Investigation of the impact of rain and particle erosion on rotor blade aerodynamics with an erosion test facility to enhancing the rotor blade performance and durability

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Abstract. During their operational life span of around 20 years, the individual components of a wind turbine, especially the rotor blades, are exposed to extreme environmental influences. This is the result of the continuous exposure of wind turbines to the elements and of particularly high rotor blade tip speeds, which exceed a velocity of 90 m/s. These effects result in leading edge erosion. Rotor blades are therefore protected by special coating systems, e.g. varnishes and foils. The durability of those surface coatings varies depending on the location of the wind turbine and often proves to be insufficient. Additionally, there is no standardised test procedure for the evaluation of the durability and protective effect of the coating materials under the highly erosive conditions at the location of the wind turbines. In the course of this project, we will develop a testing procedure to evaluate the erosion of coating materials on actual leading edges of rotor blades, which will be applied in a test facility. The test rig will be capable of simulating a realistic application of rain and sand to gauge the effects of erosion. During the application, two test objects can be tested simultaneously. The geometry of the test objects will be adapted to represent that of real rotor blade tips. In order to generate comparable and transferable results, several challenges have to be met during the implementation, especially the realistic reproduction of environmental influences and the corrosion damage mechanism. In this regard, the duration of the test procedure is very important because a time lapse factor of 100-260 is intended. An operation of 20 years can thereby be simulated within 4 to 10 weeks.

1. Introduction

Today, manufacturers are expected to develop wind turbines with a lifespan of 20 to 25 years that reliably convert energy whilst requiring the least possible maintenance [1]. To reach this goal, all options to reduce maintenance costs and maximise the energy yield have to be considered. In this context, the rotor blades play a particular role since they represent one of the most important components with regards to energy conversion, and they are exposed to high loads, which results in high maintenance costs. The aerodynamic performance highly depends on the exact shape of the airfoil. The surface of the rotor blade is exposed to operational stress caused by particles and water drops, which leads to erosion. The small lesions induced on the surface of the rotor blade have an impact on the overall performance and therefore the energy yield of a wind turbine. This explains the manufacturer's need to use coatings which are highly resistant to erosion. Hence, it became necessary to develop a test procedure and facility to study the application of water drops and particles on rotor blades.

That erosion has serious impacts on the rotor performance has been shown previously in a study at the University of Illinois [2] where the DU 96-W-180 airfoil was tested in combination with a polyurethane wind protection tape. During the experiments, an increase in drag coefficient by 80-200% was observed. Additionally, a decrease in lift coefficient for higher angles of attack was ascertained. The results also implied a significant loss in annual energy yield by 7% for an increased drag coefficient of 80%, which underlines the necessity of an independent, comparable and repeatable erosion test.

To prevent or slow down the effects of erosion, either foil or edge protection coatings can be applied. In this area, 3M and tesa SE offer solutions. There are currently no standardised test procedures for erosion protection coatings or foils for wind turbines. Existing tests for those coatings and foils are based on examinations carried out by other industries. ASTM D4060, DIN 53754, DIN 53154, DIN EN ISO 2409, DIN 4624 and DIN EN ISO 1519 are some of the test procedures used to evaluate the protective effect on the life span.

This shows the need for the reproduction of realistic conditions within a test chamber to examine the process of erosion. The goal of our research is the development and implementation of an erosion test, capable of simulating damage due to water and particles on protected and unprotected leading edges of rotor blades. To achieve this goal, collaboration between Key Wind Energy GmbH, Seilpartner Windkraft GmbH, and the specialist field Fluid System Dynamic (incumbent of the chair, Prof. Dr.-Ing. Paul Uwe Thamsen) of Technische Universität Berlin was set up.

2. Erosion-induced Damage on Rotor Blades

Wind Turbines face many different environmental influences during their operation. Maintenance and repair therefore play an important role throughout their operational life. Erosion represents one of the most significant environmental impacts on rotor blades, and yet it has not been possible to precisely quantify this aspect until now. In the case of erosion, it is necessary to distinguish between water drop and particle erosion. The permanent exposure to environmental conditions, such as water drops and particles, causes damage to the surface layer of the rotor blade material and thus leads to erosion. This mechanism is favoured by air locks in the coating material or in the base material due to the manufacturing process of the rotor blade itself. In this case, the impact of particles or water drops can lead to premature surface damage.

