



Offshore blade test challenges: infrastructure & methods

Words: Dr. Enno Petersen, Group Manager Virtual Testing; Gregor Basters, Group Manager Blade Testing; and Dr. Steffen Czichon, Head of Department Rotor Blades at Fraunhofer Institute for Wind Energy Systems (IWES)

Blades for offshore turbines have long since passed the 100 m threshold, and there is no end in sight. With increasing sizes and loads, the structural reserves of blades are being squeezed ever further by design engineers. Consequently, thorough validation at full-scale level is of the utmost importance to ensure reliability over the entire lifetime. However, as the size and weight of the blades increase, large-scale testing becomes not only more important but also more challenging.

New test infrastructure

Starting with the obvious, access to test infrastructure that can handle the latest prototypes can be a critical bottleneck on the path to certification. Fraunhofer IWES recently inaugurated a full-scale blade test rig for large offshore blades with a length of 115 m and above. With a maximum static load of 160 MNm and a fatigue range of 140 MNm, it is well equipped to test the next generations of wind turbine blades. In contrast to other rigs, IWES opted for a modular steel construction, allowing the rig to be reinforced if even larger bending moments should prove necessary in the future.

Features of the rig include a tilting mechanism, making it possible to mount the blade horizontally before tilting it to the maximum angle of 12.5 degrees, and a rotatable front plate, which allows the blade to remain on the rig between different directions of static testing. Both features help to minimise the time before the completion of the first set of static tests. This is especially important, as those are generally required for erection of the turbine prototype.

Establishing sufficient infrastructure is just one piece of the puzzle. As blades increase in size, the natural frequencies of the blade decrease significantly, which leads directly

to a much longer testing time. At the same time, as the structural reserves are minimised wherever possible, there is a tendency to test more cycles, as this allows for slightly reduced test loads. Both factors combined result in testing times that could be up to two years or even longer for large offshore blades. Since a completed full-scale test is required for certification, there is considerable pressure to reduce testing times as far as possible.

Biaxial testing

Full-scale testing for certification is performed in accordance with the IEC 61400-23 standard, which includes fatigue tests in both lead-lag and flap-wise directions. Combining both test directions into a single biaxial test setup has long been on the agenda of several test institutes, as this could reduce testing time and make the test more realistic at the same time.

The inherent complexity of this approach lies in the difference in the natural frequencies in the lead-lag and flap-wise directions. If a blade is excited in its natural frequencies, this leads to a chaotic tip movement. In 2020, Fraunhofer IWES successfully demonstrated that the system frequencies of both the lead-lag and flap-wise directions can be tuned by using leaf spring elements and decoupled masses, leading to an elliptical excitation, a 1:1 ratio of flap and edge frequency.

In the SmarTestBlade, segmented elliptical fatigue testing for future rotor blades, research project funded by the German Federal Ministry for Economic Affairs and Climate

Action (BMWK), IWES and Nordex are demonstrating that this technique can be used directly within an IEC 61400-23 certification scheme of a modern wind turbine blade. With this second successful full-length demonstration, this method is available for application on any modern blade.

Segmented and sequential testing

The tip segment of a wind turbine blade is often removed during testing to reduce testing time, as this is allowed in the IEC 61400-23 standard. Slightly more complex, but also regularly performed, is splitting a blade into a root and a tip segment in order to reduce test time even further. While some considerations have to be made (e.g., ensuring sufficient overlap or how to fix the tip segment), this is an efficient way to save testing time.

Taking this idea even further, IWES has developed the sequential testing approach. The basic concept is easy to understand: first, a limited number of fatigue cycles are performed on the full-length blade. The blade is then cut into a root segment and a tip segment on which the fatigue test is completed.

