Integrated Test and Simulation of Large-Size Bearings for Wind Turbines

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Introduction
Wind power is one of the most important sources for renewable energy and is characterized by continuous worldwide growth. Current development trends are for the production of taller and more powerful turbines as well as improved reliability and cost-efficiency. This results in particular requirements for the rolling bearings. This is especially true for the main shaft bearings which are directly affected by the dynamic forces created by the wind and the inertia forces of the blades. Furthermore, the design of the main shaft bearings has a big impact on the other components of the turbine, especially on the design of the drive train and the supporting structure. Therefore, the proper design of main shaft bearings is of particular importance. Powerful simulation tools, as well as realistic test facilities are essential for the development and assessment of reliable and economic main shaft bearings.

Analysis and assessment of main shaft bearings
The main task in the design of rolling bearings is the assessment of the static safety according to ISO 76 [1] and of the required rating life according to ISO 281 [2]. The required rating life is at least 20 years [3]. The application loads are commonly provided by the turbine manufacturer in form of load time series and extreme loads. For the analysis it is necessary to convert these load conditions into a finite number of load cases by means of a proper classification. Schaeffler Technologies AG & Co. KG uses the in-house developed program BEARINX for this basic analysis [4]. BEARINX offers comprehensive calculation options for all rolling bearing types and any number of load cases. The models range from complex gear systems with many bearings, to single rolling bearings and single contacts. Considered influences are non-linear contact stiffness, misalignment, component temperatures, operating clearance or preload, roller and raceway profiles, deflection of shafts, lubrication and contamination. The linear elasticity of adjacent structures, e.g., housings, can be considered by means of stiffness matrices, calculated by preliminary finite element analysis (FEA). Further options of BEARINX include parameter studies and optimization and a friction analysis based on the physical friction mechanisms [5]. The friction analysis especially is of particular interest for many applications.

The investigation of nonlinear effects, e.g. contact behavior in press fits and mounting surfaces, as well as the stress analysis of single components can be done by means of FEA. Results of these investigations lead to the definition of the internal clearance and the deformation of seal gaps. The models consist of the rolling bearings and the adjacent components with particular attention to the connections. Since models are typically very large, the use of specific user-defined elements for the rolling contacts is important to keep the modeling effort and the analysis time in an acceptable range. The user-defined elements consider the nonlinear contact stiffness, the roller profiles, preload or clearance and the rib contacts [6].

A dynamic simulation may be necessary to evaluate slip conditions, local friction and the risk of wear and dynamic forces inside the rolling bearing. Essential for the adequate prediction of the dynamic bearing behavior is the quality of the contact model with consideration of lubrication friction and damping, surface parameters and non-Newtonian rheology [7].
CABA3D, a multi-body simulation tool particularly developed for rolling bearings provides powerful options for the dynamic bearing simulation.

**Large-size test rig ASTRAIOS**

ASTRAIOS (Figure) is one of the world’s most powerful bearing test rigs for rolling bearings, capable of testing bearings with an outside diameter of up to 3.5 meters. The mounting situation is similar to that in a wind turbine. ASTRAIOS enables application related functional tests under realistic static and dynamic forces and moments, created by eight hydraulic cylinders. The drive train is designed for any operating conditions, such as rapidly changing load conditions as well as start and break events. It is also possible to test different bearing arrangements. Primary testing purposes are functional examinations regarding kinematics, lubricant distribution, temperatures, as well as cage and sealing performance. Friction torque measurement and accelerated service life testing are also of great importance. The application of up to 300 sensors allows the measurement of loads, deflections, drive torque, temperatures, shaft speed, speed of rolling elements, cage movement, cage speed, cage strain, pressures, bolt preload, electric voltage, and vibrations among other measurements.

In addition to the validation of rolling bearings and their components regarding robustness and reliability, the validation of simulation methods, tools and models are an important purpose of the tests. As well, the simulation of tests can be crucial for the test engineers. Almost five years of operation have shown the necessity of substantial operation understanding for the interpretation of test results regarding the influences of masses, flexibility, temperatures, and tolerances, which are of much greater significance than for smaller bearings. Often, only the combined examination of testing and simulations lead to the correct interpretation of the results. This leads to a better understanding of the overall system and the influencing parameters.

**Integrated testing and simulation**

Basic tests have been performed in order to gain operating experience and to compare test and simulation results. Examples are frictional torque measurement, roller kinematics and the deflection of the bearings [8]. The comparison of test and simulation is used for the improvement of simulation models and the adjustment of influencing parameters. A typical example for the integration of test and simulation is the stress analysis of cage segments. Generally, cages are not directly affected by the loads acting on the bearing but by internal dynamic forces [9]. These forces can be calculated by dynamic bearing simulation, but due to the complexity of the influencing factors, tests are necessary to determine the cage loads correctly. The final strength assessment has to be performed by a finite element analysis.

Another example is the evaluation of wear. Durotect® B is a special type of black oxide coating with improved properties, developed by Schaeffler. From test results and comprehensive field experience, it has been proven that Durotect® B reduces frictional torque, improves the running-in behavior, reduces the risk of adhesive wear damage, and increases the protection against white etching cracks dramatically [10, 11]. The resistance of the Durotect® B layer in a specific application depends on the local slip and lubrication conditions and can be evaluated through realistic testing. In the complex loading situation of a main shaft bearing, the dynamic simulation can be used to identify the load cases with the
most critical local conditions. The corresponding test conditions on the ASTRAIOS allows for realistic validation of the wear resistance of the black oxide coating.

**Summary**

Large-size bearings in wind turbines of increasing dimensions are complex systems. An adequate design has to take into account the mounting situation, adjacent components, and requires powerful simulation tools as well as realistic test facilities. Since 2011, the large-size bearing test rig ASTRAIOS has enabled Schaeffler to validate main shaft bearings for wind turbines as well as validate simulation tools and models. The integration of simulation and testing leads to a better understanding of the rolling bearing system in a realistic environment. Operation understanding is therefore an essential factor. The comparison of test and simulation results can be used for the improvement of simulation models and the adjustment of influencing parameters. This leads to a general improvement of simulation results. For specific design tasks, an integrated use of both simulation and realistic testing is necessary. The combination of powerful simulation tools and the test rig ASTRAIOS is an essential contribution to a fast and reliable design of robust and economic main bearings for wind turbines.

**References**

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**Keywords**

Wind turbine, large-size bearing, test rig, ASTRAIOS, simulation