

Schaeffler Technologies AG & Co. KG

Energy, Process, & Utility Case Study



Challenge

Anticipating that the trend towards bigger wind turbines would dictate a need for much larger test rigs than were available, Schaeffler wanted to design and construct the best test rig possible for their large-size rolling bearing customers.

Solution

Abaqus FEA helped Schaeffler design a virtual prototype with which they could carry out stress analysis and strength verification in order to quantify the critical operating conditions of their huge new test rig.

Benefits

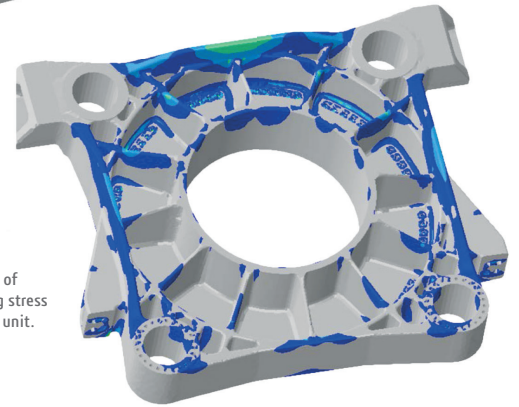
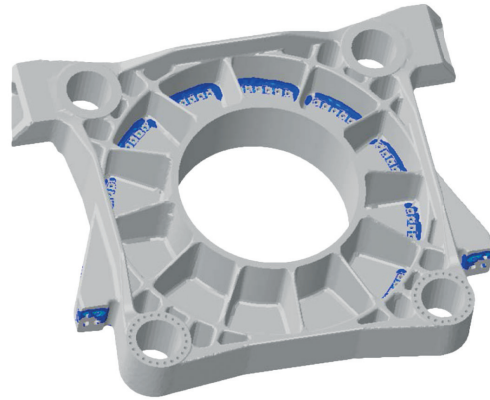
Their Abaqus models enabled Schaeffler to prove their bearing test rig reliable and applicable for all types of large-size bearings. The company can now develop more detailed instructions for operating and maintaining finished turbines. This helps them provide their customers with more precise recommendations about the optimum location and construction of their wind turbines, and also support customers in other industries.

The push to boost the energy output of wind turbines is leading the industry towards taller structures with longer blades. Wind at 100 meters flows more steadily and 4.5 percent faster than at 80 meters, with an energy gain of about 14 percent. Longer blades can rotate more slowly yet produce more electrical power. Last year close to five percent of new turbines in the U.S. were 100 meters high, and the trend is expected to continue worldwide.

But bigger size brings with it significant challenges in design and physics, increasing the burden on a wind turbine's key central bearings in a number of ways. Turbine rotor and hub weight alone generate static radial load and pitching moments. Wind forces add static and dynamic axial loads on both bearings and rotor blades. Wind also generates pitching and yawing moments that cycle with the position of the blades as they rotate. The effects of these forces can multiply as a wind turbine gets larger.

Given the significant costs involved in wind turbine construction, maintenance, and repair, manufacturers understandably want to ensure that the designs of newer, larger turbines are thoroughly proven out ahead of time. Key to that proof is ensuring that the bearings at the heart of every turbine will stand up to both the structural and the environmental stresses as long as possible, in every imaginable situation.

The industry has been using a variety of smaller bearing test rigs built to evaluate standard-size turbine performance. But until



Abaqus FEA analysis of mean and alternating stress in the rig's clamping unit.

recently there was no way to run real-world tests on the newer, large-size wind turbine bearings.

Enter Schaeffler Technologies AG & Co. KG of Germany, rolling-bearing specialists. The company's catalog of rolling bearing assemblies is one of the widest in the industry, covering nearly all industrial and consumer applications with more than 40,000 products under the brands INA and FAG. "Most people do not recognize that nearly every industry uses rolling bearings or rolling bearing parts," says Martin Stief, CAE Integration department engineer for Schaeffler. One of the highlights over FAG's 100-year history is the London Eye (officially, the Millennium Wheel). This Ferris wheel is the world's largest and heaviest, standing 135 meters high, measuring 424 meters in circumference, and weighing 2,100 tonnes. Two FAG spherical roller bearings several meters wide and weighing several tonnes help rotate the wheel smoothly.

With years of experience in testing bearings before putting them to work, Schaeffler realized that the growing trend towards larger wind turbines would quickly dictate a need for much bigger test rigs than were available.

"Before even thinking about performing expensive real-world tests on large-size wind turbine bearings, we needed to quantify the critical operating conditions to minimize testing time and costs," says Stief. "We also wanted this information to design and construct the best test rig possible for such large-size bearings." Finite element analysis (FEA) provided both insights.

