FRAUNHOFER INSTITUTE FOR WIND ENERGY AND ENERGY SYSTEM TECHNOLOGY IWES

TESTING FOR RELIABLE COMPOSITE MATERIALS AND ROTOR BLADES

Accredited according to DIN EN ISO / IEC 17025:2005 for determination of physical properties of fiber enhancedsynthetic materials and fiber composite materials using mechanic-technological and thermal testing and testing of mechanical loads on wind turbines.

Fraunhofer IWES is DIN EN ISO9001-certified in the areas of ‘product development up to the prototype stage, technology development and optimization, technology assessments and studies’ as well as ‘trials in demonstration centers’.

BRAIN UP YOUR BLADES!

Testing and validation along the value chain of wind turbine blade development is the core competence of Fraunhofer IWES. As a DIN EN ISO 9001:2008 certified institute that operates an ISO 17025 accredited laboratory, we are committed to precise processes and enhanced testing methods beyond current expectations. Our infrastructure for testing blades, substructures and smaller specimens is complemented by a manufacturing demonstration center, a blade leading-edge erosion test stand and developed expertise of aerodynamic design and structural analysis. Our track record for full-scale blade testing comprises more than 20 blades from renowned international OEMs as well as hundreds of component and thousands of material coupon tests. As an independent research provider, we work together with all major certification bodies to ensure a smooth certification process.

In addition to the structural mechanic characterization for wind turbine blades, there is considerable need for process validation, particularly since the production processes have a significant influence on the reliability of the structures. The industrialization of the material handling and placement processes reduces the risk of production faults, while better knowledge of the processes helps to prevent failure such as porosity, wrinkles and residual stresses.

In order to tackle increasing cost pressures, rising quality demands, and shorter innovation cycles, we have been working closely with leading manufacturers to improve testing procedures, shorten test periods, and achieve higher turbine availiability. By contributing to the work of international comitees and associations, our experts play a role in the development of new standards.

As an institute, Fraunhofer IWES provides the whole range of services for paving the way for tomorrow's sophisticated wind turbines. By bringing together development engineers with design method understanding and material knowledge with reliability experts, innovative approaches are nurtured. Client-specific requirements that go beyond standard testing spur us to develop exceptional solutions and compile skills from different backgrounds. Motivated by the passion to exceed limits and with exceptional wealth of know-how, we support your endeavors to set new reference points for the wind industry.

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Capability	Test Rig I
Max root diameter	4.0 m
Max static root bending moment	50 MNm
Max fatigue root bending moment	±30 MNm
Tilt angles	2.5 ° - 12.5 °
Max static tip deflection	17.5 m
Max fatigue tip deflection	±9.5 m

FULL-SCALE BLADE TESTING

From a structural perspective, rotor blades are one of the most critical components of a wind turbine. In order to ensure their reliability, IWES offers independent structural testing of large scale rotor blades both for model validation and certification. Since 2009, more than 20 blades of differing sizes have been tested from a variety of international customers.

Custom and IEC standard blade tests are conducted on one of two separate test stands, located in neighboring halls. This ensures that customers have a high level of accessibility to their blades during testing, while maintaining their confidentiality.

The facilities of Fraunhofer IWES are located in close proximity to the harbor in Bremerhaven, providing easy access for delivery of larger rotor blades.

