Dual axis testing of wind turbine blades

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Abstract: full-scale mechanical testing of blades is an integral part of the certification of wind turbines. With ever-larger rotor diameters, the importance of testing and validation is growing with the aim of minimizing operational risks. Dual axis testing can lead to a more realistic loading scenario compared to traditional single axis testing. A recent demonstration at Fraunhofer IWES revealed that spring elements and decoupled masses can be used to tune the system frequencies, resulting in a representative dual-axis test.

Full-scale mechanical testing

In the race to maximize annual energy production (AEP), rotor diameters are continuing to grow. The increasing size of the turbine blades means that fewer test facilities are able to accommodate mechanical testing of the latest blade models. Limiting factors for the capacity to test turbine blades are the length of the test hall and the hall height, which is required to accommodate the large deformations during both static and dynamic testing. However, the most crucial factor is the ability of the test rig to bear both static and fatigue bending moments.

Fraunhofer IWES operates two test rigs geared to test blades around 70 m and 90 m in length respectively. A third rig, designed to test large blades of more than 115 m in length, is under construction and will enter operation in September 2021.

Full-scale mechanical blade testing is performed in accordance with Part 23 of the IEC 61400 standard. Initial extreme load static tests are followed by a fatigue test and a final set of post-fatigue static tests.

Fatigue tests are usually executed in both the edge and flap directions separately. Shakers on the blade or ground-based excitation devices are used to excite the blade. For energetic reasons, this is done within or very close to the resonance frequency of the blade. In order to emulate the entire service life of the blade, several million fatigue cycles are performed, resulting in a fatigue test duration of several months. As blades are

