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Detailed information on energy research

Rain can damage rotor blades

Test stand facilitates the simulation and analysis of the influence of weather, climate and production faults

BINE
Information Service

Rain and other weather and environmental factors can have a detrimental effect on the rotor blades of wind turbines in the long term. The leading edges of the blades are particularly susceptible to damage. Here the protective layer erodes first and material degradation subsequently continues deeper into the blade structure. A new test stand is now investigating the mechanisms involved in rain erosion in detail. The aim is to provide better protection for rotor blades in the future so that they can be used longer, thus improving the economic viability of wind turbines.

Many forces other than wind act on wind turbines. For example, raindrops, hailstones or grains of sand that impact on the rotor blades with high speeds and thus also with high energy can cause significant damage. These damage mechanisms are collectively referred to as rain erosion. To counter this, the blades are given a special protective coating and sometimes the leading edge, which is subject to particularly demanding conditions, is also fitted with a protective film. This protection is referred to as the Leading Edge Protection System (LEP). The blade then has to resist the influence of weather, climate and UV light in day-to-day service. These stresses are increasing due to the rising speeds of newly developed blades. The tips of a 60 m long blade achieve speeds of over 300 km/h during operation. At this speed, collisions with water drops are consequential in the long term. The planned investigations aim to identify the factors involved and the relative importance of the various influences at play.
This type of damage has a significant effect on the economic viability of wind turbines. Observations of the average service life of Leading Edge Protection (LEP) systems are between four and six years for onshore wind turbines and between two and four years for offshore turbines. However, these values vary

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significantly depending on the conditions at the location in question and on the quality of the coating. Offshore wind turbines in particular, have disproportionately high repair and maintenance costs. According to data from the International Energy Agency and from the "Erode" EU research project, a wind farm with a capacity of 500 MW loses 332 million euros due to reduced performance and repairs – assuming the current state-of-the-art technology and a service life of 25 years. The Fraunhofer Institute for Wind Energy and Energy System Technology (IWES) has been operating a test stand for rain erosion since 2015 with the aim of understanding the damage processes and developing recommendations for materials and coatings. In this test stand, water drops of various sizes and in various quantities can collide with test samples under realistic weather and climate conditions.

Rain erosion slows the blades and creates noise

Rain erosion has multi-factorial causes that include rain, hailstones, sand, ice accretion, temperature fluctuations, UV light, humidity and salt, which is not a linear process. After a phase of uniform removal of the protective layer on a blade, crater-like material failure – generally aided by minor production damage – can form at one location, which then quickly spreads (Fig. 1). The course of this type of damage varies considerably depending on the site location. It proceeds approximately twice as fast offshore as it does onshore.
When a rotor blade is being manufactured, the two half-shells are generally produced by hand in moulds, using fibreglass composite materials and epoxy resin. The spar caps and trailing edge of the blade are generally added as separate components, as well as the leading edge in rare cases. The two half-shells are placed on one another and glued together. Any manufacturing tolerances are levelled using filler, after which the blade is smoothed by grinding and then coated with a special paint. Some manufacturers add a tape or film to the leading edge. In wind turbine operation, rotor blades are inspected by industrial climbers approximately every two years and minor damage is repaired on site.
The aerodynamic performance capability of a rotor blade is at its highest if the wind layer sweeps over the rotor profile without air turbulence occurring. To achieve this, the blade surfaces must be as smooth as possible. Even minor damage caused by rain erosion can lead to rough surfaces and turbulence. This worsens the aerodynamics of the blade and thus also the performance, economic viability and service life of the overall wind turbine. In addition, sound emissions are increased.

Creating raindrops in all sizes

The research project on rain erosion of rotor blades focused on the design and construction of the test stand (Fig. 2). The test stand consists of a steel-reinforced concrete shell. A rain generator at the top produces water drops. Inside the stand, test samples rotate on a supporting structure with a diameter of 2.8 m. The water is collected after it has impacted on the test sample, and any material removed from the sample by erosion is filtered out. The test samples can be accelerated along a circular path at variable speeds – which can reach 600 km/h at the tip. However, it has proven to be beneficial to work with moderate tip speeds and higher amounts of rain on the test stand to recreate the types of damage that are observed in actual service.
The test stand can vary the quantity of rain between 6 and 24 l/min and the drop size between 1 and 5 mm (Fig. 3). The samples pass through a rain area of 2 m². A preliminary investigation observed the drop forms and quantities in practice and analysed and compared them with those generated in the test stand.
The weather and climate conditions in the test stand correspond to data measured at three selected locations over a period of six years: data from the island of Norderney was used to recreate the conditions at a coastline, data collected on the island of Helgoland represented the offshore area, and data measured on Wasserkuppe Mountain in the Rhön Mountains was used for inland locations in low mountain ranges. In this way, the analysts were able to simulate solar irradiation, precipitation, temperature and wind conditions for various annual cycles.
The effects of icing on rotor blades were also to be tested using the IWES test stand. This is the only test stand in the world with the ability to com-

