



# Realistically testing large roller-type blade bearings

Most blade bearings in large wind turbines are double-row four-point contact ball bearings. They connect the blades with the rotor and allow them to be pitched along their longitudinal axis. As the dimensions of wind turbines have been constantly increasing, every component has had to get bigger too, thus also increasing the loads on the blade bearings. Owing to their design, the load rating of ball bearings is limited, and their design life could become a limiting factor. This emphasises three-row roller bearings as blade bearings for the next generation of wind turbines. In the HAPT2 project, Fraunhofer IWES is evaluating the use of roller bearings as blade bearings.

**Words:** Matthis Graßmann, Research Associate in the slewing bearings' group

## Different bearing types used as blade bearings

Blade bearings are exposed to high alternating bending moments. The wind and gravitational forces act on the blade, thus introducing the load to one of the bearing rings. The load is then transferred to the other bearing ring through rolling bodies. For modern wind turbine blade bearings, these rolling bodies are balls, rollers, or a combination of both.

Double-row four-point contact ball bearings have balls as rolling elements, and these are in contact with the raceways at four points when the bearing is not under load. Any load acting on the bearing generates forces on the ball that have an axial and a radial component because the initial contact angles are less than 90 degrees.

The result is tilting and ovalisation of the bearing rings and an increase in the contact angles, which aggravates the risk of truncation. Truncation describes the situation when the contact ellipse is cut at the raceway edge. This increases the contact pressures, which can then exceed the theoretical maximum contact pressure of a full contact.

Three-row roller bearings have two rows of axial rollers that bear the main load acting on the bearing and one row of radial rollers that transfer the smaller radial loads. With its additional row of radial rollers, this bearing type has separate raceways to carry the axial and radial components of the acting load.

It is thus possible for all axial rolling elements to have constant contact angles of 90 degrees, and hence the resultant pure axial forces do not introduce any radial loads. In contrast to four-point contact ball bearings, where any load always introduces radial forces, the constant contact angle of 90 degrees with three-row roller bearings reduces the ovalisation and deformation of the bearing rings.

A key parameter to compare different bearing types is the dynamic capacity. The dynamic capacity describes the load that 90% of the bearings can withstand for one million cycles without any damage. While ball bearings have point contacts with an elliptical contact area between the balls and raceways, roller bearings have line contacts with rectangular contact areas.

Hence, for comparable dimensions, roller bearings have larger contact areas than ball bearings and therefore lower contact pressures. Roller bearings thus have larger dynamic capacities, which means that roller-type bearings can withstand higher loads and have a longer design life than ball-type bearings of the same dimensions.

## HAPT2 research project at Fraunhofer IWES

While the calculation methods for and the behavior of four-point contact ball bearings in wind turbines have been the subject of multiple research projects, roller bearings as blade bearings raise new challenges. The calculation methods used for large roller

bearings have not yet been validated. Wear is only tested on small-scale bearings.

The effect of different greases on the wear mechanism is untested as yet, and finite element models of large roller bearings have not been validated against experimental data. In the HAPT2 project (Highly accelerated pitch bearing tests: roller bearings as blade bearings, funded by the German Federal Ministry for Economic Affairs and Climate Action under grant number 0324344A), the Fraunhofer Institute for Wind Energy Systems IWES and its project partners are making a significant contribution to gaining more knowledge in these areas.

The experimental tests in particular will help to understand the damage mechanisms and the behavior of this bearing type better. The occurrence of wear depending on the used grease is tested on small-scale bearings with an outer diameter of 95 mm and 180 mm.

Different commercial as well as model greases are tested and compared regarding their ability to prevent wear. The smaller bearings are axial roller bearings while the larger bearings are tapered roller bearings. A significant factor for wear damage is the slip between the rollers and the raceways. The rollers in a bearing must follow a circular path. With axial rollers, this results in movement relative to the raceway at the end faces of the rollers, which introduces slip. For tapered roller bearings, the slip is insignificant.

As the slip depends on the relation between roller length and raceway diameter, part of this project is also to ascertain which bearing type is best suited to investigate the wear mechanism on a small scale.

However, the most significant advantage of this project is that original-size blade bearings are tested under realistic conditions. Two different dimensions of blade bearings with an outer diameter of 2.6 m and 5 m are tested. Both bearings are grease-lubricated, three-row roller bearings. The tests focus on the validation of bearing calculation models for large-scale slewing bearings in wind turbine applications.

The standard life calculation of a bearing predicts when the first damage on the raceway will occur under specific loads. However, most blade bearings can operate further depending on the damage progression. The resulting number of overall rotations until bearing failure is called the service life.

The life of the smaller blade bearings will be tested under high axial loads and constant oscillations with an amplitude of 120 degrees. The remaining service life of the bearings will subsequently be tested under realistic conditions. To this end, a blade segment introduces a bending moment to the bearings and pitch movements can have varying amplitudes.

The larger blade bearings will be tested on the BEAT6.1 Bearing Endurance and Acceptance Test rig that is part of the unique test infrastructure at Fraunhofer IWES.

