Capacitance of the test bearing
f_e	Frequency of excitation
$F_{a,d}$	Axial dynamic bearing load
$F_{a,s}$	Axial static bearing load
$F_{r,d}$	Radial dynamic bearing load
$F_{r,s}$	Radial static bearing load
k_{AS}	Combined stiffness of the air springs
k_B	Combined stiffness of the bushings
k_{MS}	Stiffness of the mounting system
k_S	Bending stiffness of the spindle
k_{TB}	Stiffness of the test bearing
m_F	Equivalent mass of the frame
m_H	Mass of the test bearing housing
m_S	Equivalent mass of the spindle
R_K	Known resistance of the electrical circuit
R_{TB}	Electrical resistance of the test bearing
V_{in}	Voltage source of the electrical circuit
V_{out}	Voltage drop over the test bearing
Z_{TB}	Impedance of the test bearing

cheap, but bearing failure is not. A 4000€ wind turbine bearing replacement can turn into a 200,000€ project, even without including the cost of downtime [4].

Lifetime calculations of bearings are based on the ISO 281 standard. For bearings subjected to highly varying loads, recent research emphasises a strong reduction of the actual bearing lifetime w.r.t. the calculated bearing lifetime. For instance in wind turbines, fans and paper making machines, the rolling element bearings are susceptible to failure caused by external machine vibrations. Failure rates of wind turbines approximating three times the failure rate of conventional generators are observed [5]. This is partly due to the unique operational conditions of the bearings, resulting from widely varying wind loads and high vibration levels [6].

Elaborate research on the effect of external dynamic loads on the bearing lifetime is conducted by Gegner and Nierlich [7–10]. They developed a test rig which allows applying controlled static and dynamic loads on cylindrical roller bearings. Accelerated lifetime tests under high dynamic load are performed. After only 10^7 revolutions of the test bearing, significant wear of the raceway surfaces is observed. Based on XRD analysis, a decrease of the calculated bearing lifetime of 80% due to the dynamic excitation is estimated.

This paper further discusses the effect of external dynamic loads on the bearing lifetime. Two separate investigations are described. First, the behaviour of the lubricant film between the rolling elements and raceways is analysed. Increased metallic contact or breakdown of the film during dynamic excitation is investigated based on the measured electrical resistance through the bearing. Second, wear of the raceway surfaces is analysed. Surface wear is investigated after a series of accelerated lifetime tests under high dynamic load.

The behaviour of the lubricant film and wear of the raceway surfaces is analysed using a novel bearing test rig. The test rig is able to apply a fully controlled multi-axial static and dynamic load on a single test bearing. Also, different types and sizes of bearings can be tested. This unique test rig is designed and constructed in-house. In the current study, a deep groove ball bearing 6302 (designation according to DIN 623) with an outer diameter of 52 mm is mounted. It is lubricated using all-purpose industrial grease, consisting of lithium soap and mineral oil.

The test rig is introduced in Section 2. Both the test rig design and the test rig measurements are discussed. Section 3 describes the behaviour of the lubricant film under high dynamic load. The influence of both the excitation properties (frequency and amplitude) and the bearing operational conditions (static load, operational temperature and rotational speed) is analysed. In Section 4, the results of a series of accelerated lifetime tests are reviewed. The failure mode, test conditions and results are discussed.

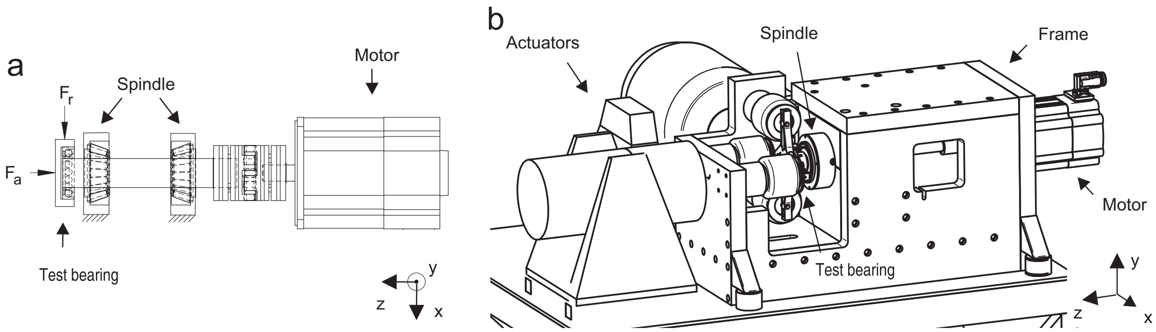

Fig. 1. Concept (a) and overview (b) of the presented test rig. The test bearing is mounted on a spindle and driven by an electric motor. The actuators apply a radial force (F_r) and an axial force (F_a) on the test bearing.