The damage mechanism due to droplet impingement is based on enduring loads from individual impacts. The stress duration of an individual impact amounts to just a few milliseconds [3]. According to [4], the surface damage is induced by high pressure and the formation of a lateral jet that occurs at the burst of a droplet. Additionally, it is described in [4] that pre-stressed material is even more vulnerable so that existing cracks are widened and the material is easily eroded. The occurrence of jets leads to sheer stress on the surface material. Stresses caused by lateral jets are particularly high in existing minor cracks or grooves. Another important aspect in the damage mechanism is the angle of incidence, which is described in [5].

Particle erosion as a form of jet abrasion depends on fracture processes [6]. The four basic mechanisms that lead to particle erosion are abrasion, surface fatigue, plastic deformation and brittle fracture [7]. The extend of the damage caused by particle erosion is even more dependent on the angle of incidence and the specific material used as coating. This is accounted for by the overlay of frictional stress and impact stress. The potential damage caused by the process of erosion is illustrated in Fig. 1 and 2.

Figure 1. Typical damage caused by erosion on a rotor blade.

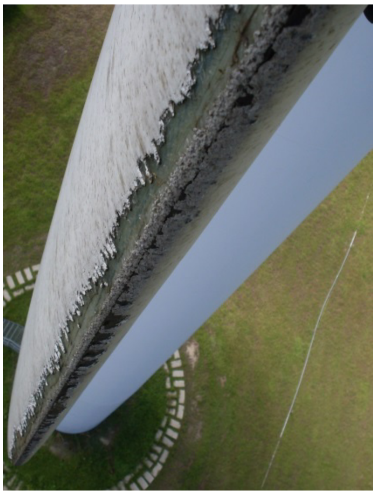

Figure 2. Leading edge erosion of a rotor blade.

3. Modelling of Realistic Erosion Test Conditions

For the investigation of the erosion process, we will focus on leading edge erosion. Creating realistic test conditions requires several considerations. Tests have to be repeatable and comparable in absolute terms, and in relative terms between the samples.

It is therefore reasonable to use test specimens with the actual geometry of rotor blade edges. Due to high rotational speeds and the exposure to environmental influences, only the leading edge of the rotor blades is examined. For comparative testing purposes, coated specimens as well as unprotected specimens can be tested.

To understand and reproduce the damage inflicted on the surface of a rotor blade, it is necessary to simulate the damage severity at the term of a 20-year operational period. It is economically necessary to introduce a time lapse effect. We strive to achieve a time lapse factor of 260 to attain a maximum test duration of four weeks. Unlike other performed tests or planned test chambers, provisions are made to alternate between water drop and particle erosion conditions. During the water drop erosion phase, we will allow for a volume flow of up to 150dm³/h, which corresponds to constant rainy weather conditions over the whole operational period of the wind turbine. For the particle erosion phase, we are planning to achieve a mass flow of about 5kg/h. Two specimen can be tested simultaneously as they can both be mounted on the same rotating carrier. A motor with a rated power of 12.8kW moves the shaft to provide the drive for the intended rotational speeds. For safety reasons, the test chamber is located within a 40 foot high cube.

The test conditions will be validated during the research period of two years.

We are working towards realising tip speeds of more than 120 m/s. In Fig. 3 and 4 we show the design drafts of the erosion test facility.