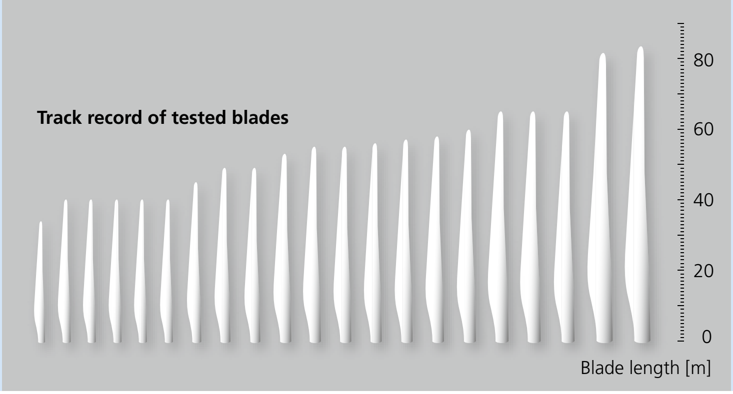
Static Testing

During static testing, loads are applied using hydraulic cylinders and a pulley system. They are connected to a series of up to eight load frames mounted on the blade. Each load frame is custom designed and built, based on the specific geometry of the blade being tested. In order to limit forces due to the deadweight of the blade, these tests are performed perpendicular to the floor of the test hall. Loads of up to 500 kN can be applied at each load frame, which can be combined with tilting of the block of test rig II to accommodate blades with large deflections.

The tests are monitored using several hundred measuring signals at frequencies of up to 400 Hz, in combination with an optical measurement system that can record three-dimensional deflection of the blade.

Test Rig II

6.0 m
115 MNm
±30 MNm
0 ° - 20 °
30.0 m
±11.0 m



Cyclic Fatigue Testing

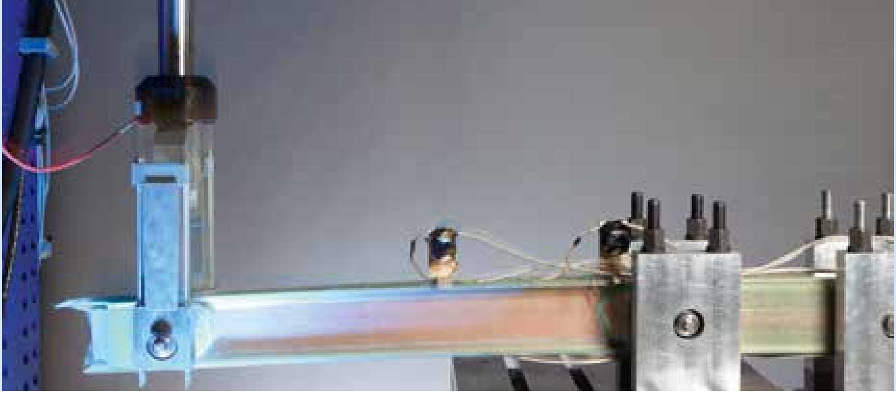
During uniaxial dynamic fatigue testing, the blade is loaded in either the vertical or horizontal direction. Using a servo-hydraulic cylinder coupled to the blade, a flap-wise (vertical) or lead-lag (horizontal) excitation is applied. The cylinder is programmed to excite the blade at its natural frequency – consequently, the force on the blade is minimized. This method of hydraulic excitation allows for extremely precise testing.

Additional Services

IWES offers a variety of additional services including setup of comprehensive test programs, customized tests such as torsional loadings, and testing of lifting systems or other large structures.

Also ´experimental modal analysis` can be conducted using impact or modal shaker testing. Either a specific frequency or a range of frequencies can be excited, allowing for modal parameters to be determined, i.e. eigenfrequencies, damping ratios, and mode shapes.

Currently, IWES is working to optimize the methods used in biaxial fatigue loading, as well as developing new simplified methods to test blade segments; thus effectively decreasing duration and cost of blade tests.



COMPONENT TESTING

The usual certification process of wind turbine blades is based on material tests, material and structural models and a single full-scale blade test. In particular, the global blade properties can be verified using this method. On the structural level, the applied damage initiation and propagation models usually cannot be validated. Risks and uncertainties are introduced in the design process by the huge dimensional jump between the material and blade level, differences in the manufacturing processes, and also modelling imperfections. 'Sub-component' or 'element and detail'-level testing is a possibility to validate the models and achieve significant mitigation of the risk of structural damages during a turbine´s operational life time.

