Fraunhofer IWES

FRAUNHOFER INSTITUTE FOR WIND ENERGY SYSTEMS IWES

CHALLENGE YOUR BLADES

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

Fraunhofer IWES is DIN EN ISO9001-certified in the following areas:

· Product Development up to Prototype State
· Technology Development and Optimization
· Assessment of Technologies and Studies
· Evaluation in Test Centers

SLENDER, LIGHTER AND MORE DURABLE

The wind energy industry remains a global growth market and an important pillar of the transition to an energy supply based on renewable energies. The pressure to reduce costs has increased significantly in recent years and is becoming the driver of innovation: The technical demands being placed on the turbines are constantly increasing. At the same time, the costs for manufacturing and operation have to be reduced. Rotor blades have a key role to play here. The goal is for them to become slender, lighter and more durable.

We are convinced: These challenges can only be mastered by adopting a holistic and interdisciplinary approach. Our scientists are therefore working on innovative solutions for better and better rotor blades – and combining approaches from different disciplines in their blade design, full-scale blade testing, component testing, and manufacturing.

In 2018, we carried out our 30th full-scale blade test for the certification of prototypes. This also allows us to improve our test methods continuously. We develop large component tests, for example, whereby the investigation of individual blade details is possible under particularly realistic mechanical loads. We use segmented testing methods to test ever longer rotor blades for offshore turbines.

Our test bench for Leading Edge Protection (LEP) is also a piece of equipment which we developed ourselves. Its unique feature: We use it to investigate the formation of ice accretion in addition to rain erosion. This facilitates a detailed consideration of the complex interactions.

To fully exploit the lightweight construction potential of modern fiber-composite materials, an accurate understanding of their mechanical behavior is required. This is why we have conducted hundreds of component tests and thousands of coupon tests for our customers in recent years. In parallel, we are working intensively on the development of test methods and material models.

Since a successful blade design combines good aerodynamic characteristics with low production costs, we additionally offer advice on structural design/manufacture and also develop our own CFD design tools.

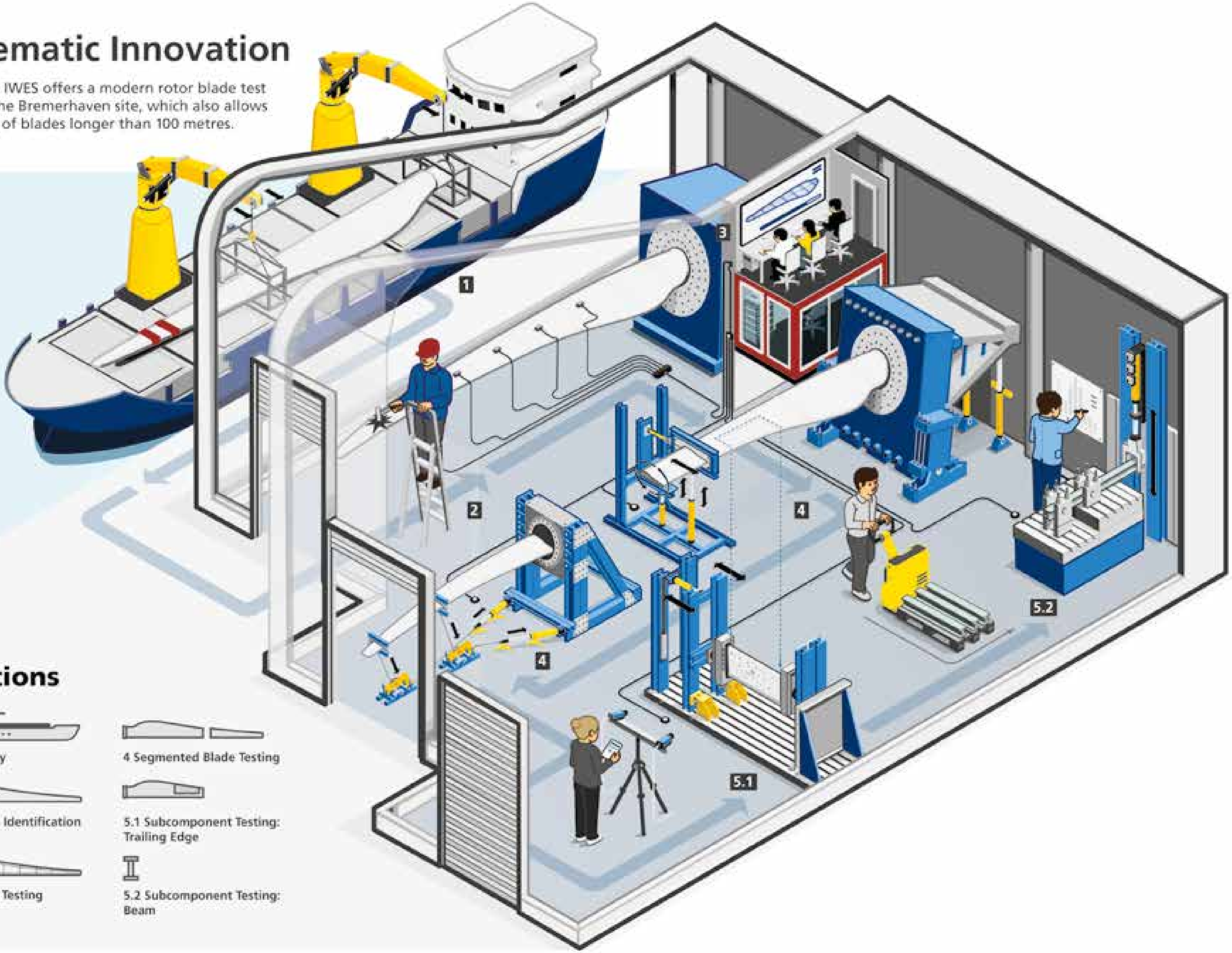
The future of rotor blade manufacturing can be experienced in our BladeMaker demonstration center. Turbine manufacturers can test alternative production processes and materials, and suppliers have a development platform for new products and services at their disposal.