While this approach is even more complex in terms of test execution, it offers a significant benefit over testing segments right from the start: a significant reduction in overtesting. Figure 2 shows a case study in which the overload, expressed as equivalent damage, was reduced by 73% compared to the standard approach, while also reducing testing time by 66, from 173 to 58 days. While the benefit of a

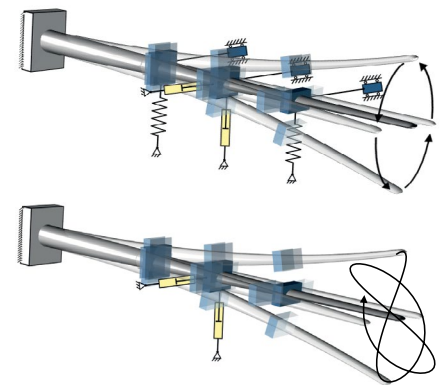


Figure 1: Top: elliptical excitation. Bottom: chaotic excitation at tip © Fraunhofer IWES

reduction in testing time is quite direct and obvious, the benefit of reduced overtesting is slightly more subtle. If more equivalent damage is introduced in some areas of the blade as required, there is a high probability of fractures in that area. While this does not influence the certification itself, as the area has been exposed to longer than the design life before failure, this damage does need to be repaired, and the test needs to be interrupted.

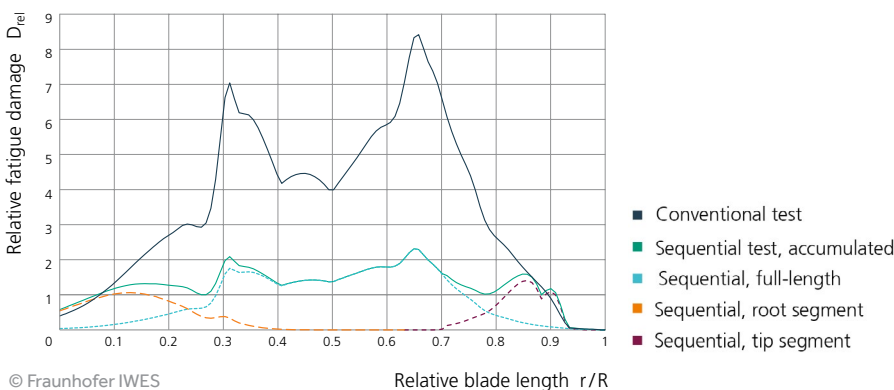
While the general idea is quite easy to understand, identifying the right location at which to split the blade or determining the right number of cycles after which to make the switch from full-length to segment models is non-trivial.

For this purpose, IWES has developed and validated ALBATROSS, a numerical tool chain for fast and accurate optimisation of test setups for full-scale certification tests. While the tool chain was optimised for and validated against the IWES infrastructure, it can also be used to help optimise tests at other facilities.

Beyond certification

In some cases, a full-scale blade test is viewed as just a necessary requirement to obtain the type certificate. However, especially with the increasing size of the turbines, there is a tendency to learn as much as possible about the blade under testing. A free-free modal analysis can be used to update the numerical blade model more precisely. Torsional tests help to update torsional stiffness properties, which become increasingly important for longer blades.

Thermography is frequently used to monitor hotspots and compare the distribution damage to numerical predictions. Digital image correlation provides additional insight into the local three-dimensional deformation. A typical application is studying the 'breathing effect', i.e. ovalisation of the root section. Fatigue tests until failure can give valuable insight into the actual reserve factor.



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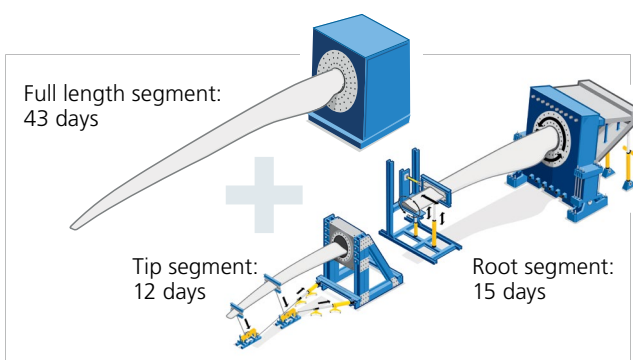


Figure 2: Sequential vs. conventional testing © Pascal Behning for Fraunhofer IWES