A profound knowledge of the blade manufacturing processes and the mechanical loading of the blade structure is required to design and manufacture such specimens and to conduct the test. The correct representation of the blade boundary conditions, if not intentionally simplified, is required – and it needs to be verified by numerical simulations. Usually, the load magnitude and direction of the blade test are the basis to design component tests. However, one of the major advantages of component tests is the possibility to investigate the structural performance under alternative load situations. In addition to the rather simple specimen manufacturing and testing, this allows the evaluation of manufacturing, material or load direction effects.

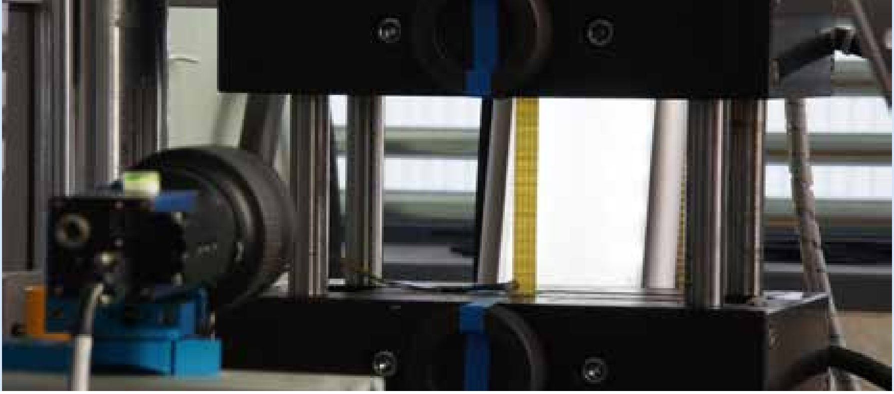
Fraunhofer IWES has developed and conducted component tests on different scales. Further infrastructure assets are in the pipeline, and additional test variations will be generated: for example a beam test for adhesive bond lines ('element and

detail' level), trailing edge tests ('element and detail' as well as 'sub-component' level), ply drop tests for laminates with thick plies, root end connection tests and large-scale tests for blade transition areas.

In order to gain more insight into the structural behavior of the blades, component tests can be supported by NDT or SHM methods such as thermography, ultrasonic or acoustic emission. The application of local displacement sensors and optical/electrical strain gauges, as well as force and global displacement measurements, complete the portfolio. In combination with temperature sensors such strain measurement systems are applied for residual strain measurements on composite structures.

Equipment

- 1 & 2.5 MN servo-hydraulic test machine
  - 150 mm stroke (±3.5 mm at 2 Hz)
  - max. specimen length: 3,000 mm
  - flexible test set-ups by T-notch table
- strong floor and strong wall
  - dimensions: 12 x 3 m
  - 3500 kNm bending moment
  - hydraulic cylinders (25 to 200 kN and up to 800 mm displacement)
- proven shut down strategies
- NDT to accompany tests



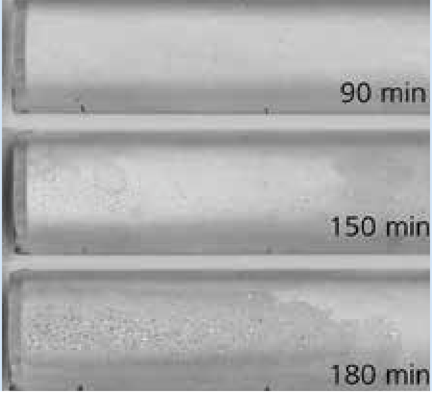
MATERIAL TESTING

Structural material properties are the design basis for the development of wind turbine blades. In addition to the static material performance, the cyclic performance of the material is essential in the design of highly fatigue loaded wind turbine blades.

IWES´s focus on structural material testing for blades is on composite materials. The variety of possible materials for testing is huge: e.g. the composites differ with regard to the textiles, the resin systems, the fiber architecture and the test direction. Furthermore, testing of adhesives and core materials plays a major role. The DAkkS accreditation of our lab confirms the reliability of results and the high quality standard.