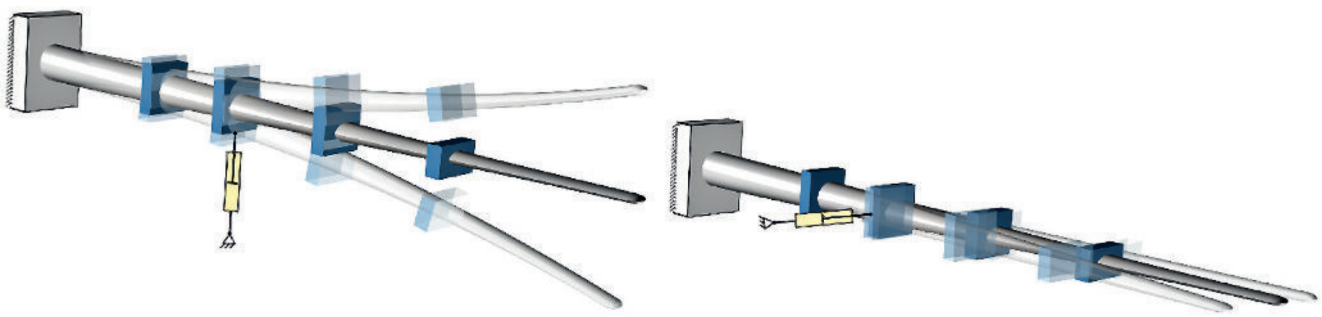

Figure 1: Single axis excitation in flap and edge directions

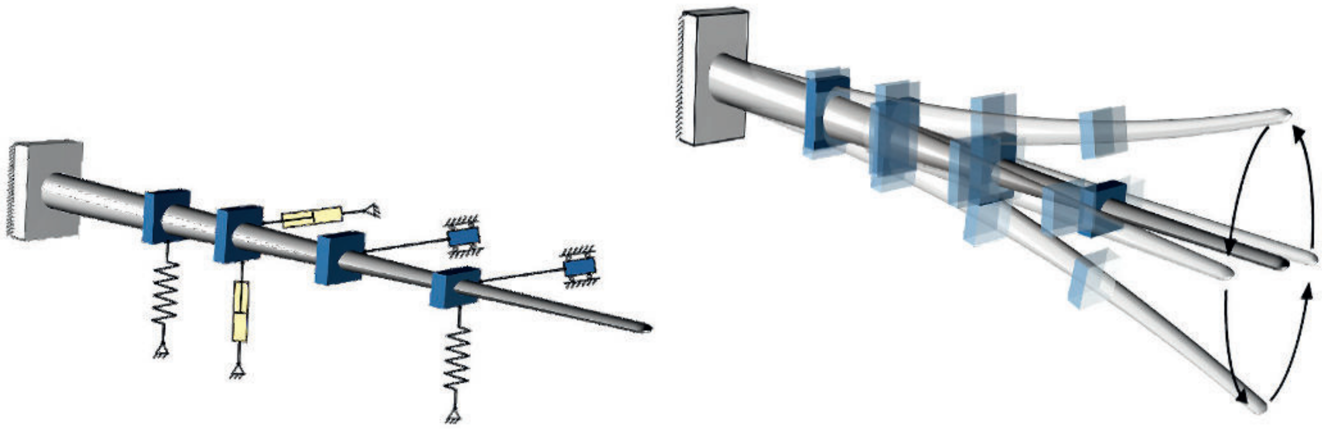

Figure 2: Test setup using spring elements and decoupled masses (left) leading to elliptical excitation of the blade (right)

becoming longer and heavier, this leads to lower natural frequencies and even longer test durations.

As blade certification tests are often on the critical path to market entry, it is generally desirable to speed up the fatigue test. In addition, the availability of test rigs can represent an additional factor in the need to shorten test times.

Dual axis testing and elliptical excitation

The concept of dual axis testing is anything but new. In principal, there are two main motivations behind the idea.

Firstly, performing both flap and edge tests simultaneously could significantly speed up the test. Secondly, dual axis tests allow more representative testing, as the off-axis directions are loaded in a more realistic way compared to single axis tests. This can potentially reduce the risk of blade damage during operation.

However, the main challenge with dual axis testing is dealing with the different natural frequencies in the flap and edge directions. Dual axis tests performed by various testing institutes in the past have excited the blade in different frequencies in flap and edge, leading to a higher order tip deformation pattern (Lissajous figure), which is not trivial to account for and does not necessarily lead to a more representative test result.

Fraunhofer IWES has proposed a test setup using spring elements and decoupled masses. The decoupled masses are attached to the blades using lever arms in such a way that they only act in the edge direction of the blade, decreasing the edge frequency. Likewise, spring elements only act in the flap direction, increasing the flap frequency. This way, the system frequencies can be tuned to match in flap and edge, resulting in elliptical excitation.

Virtual test optimization

In every full-scale blade test, the system behavior is influenced by the position, magnitude, and frequency of the load introduction as well as by additional masses which are mounted on the blade in order to change the bending moment distribution to match the prescribed target loads, which is based on the load analysis. Identifying the best possible test setup is a crucial part of any testing campaign.

For this purpose, Fraunhofer IWES has developed a test setup optimization tool based on beam models using the finite