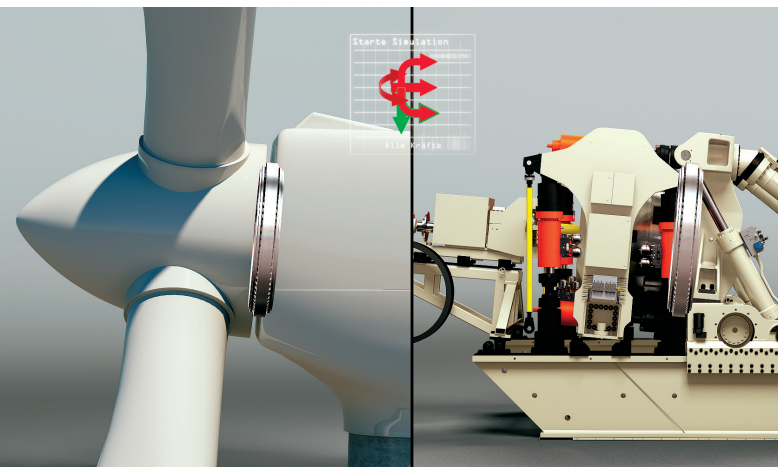
Big bearings require a big test rig

While Schaeffler had small test rigs for simulating and applying real-world bearing loads on small-size roller bearings, it did not have

a large rig for simulating the conditions in a commercial, multi-megawatt wind turbine. “When planning our large rig project, conservative engineering was the watchword for extrapolating bearing lifetime tests from small to big bearings,” says Stief. “FEA helped us determine the lifetime of larger bearings more exactly. We can now design precisely the size of bearing required by a particular turbine geometry, which helps keep costs down. We were also able to do kinematic analysis with original parts, from both bearings and assemblies provided by customers. This saves on development time in the re-engineering and design process.”

The finished test rig is 16 meters long, 6 meters wide and 5.7 meters high. Its mass is approximately 350 tonnes. As with wind turbines in the field, the rig is on a 5-degree tilt. It has five main subassemblies: drive train, loading frame, auxiliary bearing, test bearing, and tensioning frame. Eight radial and axial cylinders replicate real-world loads. Approximately 500 bolts are needed to mount the auxiliary and test bearings. The finished rig can test bearings with a maximum diameter of approximately 3.5 meters, making it the most modern, largest, and highest performing large-size bearing test rig in the world. At a cost of approximately seven million Euros, the rig represents a significant investment in Schaeffler’s future developments in renewable energy, as well as other large-size bearing applications such as the heavy equipment used in construction, mining, and excavation.

Despite the two years spent designing and constructing the test rig, the time spent on mechanical finite element (FE) simulation was short: just two months for strength assessment and modal analysis. “Because the wind industry is booming right now, we wanted to make the test rig as fast as possible,” says Stief. “This meant having a quick and accurate way to simulate, analyze, and verify rolling



Large wind turbine nacelle (left) showing bearing in silver, and Schaeffler large-size bearing test rig (right) with silver bearing in test position.



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Martin Stief, CAE Integration department engineer, Schaeffler Technologies AG & Co. KG

bearing assemblies—so we could create a test rig that could accurately measure them in action.”

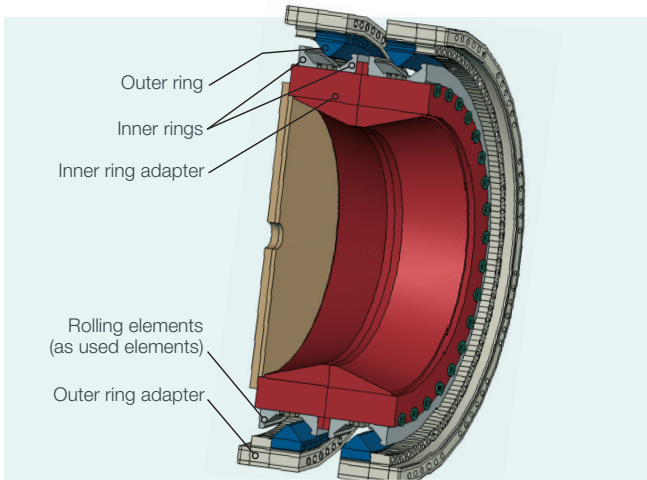
Surmounting design challenges

Schaeffler started by creating a virtual prototype to validate the physical test rig, which itself would replicate the actual conditions for roller bearings in a wind turbine. To do this, Stief formed a simulation team of five full-time and two part-time members, all of whom were experienced with using Abaqus finite element analysis (FEA). “Abaqus has been Schaeffler’s primary FEA tool for years,” says Stief.

The team divided the test rig analysis into smaller, manageable, functional FE submodels, which were then connected together to represent the overall test rig. To ensure the accuracy of this global representation, the team used its engineering judgment in defining loads, transition regions, and boundary conditions (e.g., stiffness, mass, and damping) between FE submodels. Parts of the submodels were replaced by interface conditions that could be determined by analytical or simulation-based calculations. This approach helped reduce the size of the submodels and sped the creation of working models.