A wind turbine blade-specific material requirement is the rain erosion resistance of coating systems. Rotor blades are exposed to severe environmental conditions: rain, hail, sand, salty sea water and dirt, all these lead to soiling and roughening of paint and coating systems on the leading edge of the blades. In order to evaluate the performance of coating systems, Fraunhofer IWES has developed a rain erosion test rig based on the rotating arm concept. Coated aerodynamic profiles are tested with up to 550km/h and 2000 l/h of rain. Rotational speeds and climatic conditions can be individually adjusted in order to mimic the actual rotor blade operating conditions or in order to shorten the test duration.

Structural design is determined by the impact of material qualification and evaluation no less remarkably than by manufacturing aspects. Examples of manufacturing elements include the viscosity, glass transition temperature, area weight,



fiber volume fraction, sag resistance and porosity. Many of the manufacturing related material parameters are used during incoming inspections.

Since the manufacturing process of composite materials is an essential step in material test programs and can largely influence the results, Fraunhofer IWES offers specimen manufacturing as a service to its customers. In a dedicated lab the specimens can be manufactured with different methods, assuring high reliability and repeatability. State-of-the-art equipment is used to avoid imperfections and to achieve the best possible quality.

Equipment

- multiple servo-hydraulic test machines for static and dynamic testing (force ranges from 25 to 2500 kN)
- tension-compression-torsion servohydraulic test machine for biaxial testing
- climate chamber for parallel mechanical and climatic load simulation (-45 °/130 °/humidity/UV)
- helicopter rain erosion test rig
  - max. speed: 550 km/h
  - temperatures: 4 ° to 40 ° C
  - variable drop size: 1.5 to 5.5 mm
- composite lab
  - controlled climatic conditions
  - different manufacturing processes
  - GFRP and CFRP manufacturing
  - max. sample size: 6 m
  - accurate specimen machinery

BLADEMAKER DEMO CENTER

Rotor blades constitute approximately a fifth of the total costs of an onshore wind turbine. Their manufacturing is still dominated by manual processes with a cost distribution of 30 per cent for labor and 60 per cent for material. In order to increase quality and reduce costs, Fraunhofer IWES develops industrialized processes based on a cost model which considers an economic rating of alternative production scenarios. Frequent workshops with leading manufacturers make sure that current demands are understood and taken into account. IWES focuses on the industrialization of the entire process: Along with the development of blade-specific procedures and new materials, the manufacturing of blade segments with an industrialized production is evaluated. Core technologies include the lay-up of cuttings and preforms, in-situ foaming processes for sandwich structures, as well as bonding application and finishing. The processes achieve a high level of maturity via integration into the multi-function BladeMaker gantry – which provides the evaluation in a one-to-one-scaling. This is assisted by CNC-integrated CAD-CAM and adapted process simulation tools. An initial result is a direct tooling approach that has been set up to shorten the time to market for blade molds.

Manufacturing of heavily loaded parts like spar caps is performed with an innovative solution for high throughput production and lay-up of prepregs. Direct resin infusion and integrated sensors in the mold provide a highly reliable infusion process with many possibilities for control and analysis.

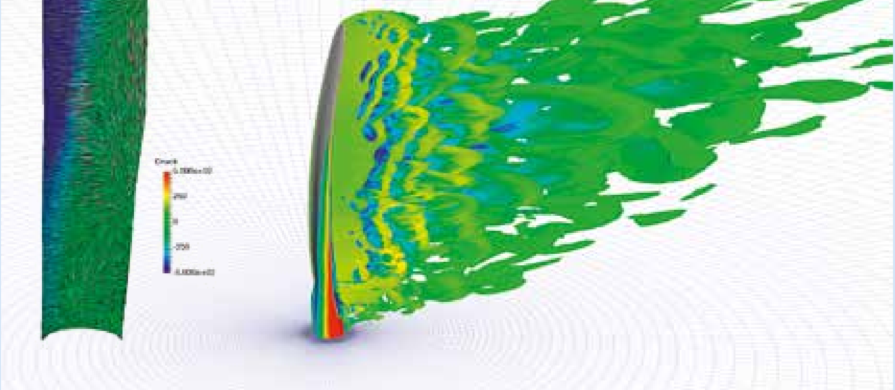
Within the project duration, savings of 10 per cent of a blade´s costs are targeted. The continuous improvement in quality

through industrialized production will lead to decreased rework costs, as well as to a higher level of availability in the field.