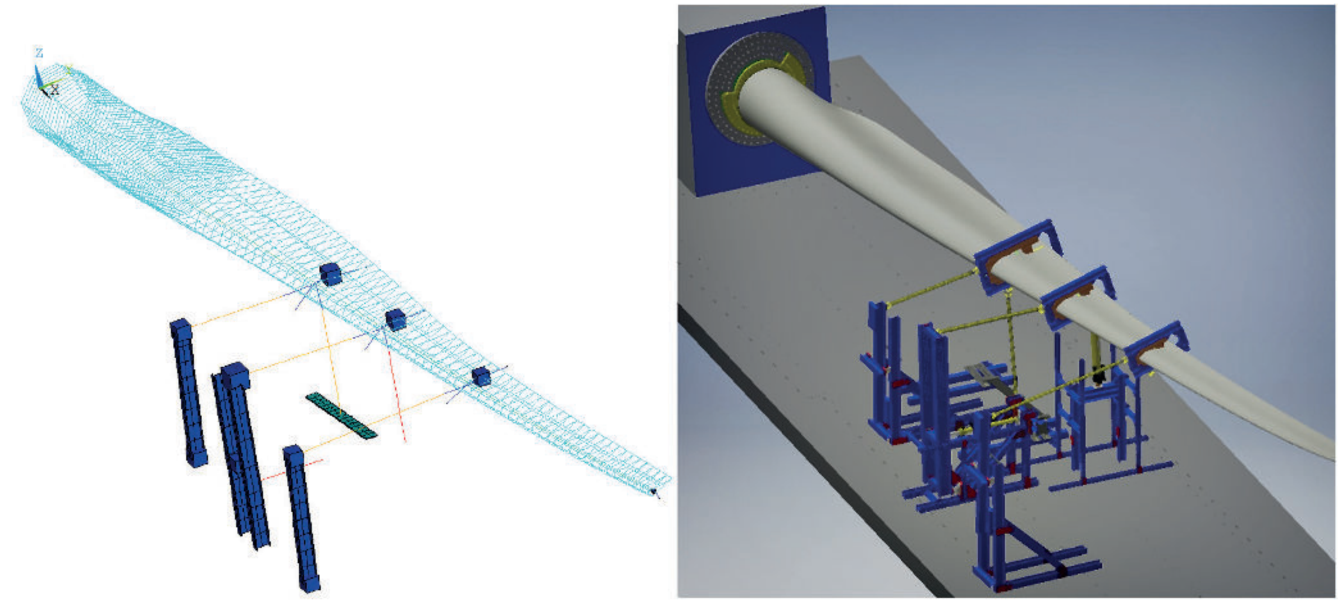

Figure 3: Dual axis test setup obtained through test setup optimization (left) and CAD drawing of physical implementation (right)

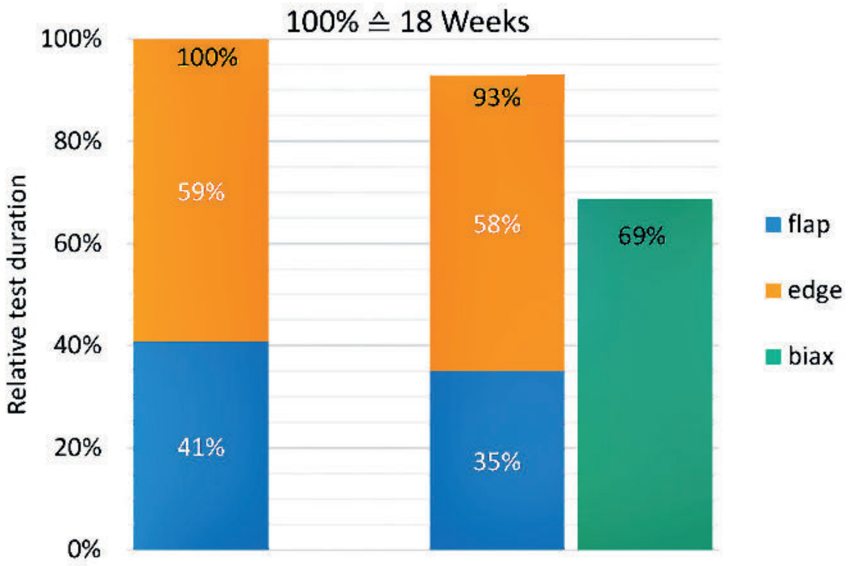

Figure 4: Reduction in fatigue test duration: single axis test (left), single axis test with springs (center), and dual-axis test (right)

element code ANSYS. Both transient and harmonic simulations are employed in order to achieve a trade-off between accuracy and efficiency in the optimization loop. This software tool has been well validated and is frequently employed when preparing certification tests.

For a dual axis test using spring elements and decoupled masses, the optimization becomes significantly more complex as the number of parameters increases. At the same time, the number of target functions increases, as not only the edge and flap moments, but also the off-axis target moments have to be met.