Much remains to be done and spurs our ingenuity. We are well positioned to master new developments and challenges: Put us to the test!

Dr.-Ing. Steffen Czichon
Head of Department

Systematic Innovation

Fraunhofer IWES offers a modern rotor blade test facility at the Bremerhaven site, which also allows the testing of blades longer than 100 metres.



Stations

- 1 Delivery
- 2 System Identification
- 3 Virtual Testing
- 4 Segmented Blade Testing
- 5.1 Subcomponent Testing: Trailing Edge
- 5.2 Subcomponent Testing: Beam

ROTOR BLADE TESTING AT FRAUNHOFER IWES

Ever longer rotor blades demand an excellent understanding of their structure as the reserve load-bearing capacities of the lightweight construction materials need to be utilized particularly efficiently. Fraunhofer IWES is thus constantly working on improving the test methods it employs in order to achieve even more comprehensive results. At its site in Bremerhaven, Fraunhofer IWES offers the entire spectrum of mechanical tests on rotor blade structures. At the same time, customers benefit from innovative testing methods: the state-of-the-art infrastructure is also set up for tests on rotor blades up to lengths in excess of 100 meters. The complementary testing stations allow complete investigation of all aspects of the rotor blade.

1 Delivery

Land transport poses a particular problem for blades measuring over 100 meters in length. As Fraunhofer IWES is located directly next to the port of Bremerhaven, the institute offers ideal conditions for the delivery of particularly long rotor blades by sea.

2 System Identification

Following delivery, system identification is performed with the help of experimental modal analysis (EMA) among other methods. A defined energy input is applied to the blade to make it oscillate, and the system response measured using accelerometers. Together with the results of the weight and center of gravity measurements, these data are fed into the computational model of the blade and help to refine it.

3 Virtual Testing

The computational model can be used to design the optimal test set-up. The precise determination of the state of construction compared with the design will also allow more precise designing of the structure of the rotor blades in the future.

4 Segmented Blade Testing

Segmented testing in which the tip and root of the blade are tested separately is a practical solution for particularly long blades. It can accelerate testing considerably and allows targeted realistic loading of individual sections, which can be effected with biaxial excitation and the application of torsional loads.