The demonstration center offers companies from the automation industry and material suppliers access to proven blade production equipment. They can validate their processes, equipment or material and develop it to a high technological readiness level. Blade manufacturers have the chance to become familiar with automation equipment, train their staff and perform trial tests. The BladeMaker demonstration center has been designed as a platform for joint development and testing of innovations; state-of-the-art equipment is available to run through the whole manufacturing process.

Equipment:

- CNC-controlled production cell with 2 cooperating 6-axis gantries (5 x 2 x 25 m)
- payload: max. 400 kg per unit
- blade molds with flat back profiles and integrated sensors (20 m section of a 40 m blade)
- precut center
- roving-impregnation and -placement technology
- automated placement of large precuts and preforms
- automated in-situ production of core materials
- direct-infusion equipment
- automated bonding application and surface finishing system

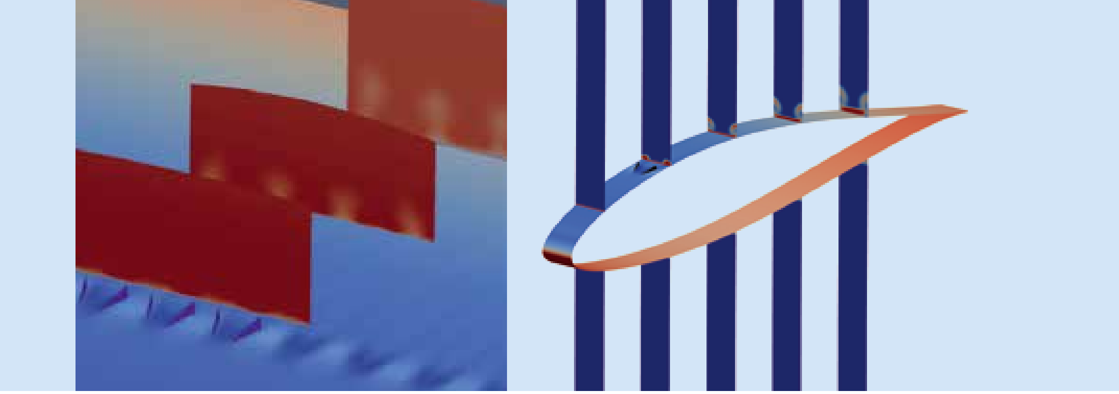


BLADE DESIGN

Rotor blades are a central component of every wind turbine. As such, their design is fundamental for ensuring the economic success of the overall structure. In order to assist developers during the design process, Fraunhofer IWES contributes its extensive know-how of aerodynamic and structural dimensioning as well as of rotor blade production.

Depending on the goal of the turbine design, blades can be created based on various criteria: optimum performance yield from a single turbine or a group of turbines, load minimization, noise reduction, or the most cost-effective production design. For the most part, the criteria for a blade design represent primary and secondary conditions in the optimization process and must be adapted to the specific wind turbine concept.

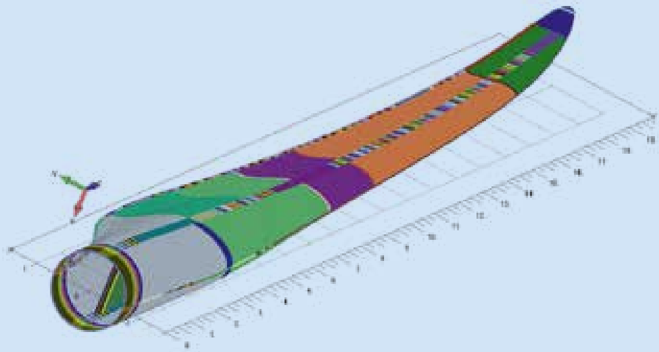
In terms of the design of long, highly flexible rotor blades, the standard methods for dimensioning have shown considerable uncertainties. In order to reduce the degree of imprecision in the development process Fraunhofer IWES prefers computational fluid dynamics (CFD). It offers the opportunity to consider fluid structure interaction in the process of examining blade concepts, which allows critical areas to be identified and improved. Elements which impact the fluid dynamics are accounted for as early as possible in the blade design stage and acoustic effects can also be included.