“We used Abaqus to test the strengths of joints and to check specific connections,” says Stief. “When the overall design of the test rig became clearer, we began using Abaqus on the submodels for strength verification. From those results, we improved the test-rig design using basic mechanical engineering knowhow, such as strengthening ribs by making them larger. Then we’d run the submodel through Abaqus again for another strength assessment.” The team also created an additional FE model to quickly evaluate the entire test rig’s modal behavior, as well as confirm their definitions for the boundary conditions between submodels. The modal analysis was also used to estimate the eigenfrequencies for the test rig. “Obviously, we don’t want resonance,” says Stief. “We don’t want the test rig shaking itself apart.”

Wind turbines typically rotate about 16 revolutions per minute, but the engineers wanted their test rig to run up to 60 revolutions per



The submodel of the bearing package included the raceway (inner and outer rings), inner ring adapter, and rolling bearings. For the Abaqus FEA analysis, the rolling elements were replaced with customized user elements representing the precise stiffness behavior of the rolling elements and the associated degrees of freedom. The precise representation of bearing stiffness significantly reduced computing times.

minute—the same as a critical excitation frequency of 1 Hz. The modal analysis confirmed that the first natural frequency of the rig was 13 Hz, well beyond this 1 Hz value and thus not an issue (subsequent frequencies were even higher).

To validate their virtual prototype, Schaeffler ran the full FE model of its test rig through a large number of load cases within Abaqus. Even with a very coarse mesh of the entire test rig, the load-case calculations initially hit the limits of the available computing capacity. With 32 GB of RAM, calculating 17 load cases took 48 hours. However, this time was later slashed to 10 hours using a newly built-up HPC Linux Calculation Cluster with faster CPUs and more RAM.

Software features to the rescue

Various functions within Abaqus helped make model creation efficient and fast. For example, Abaqus includes hundreds of types of user elements—subroutines that allow the user to define their own finite element behavior inside an Abaqus model. In the bearing package submodel, the rolling elements of the bearings were replaced by customized user elements that represented the precise stiffness behavior of the rolling elements, as well as several degrees of freedom that would have had to be calculated separately. These special elements reduced the degrees of freedom by several orders of magnitude (from a range of 10^5 down to approximately 10^2). This significantly shortened the time, effort, and cost of 3D modeling and meshing each of the rolling elements. Computing time for analysis plummeted from about 5 hours to about 5 seconds. “The large-size bearing test rig has at least 500 of these rolling elements. It would have been impossible to make any FE calculations without user elements,” says Stief.

Other Abaqus functions helped facilitate stress analysis and strength verifications. The screw bolt modeling function, says Stief, proved “extremely useful because of the high number of bolts we preloaded with real-world values for stress and strain.” This function let the team create bolts, mesh them, and copy them as many times as needed in the 3D models. All subsequent copies were automatically meshed as well for FE analysis.

Geometry-based modeling helped the team quickly mesh variants of the whole model and the numerous submodels. Scripting and other process automation techniques made modeling and evaluating the results easier and faster, greatly simplifying strength verification. Assembly/part/instance functionality promoted team collaboration, such as when exchanging parts between team members or replacing instances or parts where the design or FE properties had been changed. With Abaqus’s options for abstraction (e.g., mass, stiffness, and connectors), says Stief, “We could reduce the size of the models by replacing large 3D structures with shell or beam structures, or by linking whole-model parts with the appropriate interface conditions.”

Analysis leads to optimization and time savings

After stress analysis, the team focused on strength verification according to Germany’s FKM Guideline for analytical strength assessment and the VDI 2230 standard for screw connections. The results pointed to additional design modifications in the test rig, such as optimizing screw connections, adding components for increased reliability, optimizing radii to reduce stresses, and adding reinforcing ribs.

“The simulation models we created proved our large-size bearing test rig reliable and applicable for all types of large-size bearings,” says Stief. Going forward, simulation—validated with test rig runs—will also provide Schaeffler with bearing-specific values, such as load distribution, pressure distribution, and contact angles, and important data about the elastic behavior of bearing components under high preload. “This will lead to even more realistic results in bearing lifetime calculation,” says Stief.

Their current work now helps Schaeffler detect critical operating conditions early in the development of large-size bearings, and minimize bearing test time on the rig (with associated operating costs). From this, Schaeffler can optimize its bearing products earlier and easily in all the design stages and put added focus on reducing friction in its roller bearings.

In total, says Stief, simulation with Abaqus FEA has been invaluable in maximizing the performance of Schaeffler’s own products—as well as those of their customers. “In the wind industry, we can now develop more detailed instructions for operating and maintaining finished turbines,” he says. “This in turn helps us provide our customers with more precise recommendations about the construction of their wind turbines. And our new test rig enables us to support customers in other industries as well.”



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