Subcomponent Testing

A detailed understanding of the variance of the material parameters is essential to get the most out of the materials as this makes it possible to reduce the safety factors. This requires consideration of the variance of the parameters at not only a material, but also at a structural level. Statistical validation by means of repeated full-scale blade testing is not a viable option due to the high associated costs. Component tests represent an alternative solution. Fraunhofer IWES is developing new procedures to this end.

5.1 Subcomponent Testing: Trailing Edge

One approach is to test sections of the full blade such as the trailing edge segment. This procedure allows particularly realistic reproduction of load applications and stress states.

5.2 Subcomponent Testing: Beam

The second approach is to test generic subcomponents – such as special bending beams for the testing of adhesive joints. This allows a large number of tests thanks to the comparatively low associated costs.

FULL-SCALE BLADE TESTING

From a structural perspective, rotor blades are some of the most critical components of a wind turbine. Fraunhofer IWES is an independent institution which offers structural testing of large-scale rotor blades for both model validation and certification to ensure the blades are reliable. Since 2009, more than 30 blades up to 83 meters in length have been tested.

High degree of confidentiality

The testing methods used at Fraunhofer IWES are accredited in accordance with IEC 61400-23. The institute conducts customized and IEC standard blade tests on one of two separate test stands, located in neighboring halls. This ensures that customers have a high level of access to their blades during testing, while guaranteeing a high degree of 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. The cylinders are connected to a series of up to eight load frames mounted on the blade. Each load frame is custom designed and built for the specific geometry of the blade being tested. In order to limit forces exerted by the deadweight of the blade, the tests are performed perpendicular to the floor of the test hall. Loads of up to 500 kN can be applied at each load frame. In order to accomodate blades with large deflections under static loading, the larger of the two test blocks can be tilted during static testing. The tests are monitored with the aid of 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.

Cyclic testing

During uni-axial dynamic fatigue testing, the blade is loaded in the vertical and horizontal direction in turn. A flap-wise (vertical) or lead-lag (horizontal) excitation is applied by means of a servo-hydraulic cylinder coupled to the blade. The cylinder is programmed to excite the blade at its resonant frequency. Consequently, the force on the blade applied by the cylinders is minimized. This method of hydraulic excitation facilitates extremely precise testing.

Highly realistic load application

Developments for biaxial blade testing are a further focus of the work. This will lead to more realistic blade loading and also to a reduction in the test time. The time saving is down to the fact that the two fatigue tests (in flapwise and edgewise direction) can be performed concurrently, not consecutively. The tested part of a blade is expanded, as – in addition to all areas which are loaded in the uni-axial tests – areas away from the main axes are loaded as well. This results in improved reproduction of the loads and makes the blade test more realistic. Fraunhofer IWES is particularly focusing on the development of procedures which affect the blade´s resonance frequencies for testing. To this end, various procedures are considered in order to apply uni-axial loads. One important step here is the numerical design of the planned blade test. All parameters relevant to the test stand and blade are emulated and the fatigue test is simulated in advance. This has already been realized for the uni-axial tests, and the method has been further refined to achieve the target bending moments specified as accurately as possible. This aspect is also set to become more important for biaxial testing in order to make it possible in the first place and effective.

IWES is currently developing methods to include virtual testing as a supplementation to physical testing. Details of the material, manufacture, and design of the component or complete structure will be determined and today´s design models will be supplemented accordingly. The numerical representation of the test specimen and the test setup is validated experimentally, using critical failure modes, in order to evaluate the reliability and validity of the blade model.

Additional services

IWES offers a variety of additional services including setting up comprehensive test programs, customized tests such as torsional loadings, and testing of lifting systems or other large structures. Moreover, experimental modal analysis can be undertaken using impact or modal shaker testing. Either a specific frequency or a range of frequencies can be excited, allowing modal parameters to be determined, i.e. resonance frequencies, damping ratios, and mode shapes.