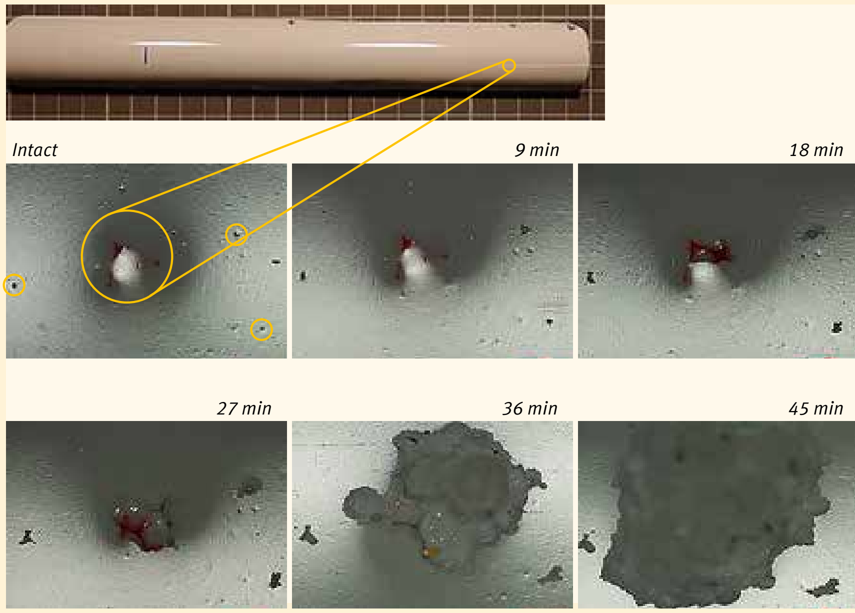


Fig. 1 Example of the course of damage as a result of a minor production fault with a trapped dust particle, scale 500 µm

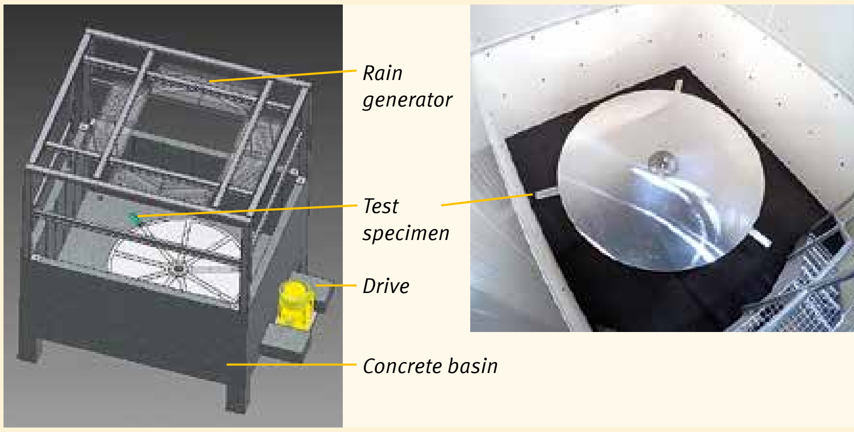


Fig. 2 Parameters such as speed, drop size, quantity of water and weather and climate conditions can be varied in a test stand for rain erosion. The test stand has a base area of 3.3 x 3.8 m and a height of 4.5 m. The test samples have a length of 25 cm and a height of 3 cm.

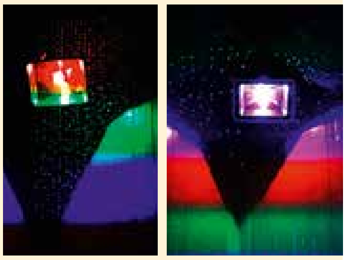
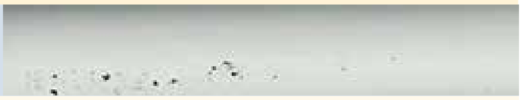


Fig. 3 *View inside the test stand: on the left the rotating disk with a sample holder that 1–2 mm sized raindrops impact upon. Top right: image with different drop sizes. Left: 1–2 mm; Right: 4–5 mm.*

Original image	
Thresholding procedure	
Original image *(Subsequent situation)*	
Tresholding procedure *(Subsequent situation)*	

$$\text{Damage} = \frac{6{,}926}{58{,}830} = 11.8\,\% \qquad D = \frac{\textit{Pixels in damaged area}}{\textit{Pixels in overall area}} \times 100$$

Fig. 4 *Damage analysis: with the original image with the blue background and the result of the thresholding procedure with the yellow background.*

bine stresses in an alternating sequence of ice-rain-ice. Presently the samples can be cooled to a minimum of –4 °C. This is not sufficient for permanent ice accretion. For this reason, the existing insulation is being boosted and a more powerful cooling system is being installed. The aim is to investigate the influence of microerosion on ice accretion.