**Bearing Endurance and Acceptance Test rig: accelerated evaluation of bearing life**

The BEAT6.1 has been in operation since 2019 and is among the most advanced bearing test rigs ever built to test large slewing bearings. The track record consists of 11 tested bearings with diameters of 5 m and even larger. The test rig design can emulate real world operating conditions

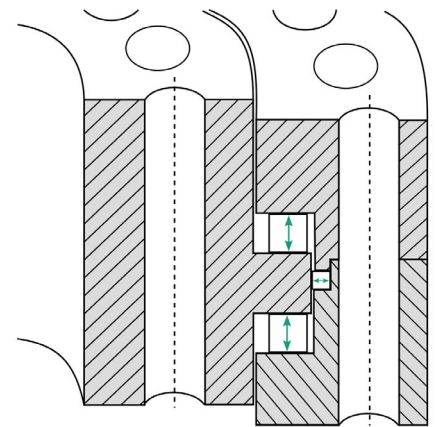
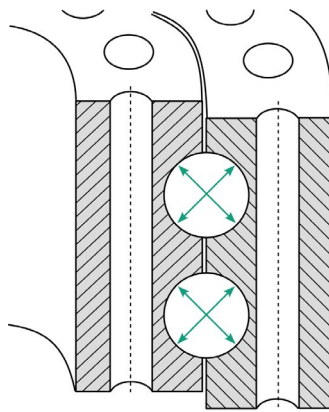


Figure1: Cross-sectional view of a double-row four-point contact ball bearing (left) and a three-row roller bearing (right). © Matthis Graßmann, Fraunhofer IWES

of wind turbines for bearings up to 6.5 m in diameter, testing two bearings simultaneously.

Six hydraulic cylinders in a hexapod configuration can introduce any load combination in all degrees of freedom. In a compact test environment, specially designed adapters emulate the realistic stiffness distribution that the bearings would be exposed to in a wind turbine. This is important because the inhomogeneous stiffnesses of hub and blade have a significant effect on the deformation behavior of the bearing.

On the BEAT6.1, the bearings are then tested with different test profiles. First, the combined friction torque of the bearings is tested: different load levels are applied in increments and in several degrees of freedom, which is a unique feature of the BEAT6.1.

At each load, the bearings are pitched, and the friction torque is measured. These tests are also used to evaluate the bearing deformation obtained using strain gauges and laser sensors at each load level, to validate finite element models of the complete test rig.

Second, the bearings run through a standstill test program. Simulation data of the Fraunhofer IWES IWT-7.5-164 reference wind turbine are used to deduce the most critical operating conditions that lead to wear. All sequences of critical load and pitch movements are then stitched together to give a program that tests the vulnerability of the bearing to wear under the simulated wind conditions.

The third and final step is to test the life of the bearings in a rolling contact fatigue (RCF) test. The RCF test consists of repeated large-amplitude sweeps at a high constant bending moment. It is run until significant changes occur in the measured data (e.g., friction torque, temperature, and bearing deformation) that indicate damage on the raceway in order to validate calculation models that predict the life of the bearing.

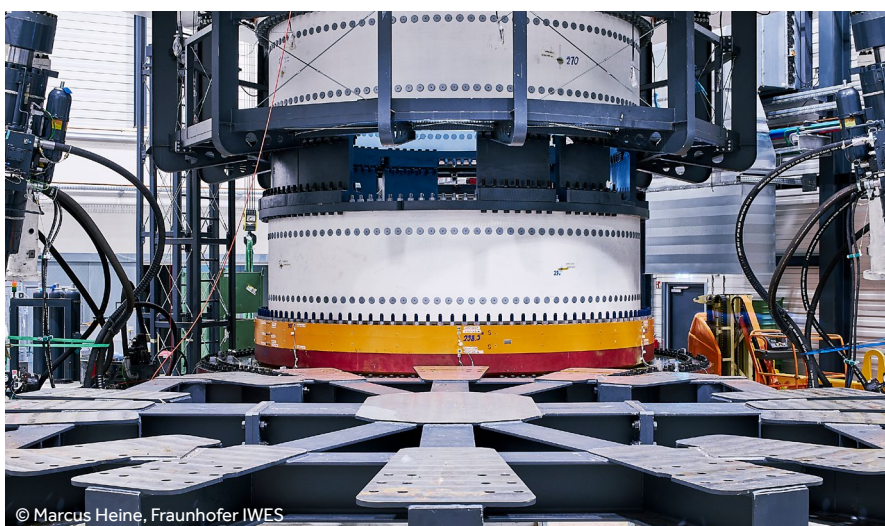
All tests of this test campaign are designed to evaluate the robustness of the bearings and their suitability for wind turbine applications. The tests will generate a unique data set and information which will be used to validate calculation and modeling approaches. This will consequently lead to more robust and future-proof designs of three-row roller-type blade bearings for the next generation of wind turbines.

The knowledge gained in the HAPT2 project from the tests with bearings of different dimensions will close knowledge gaps on the damage mechanisms of wear and rolling contact fatigue in roller bearings as well as the effect of different greases in preventing wear.

Furthermore, calculation models that predict the service life and finite element models will be validated against experimental data.

🔗 <https://www.iwes.fraunhofer.de/de/forschungsprojekte/aktuelle-projekte/hapt2.html>

🔗 <https://websites.fraunhofer.de/IWES-Blog/en/it-starts-with-a-beat-2/christian-broer>



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Figure2: Bearing Endurance and Acceptance test rig BEAT6.1 with two installed 5m bearings (shown in orange)