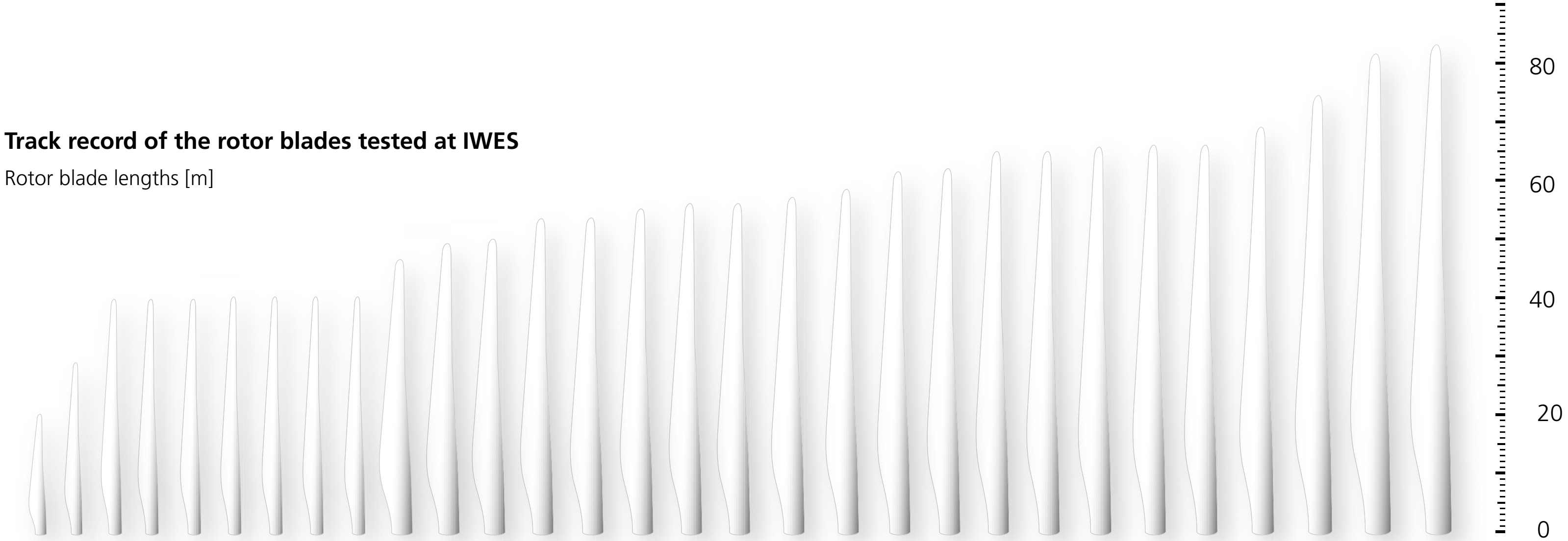
Innovative testing of blade segments

To achieve its goal of maintaining its ability to test XXXL blades, Fraunhofer IWES is also developing new methods to test blade segments. Parallel testing of structurally significant blade parts means simplified logistics, less loading by dead weight, and a reduction in the test time.

Equipment	Test Rig I	Test Rig II
Max. root diameter	4.0 m	6.0 m
Max. static root bending moment	50 MNm	115 MNm
Max. fatigue root bending moment	±30 MNm	±30 MNm
Tilt angles	2.5° - 12.5°	0° - 20°
Max. static tip deflection	17.5 m	30 m
Max. fatigue tip deflection	±9.5 m	± 11.0 m

Track record of the rotor blades tested at IWES

Rotor blade lengths [m]