For this reason, a multi-objective optimization algorithm is utilized, with the aim of matching the target moments for various axes and along a defined region of interest along the blade and minimizing the overall test duration at the same time.

The resulting test setup, described by the position, mass, and stiffness of decoupled masses and spring elements is then converted into a physical implementation of the test setup.

The resulting dual axis test is 31% faster compared to the standard single axis test in two separate directions. As it must be noted that springs can also be used to speed up a single axis test, the dual axis test is additionally compared to a single axis test with springs. Even then, a significant shortening of the fatigue test is achieved.

Experimental demonstration

At the beginning of 2020, a full-scale dual-axis demonstration test of the proposed setup was performed at Fraunhofer IWES using a commercial 65 m blade. Two different test setups were built and run in a resonance fatigue test.

Actuator forces and displacements were measured at various cross-sections along the blade and the related bending moments were calculated and compared to the simulation results. The measurement results are in very good agreement with the simulations for a wide range of load amplitudes and phase angles, with the full transient simulation being closer to the test results than the simplified harmonic simulations. This demonstrates that the test setup optimization tool is fully capable of predicting the behavior of a dual-axis test and can be used when designing test setups.

Furthermore, it was successfully demonstrated that decoupled masses and spring elements can be efficiently used to tune the system frequencies of the blade test to achieve elliptical excitation for commercial scale blades. With this successful proof of concept, it can be expected that it will be possible to perform future certification tests using these techniques. However, it must be noted that a dual-axis test setup remains significantly more complex than a single axis test, which renders detailed blade per blade analysis of the specific advantages and drawbacks of both approaches necessary.

Summary and outlook

Large blades require special care in terms of testing and validation, as the costs associated with structural failures are increasing. Therefore, a more representative testing regime is in the shared interests of turbine manufacturers and wind farm operators.

The demonstration test performed clearly shows the advantage of dual-axis testing over single axis testing and has proved that decoupled masses and spring elements can be used to tune blade frequencies in full-scale tests. Studies performed at Fraunhofer IWES have also revealed the potential benefits of segmented blade testing. Since combinations of segment testing and dual-axis testing are also feasible, this offers additional potential for the shortening of testing times.

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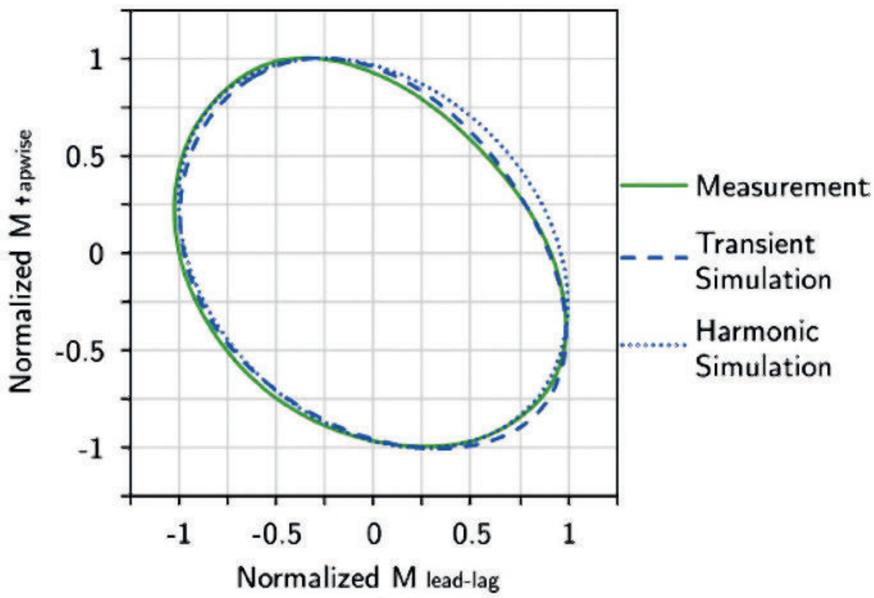

Figure 5: Comparison of bending moments from simulation and test