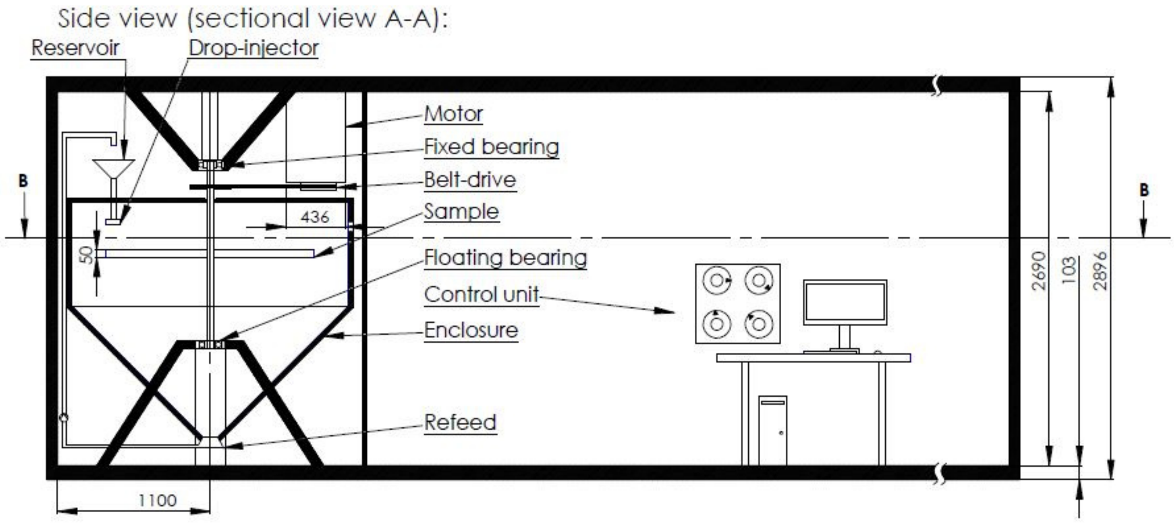

Figure 3. Side view of the erosion test facility.

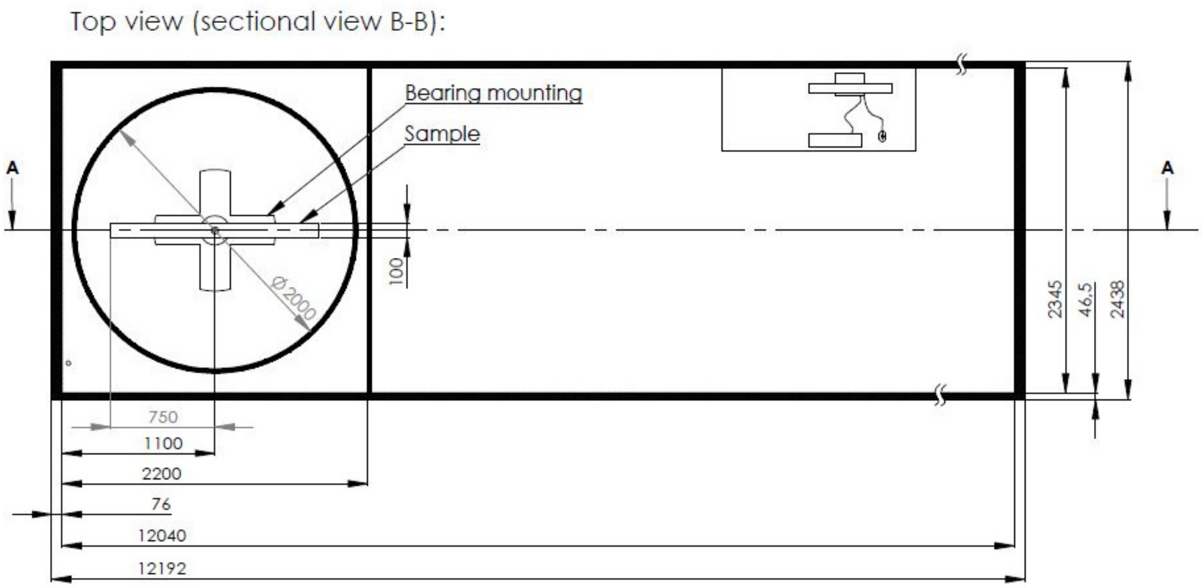

Figure 4. Top view of the erosion test facility.

4. Conclusion

As shown above, the examination of the water drop and particle erosion damage process concerns a variety of industry branches, including rotor blade, wind turbine and varnish manufacturers, as well as wind turbine operators and service companies. Our research will have significant impact on the further development of rotor blade coatings and therefore energy yield stability during the operational period of wind turbines. Moreover, the upcoming tests will serve as a basis for consistent testing to provide comparable findings for customers and manufacturers.

The realisation of this project, including the construction of the test chamber and the running of several tests, is intended to be finished by August 2015. It combines the knowledge network of Key Wind Energy GmbH with the research capacity of Technische Universität Berlin and the practical experiences of Seilpartner Windkraft GmbH.

Acknowledgments

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