LEADING EDGE PROTECTION

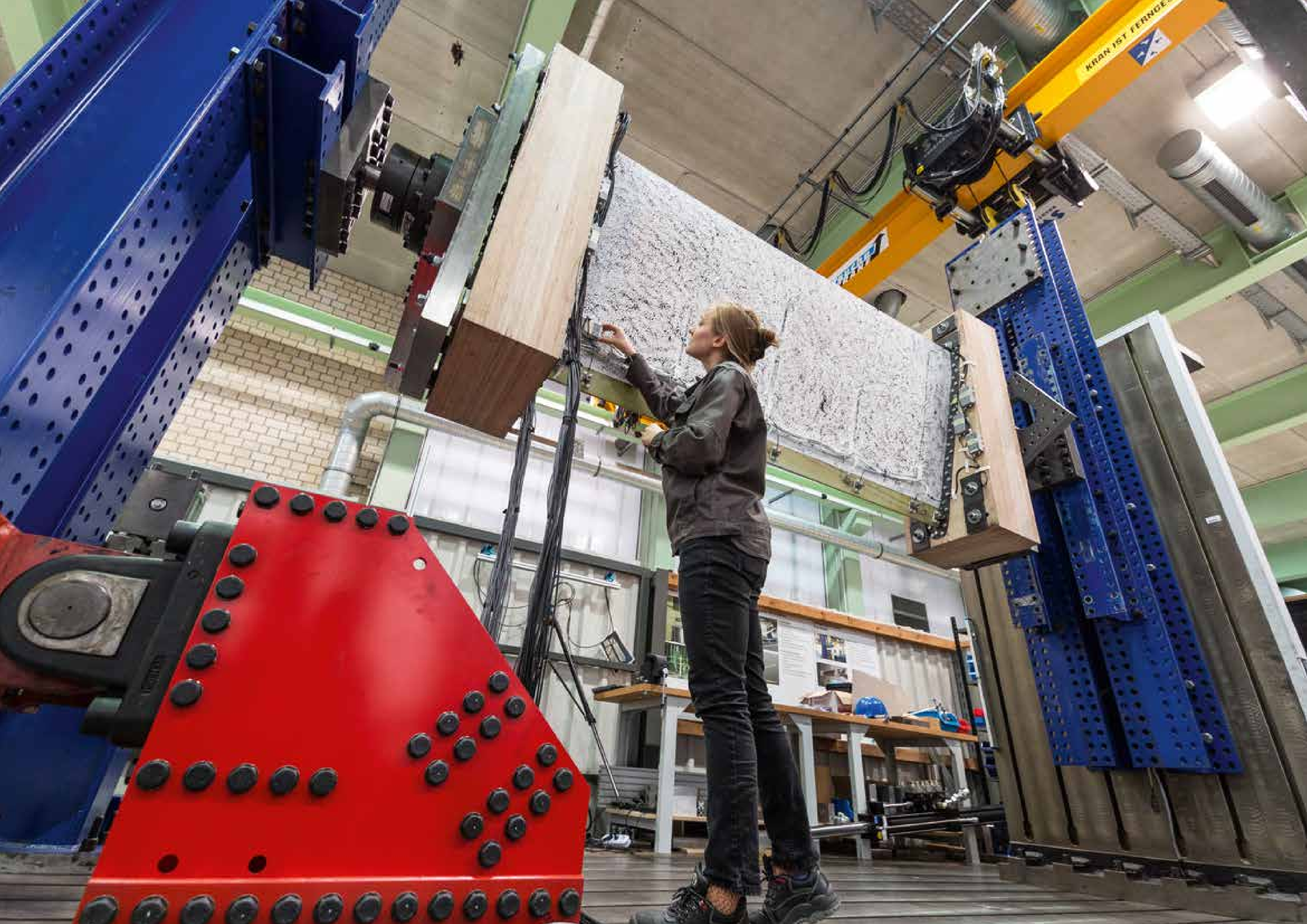
The rotor blade tips of a wind turbine reach speeds in excess of 300 km/h in full load operation. At this speed, raindrops act on the surface like sandpaper. Even slight damage causes the surfaces to become rough at certain points, which reduces the aerodynamic efficency and thus affects the economic efficiency and the service life of the whole turbine.

The parts which are very seriously affected such as the leading edge of the wind turbine blade are therefore equipped with special protection systems, for example films or coatings – known as Leading Edge Protection (LEP). The problem: there is still no protection system which can survive rain, hail, temperature fluctuations, UV light, and humidity over the whole service life of a turbine. Hence, Fraunhofer IWES has been operating a rain erosion test bench since 2015 to better understand damage processes and derive effective protection measures. On the rain erosion test bench, substrates with different coatings are tested under a variety of conditions. The number and size of the drops, the point in time and frequency of the impacts, the temperature, and the UV irradiation can be controlled very precisely.