Depending on the turbine concept, adjoint methods can be employed to optimize the aerodynamic profiles in line with the specific requirements whilst taking several hundred design parameters into account. The design tools used by Fraunhofer IWES are based on the open source CFD code 'OpenFOAM' and can be made available to interested blade designers.

The structural properties of the rotor blades depend to a large extent on the material chosen, the production processes, and the structural dimensioning. The concept presumes advanced simulation methods which are able to reproduce the fiber composite structures exactly. The main emphasis here is on calculation of the bending lines for cyclic (fatigue) full-scale tests and detailed models for structural assessment as well as for the dimensioning and analysis of component tests. In particular, adhesive bond line strength and stability calculations are conducted and the results thereof are analyzed in detail.

Moreover, Fraunhofer IWES has designed a variety of blades for research purposes, including a 20 m, a 40 m, and an 80 m blade. These blade designs can be made available upon request. With the 20 m and 40 m blades, access to the mold construction can also be provided.



CURRENT PROJECTS

LENAH

The aim of the project LENAH is a lifespan extension and lightweight construction optimization due to nanomodified and hybrid material systems in rotor blades. New nanoparticle-modified plastics are being developed in order to further improve the robustness of rotor blades. Furthermore, hybrid laminates are being tested for their suitability for rotor blades. The project comprises numeric simulation with multi-scale methods and the development of the materials through to the construction and testing of components, e.g., at Fraunhofer IWES' test stands in Bremerhaven.

SmartBlades 2

Within the project, researchers scrutinize passive technologies for load reduction both by experimental activities at test rig with a 20 meter blade and by measurements on a test turbine with Bend-Twist-Coupling blades. The results of lab and field measurements provide the cornerstone for the validation process. Moreover, the coupling creates a new phenomena that will be measured and analyzed from the structural design point of view to properly account for future developments. Additional activities are devoted to the investigation of the aerodynamic effects on the complete rotor – focusing on active technologies, such as flap and slat, to include these findings in the design and implementation.

Blade Validation – Future Concepts

Currently, rotor blade prototypes are tested by moving them separately both perpendicular to and in the direction of the wind - in order to obtain information about structural behavior over their 20 year service life. This rapid test method is a major simplification, because loads actually occur simultaneously in the field. As part of the 'Blade Validation – Future

Concepts' research project, Fraunhofer IWES is developing new methods that provide significantly more realistic data and allow a load-appropriate design to be produced. Three different test methods are addressed within this project: On the full-scale blade level, biaxial test methods are developed further. Additionally, blade segment testing and large-scale component testing are investigated. These innovative approaches will lead to improved full-scale blade tests with regard to the load representation, as well as a reduction of test time around 30 per cent.

Additive Sandwich Manufacturing

The joint project of eight partners targets the additive manufacturing of large composites parts for direct use in low load applications. The production by means of additive manufacturing is a more cost-effective approach compared to traditional production processes, which usually require to build molds. However, there is still a need for developments that take full advantage of this approach for the production of ready-to-use components. The size of components and achievable stability are still limiting factors. The aim of Additive Sandwich Manufacturing ('ASM') is the development and testing of a novel additive method including the necessary systems engineering, materials and software tools. This method will be used for the manufacturing of large and functional components by combining foam structures with fiber-reinforced materials. Tight tolerances of the produced parts can be achieved by integrated machining processes and by simplifying their direct use after manufacture. The manufacturing processes and materials developed in the project will contribute to a reduction both in production costs and time to market of over 25 per cent each.

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