The researchers are using high-resolution scanners with automatic image analysis and photoelectron spectroscopy to survey damage. Photoelectron spectroscopy measures chemical and electrical changes in surfaces, and the data collected allows conclusions about material to be drawn. A new process in this area performs automatic image analysis on the scanned specimens, which allows researchers to evaluate damage in a comprehensive manner (Fig. 4). The images undergo a thresholding procedure such that the ratio of black (eroded) to white (intact) areas is calculated. A percentage value for the damage can be derived from this.

Preliminary tests to calibrate the test stand were carried out as part of this project. Initial investigations of individual parameters have already delivered the following trends: Larger drops cause greater damage than smaller drops for the same quantity of water. Damage spreads more quickly the longer the samples have been exposed to UV light beforehand and the higher the speeds were. Harder materials exhibited more serious damage than soft materials on the test stand; the difference increased with increasing speed.

The mobile system for measuring layer thicknesses

An additional focus of research was the development of a mobile system for measuring layer thicknesses as a demonstration system. This system should be able to investigate the thickness of blade coatings on site in a non-destructive manner. A refined terahertz spectrometer was used, as THz radiation can penetrate non-conducting materials and radiation is reflected at the individual coating transitions. The thicknesses of these coatings can be measured in this way. This method can already identify damage in the layered structure even if this damage is not yet visible on the surface. The developers adapted the device for mobile use and developed software for data evaluation. As a result of the shape of the samples, it proved difficult to carry out mobile measurements with the same precision as for stationary measurements. At the moment, the developer, Automation Dr. Nix GmbH, is currently not pursuing mobile use of this equipment on wind turbines.

Calibrating and validating the test stand

Researchers plan to develop and validate measurement procedures and evaluation methods with the aid of experimental investigations in the coming years. The goals are:

- To predict the prospective service life of coating systems. The results from the test series will be used as input for a simulation model and, later on, for maintenance programmes for rotor blades.
- To optimise on-site material tests and repair measures on blades. In this regard, the influence of the weather – particularly of humidity and temperature – on the quality of repair measures is to be investigated and methods of non-destructive material testing are to be improved.
- To determine the shape and distribution of drops in detail. A high-speed camera and a drop impact system record each drop and show where and with what energy it impacts. The data collected will be used as input for a damage model with the aim of achieving a better understanding of the formation of damage on rotor blades.
- To increase the testing throughput using an automated inspection system with high resolution.
- To develop recommendations for more weather-resistant coating systems as a result of the investigations.

Rotor blades with elastic edges

The new test stand for rain erosion is not just being used to investigate whether leading edges with hard or soft coatings are better able to withstand rain erosion. In another research project that goes by the name of “Multifunctional hybrid solution for the protection of rotor blades (Multifunktionale Hybridlösung zum Schutz von Rotorblättern, HyRoS)”, researchers are already developing an elastic leading edge for rotor blades. The Institute for Integrated Product Development (BIK) at the University of Bremen and the material manufacturer SAERTEX are cooperating with five other partners on this project. It is planned that work on HyRoS will be completed in 2018.

The newly developed leading edge consists of a combination of a multiaxial technical fabrics with an elastomer. As part of this research project, developers are pursuing the goal of investigating suitable materials, determining the aerodynamic properties of the new component, and testing the overall combination with the other components of the blade. In addition, a controllable rotor blade heating system will be fitted to the new leading edge. This system should prevent ice accretion on the blade during critical weather conditions. Downtimes due to ice formation have a significant economic impact on turbine operators, as the best wind conditions for electricity generation occur in winter.

Material tests have been completed, and the focus is now on production processes. The steps to specify requirements are underway in cooperation with industrial partners. As part of their sub-project, researchers at the BIK are currently developing the application technology per se, i.e. the definition and the structure of the production processes with the associated system technology. It is particularly important here that it should be possible to integrate these new production processes into proven existing processes for the production of rotor blades and into future processes too. In addition, it is planned to test and validate the new production process in pre-defined realistic scenarios and in actual rotor blade production.

Project participants

- **Project management and test stand:** Fraunhofer Institute for Wind Energy and Energy System Technology (IWES), Bremerhaven, Benjamin Buchholz, Benjamin.Buchholz@iwes.fraunhofer.de | www.iwes.fraunhofer.de
- **Mobile system for measuring layer thicknesses:** Automation Dr. Nix GmbH & Co KG, Cologne | www.q-nix.com/en

Links (in German)

- HyRoS research project | www.hyros-projekt.de

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