A droplet impact system that can detect the position and the impact energy of the droplet strikes is currently under development. The complete test bench will be reproduced in a CFD simulation and the damage events will be documented with a laser-based inspection system and a high-speed camera. Also documented are the topology of the samples, and damage in the micrometer range. Developing a suitable material and damage model makes it easier to understand the processes on the material level. The results assist suppliers providing material for the rotor blade production to achieve optimum adaptation of their products to the practical demands. In 2018, the erosion test bench was expanded such that ice accretion tests can be carried out with a high degree of reliability.

Equipment

- Max. speed: 550 km/h
- Temperatures: 4°C to 40°C
- Variable drop size: 1.5 to 5.5 mm



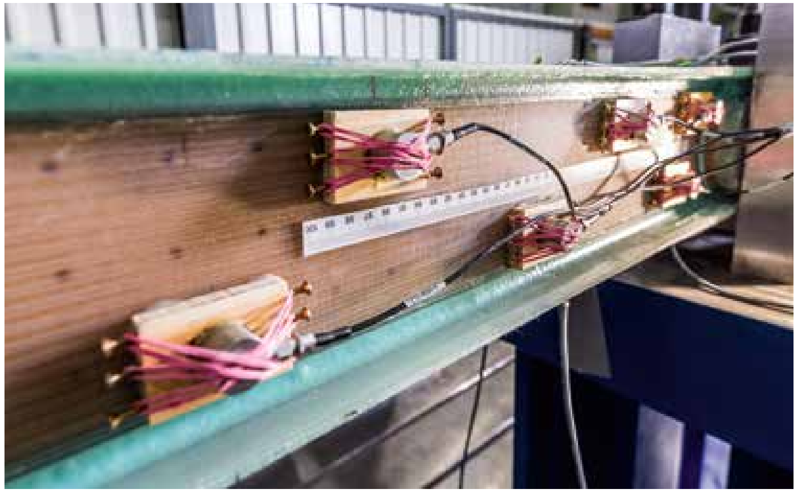
COMPONENT TESTING

The large differences in dimensions between materials testing and the finished parts lead to uncertainties and risks in the design process of rotor blades. Validating the models or determining structural parameters offers the opportunity to reduce these risks significantly during the service life of a turbine.

The expertise at Fraunhofer IWES lies particularly in the testing of extremely critical and structurally relevant areas such as bonded joints, ply drops, spar caps, and blade trailing edges. One focus of the work is the testing of spar cap to web bond lines on which a special combination of shear and axial loads acts. In fatigue tests, different adhesives can be compared and their respective failure thresholds and the permissible thicknesses of their bonded joints determined.

Producers of materials, blade manufacturers, and other industrial customers benefit in particular from the flexible infrastructure at Fraunhofer IWES, which is tailored towards individual customer requirements. In addition to ten years of experience in component and structural testing, the institute offers a state-of-the-art testing environment which includes an air-conditioned testing laboratory.

The tests are accompanied by non-destructive examinations. Here, Fraunhofer IWES uses a combination of thermography, ultrasonic tests, and acoustic emission. Our experts also have outstanding expertise in the production of test specimens which are manufactured according to the wishes of our customers.



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
  - 3,500 kNm bending moment
  - Hydraulic cylinders (25 to 200 kN and up to 800 mm displacement)
- Proven shutdown strategies
- NDT to accompany tests

MATERIAL TESTING

The aim is for wind turbines to provide a maximum energy yield. Since the length of the blades is limited by their weight, the industry is focusing on the use of lighter, high-performance materials. A sound knowledge of the materials is therefore becoming more and more important for manufacturers and suppliers involved in rotor blade production.

Fraunhofer IWES has more than ten years of expertise with fiber-composites and rotor blades and offers customized material certificates in addition to standard tests. A particular focus is placed on the specific production methods of fiber-composite test specimens and the implementation and evaluation of testing methods.

These range from a rough material screening through to a complete characterization. Depending on the problem, materials such as non-woven fabrics, resins, and foams are investigated as to their suitability for rotor blades. Material samples are manufactured according to the customer specifications.

Since rotor blades in operation are subjected to enormous loads, fatigue tests play a key role here. The institute is accredited in accordance with DIN EN ISO 17025:2005 and employs the latest equipment and efficient test methods.

The servo-hydraulic testing machines are equipped with particularly stiff and precise clamping tools which have been developed especially for the testing of fiber-composite test specimens under dynamic load. All activities on the test bench are recorded with the most up-to-date camera technology. This facilitates the complete and detailed documentation of the damage progression and makes it easier to understand the formation of cracks.

The parallel simulation of climatic and mechanical loads is conducted in a climate chamber, which can be cooled to minus 40 degrees Celsius, conforms with standards (DIN/ISO), can be controlled with high precision, and is reproducible. Moreover, Fraunhofer IWES has an analytical laboratory for the investigation of fundamental physical material properties. These include the glass-transition temperature and the density of material samples, for example. The range of services offered also includes a large number of non-destructive tests. They provide accurate information on the damage progression during a mechanical test.

Equipment

- Universal testing machines for static and dynamic testing with maximum force of between 25 and 2500 kN
- Servo-hydraulic tension-compression-torsion testing machine for biaxial testing
- Climate chamber for parallel mechanical and climatic load simulation (-45°/130°/humidity/UV)
- Composite Lab
  - RTM
  - Vacuum infusion
  - Heating bench
  - Precision specimen manufacture
- Differential Scanning Calorimetry (DSC)
- Dynamic Mechanical Analysis (DMA)
- Heat Deflection Temperature (HDT)

ROTOR BLADE MANUFACTURING

Rotor blade manufacturing accounts for up to 20 percent of the total cost of a wind turbine and much of the work is still performed manually. The costs of rotor blade production can be noticeably reduced using innovative manufacturing technology and alternative materials.

The BladeMaker demonstration center covers the whole production chain of rotor blade production and links design and manufacture in a novel way: innovative materials are used, processes optimized, and new methods applied. The fundamental integrated machining concept allows significant time savings to be made in the production process and results in constantly high production quality.

In the demonstration center, blade manufacturers, suppliers of materials for rotor blade construction, and the engineering industry can conduct test runs with their own molds and materials or can use those provided (18-meter-long segment of a rotor blade with a total length of 40 m) to identify opportunities for cost savings in their production process.

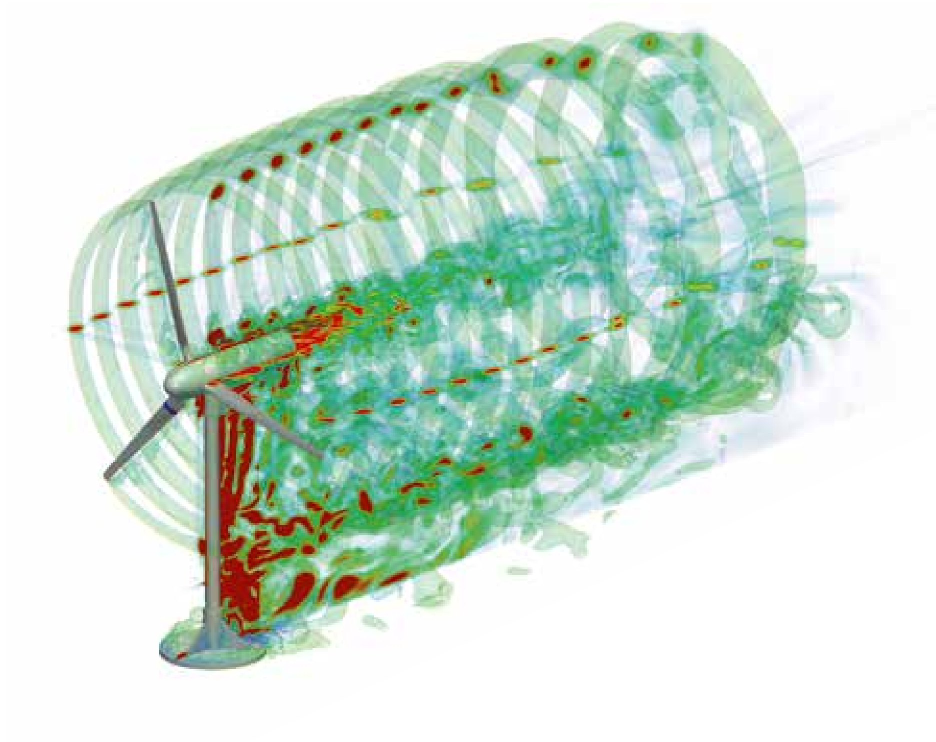
Technical process optimizations:

- Different production steps can be carried out at the same machine with the aid of a gantry system by simply changing the tool.
- A direct tooling concept is available that allowes the manufacturing of molds without a master plug by using CNC controlled processes in combinations with CAD-CAM tools.
- Innovative gripping principle for positioning fabric blanks involves taking hold of several planar layers and placing them on a substrate, where the next step of the forming takes place. The gripper system subsequently places the formed stack in the mold with spot-on precision.

Since the demonstration center went into operation in 2017, IWES´ scientists have been working on refining manufacturing technologies extensively. Emphasis is being placed on refining individual process steps and developing new processes such as 3D printing technologies for the efficient production of rotor blade details. The focus remains on the industrialization and digitization of the entire process chain.

Equipment

- CNC-controlled production cell with 2 coordinated 6-axis gantries (5 x 2 x 25 m), payload: max. 400 kg per unit
- Rotor blade molds with flatback airfoils and integrated sensors (18 m section of a 40 m blade)
- Cutting center
- Prepreg machine and tape-laying system
- Automated placement of large precuts and preforms
- Automated foam application system
- Direct-infusion equipment
- Handling jigs for blade components
- Automated adhesive application and surface finishing systems



AERODYNAMIC BLADE DESIGN

In wind energy, numerical simulations have great potential for cost savings and increases in efficiency. Fraunhofer IWES plays its part by supporting the developers of rotor blades with comprehensive know-how in aerodynamic blade design and the structural simulation of rotor blades.

The trend is towards longer and more and more elastic blades. It is consequently becoming much more important that aero-elastic effects are taken into account. The institute uses numerical flow simulations – Computational Fluid Dynamics (CFD) – in combination with Fluid Structure Interaction (FSI), to fully replicate the aerodynamics of rotor blades.

This combined process allows statements to be made about the dimensioning of rotor blades which are much more precise than those possible with conventional methods. With more precise data, calculated safety factors can be significantly reduced – this applies particularly in situations where air streams onto the blade at an oblique angle or when the blades are very flexible. IWES´ aerodynamics experts have a complete simulation chain at their disposal which is able to fully numerically replicate the situations to which turbines are exposed as standard. With cross-flow conditions or in extreme storm situations, the computation includes all the flow-structure coupling. The design tools at the institute are based on the open source CFD code "Open Foam", which can be made available to interested blade designers.

The manufacture of fiber-composites is complex, time consuming, and requires a great deal of know-how. Its many years of experience in fiber-composite simulation mean Fraunhofer IWES is able to offer competent support to the manufacturers on this issue. Its portfolio of services includes the numerical checking of structural details – also as part of validation tests – the design of test samples, performing damage calculations, and the implementation of material models. The calculations are carried out with modern numerical methods such as FEM simulations with ANSYS.

CUSTOMER BENEFITS

Longer, slimmer, and with a longer life – all at lower production and operating costs: exceedingly high demands are placed on rotor blades. As a development partner of the global wind energy industry we offer research services of the highest quality:

- Unique infrastructure: from materials testing and production through to full-scale blade testing
- Certified in accordance with DIN EN ISO 9001:2008 and testing laboratory accredited in accordance with ISO 17025
- Experience of more than 30 completed full-scale blade tests for certification
- State-of-the-art demonstration center for rotor blade manufacture
- Individual and flexible development services customized to customer demands
- Fully up to date with the latest developments thanks to our involvement in international standardization committees and bodies
- Excellent networking with German and European universities

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