DEVELOPMENT OF A RAIN AND PARTICLE EROSION TEST SCENARIO TO ENHANCING THE ROTOR BLADE PERFORMANCE AND DURABILITY

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Summary

Leading edge erosion of wind turbine rotor blades is a known issue during the operation of wind farms under different site conditions. The effectvaries due to certain key parameterse.g. climate conditions as well as distribution and impact frequency of particle and water droplets. The damage propagation of leading edge erosion is a statistical process driven by complex physical and material aspects. It is therefore important to develop an independent and mainly accepted testing procedure to investigate different erosion damage scenarios. The paper describes the development of a mobile test facility (MET), which is open to awide range of realistic erosion scenarios. During the tests two specimens with realistic leading edge geometry and dimension will be tested simultaneously. The intended time-laps factor is up to 9000, with the result that one year of operation corresponds to less than one hour of testing. The test conditions are based on actual weather conditions on wind turbines sites and researches concerning the particle density and size as well as droplet distributions and rainfall intensity. First results will be compared to free field leading edges of rotor blades in future studies, to improve the test scenarios.

1. Introduction

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. These effects result in leading edge erosion due to water droplet and particle impact. Observations from free field show, that the most affected areas are the rotor tip’s leading edges. This is the result of the blade’s orientation and the fact that the circumferential speed reaches the maximum valueof around 80 m/s (Fig. 1).

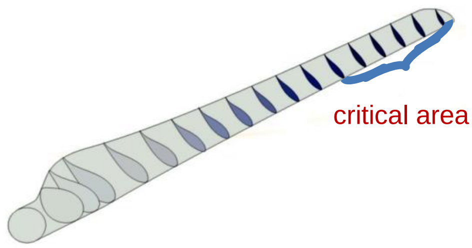

Fig. 1 Erosion effected area at blade tip

Erosion has significant effect on the rotor performance which has been shown previously by Sareen et al. [1] where an increase in drag coefficient by 80% - 200% was observed. Additionally, a decrease in lift coefficient for higher angles of attack (AOA) was ascertained. The results implied a significant loss in AEP by 7% for eroded rotor blades.
Erosion damages not only alter the aerodynamic properties of rotor blades, but they also reduce the durability due to damage propagation. In combination with

poor inspection or insufficient service the risk of further damages increases and thereby maintenance costs rise.

2.Erosion damage mechanisms

The main damage mechanism of erosion following the theory of Preece and Macmillan [2] is described as an erosion rate W and is driven by the following parameters:

Diameter	***d***
Relative impact velocity	***v***
Angle of incidence	***α***

Particle diameter and relative impact velocity are weighted by empirical gained material parameters x and y, see formula (1). The material parameters vary in a range of 0.9 to 3.0 for parameter x and 2.0 to 6.5 for parameter y.
These values influence the erosion rate in a significant way which leads to the insight that there have to be a variety of test scenarios to reproduce the whole spectrum of erosion damages on rotor blades. As a consequence, the test facility needs to be very customizable to cover all relevant scenarios.

$$W \approx d^x \cdot v^y \cdot f(\alpha) \quad (1)$$

Furthermore the erosion rate W is influenced by f(α), which is a function of material properties of the impacted surface, e.g. the rotor blade’s painting and sub-layers.
For low incident angles α, small particles furrow the material. For *higher* α, small particles cause material fatigue (Fig. 2)

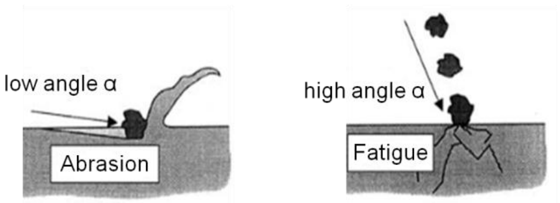

Fig. 2 Different damage effects for small (left) and high angles of incident (right) [3]

The relative erosion rate as a function of the angle of incident is shown in Fig. 3, where different shapes represent different material properties like ductile, semi-ductile or brittle material.
Since bigger diameters of droplets and particles increase the erosion rate, only particles bigger than 10µm are considered during the tests. Thus fine dust will not be tested in the test scenarios.

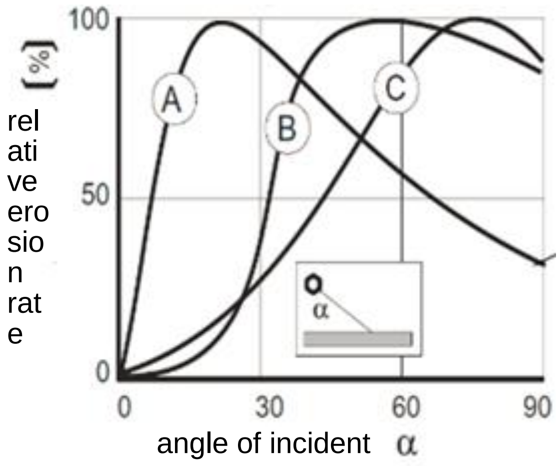

Fig. 3 Erosion rate influenced by type material (A ductile, B semi ductile, C brittle) versus angle of incident α [4]

Droplet as well as particle erosion show specific propagation patterns. When droplets hit the surface material, an impulse is induced. Additionally a strong shear strain along the plane of the surface occurs. The process of an impinging droplet also shows jets (J), which move significantly faster than the impinging droplets [5]. Also cavitation (R, F) inside the droplets may occur due to pressure waves, see Fig.4. It is assumed, that specimen with a pre-existing damage e.g. due to particle erosion with low angle of incident, are considerably more sensible to the damage propagation due to rain or droplet erosion. Hence the design of the mobile erosion test facility provides the application of particle and droplet erosion.

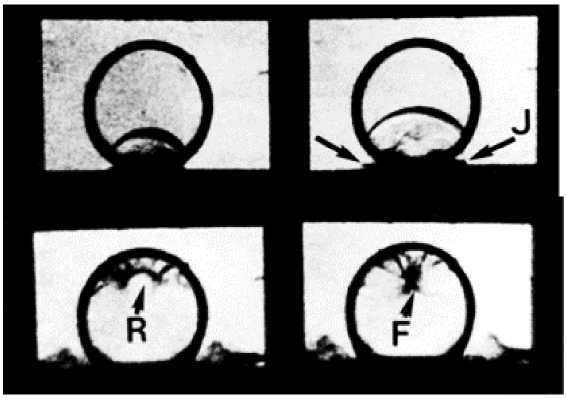

Fig. 4Characteristic progression of droplet erosion with jets and pressure waves [5]

The velocity of falling droplets depends on their size but is usually lower than 10 m/s. Furthermore there is a correlation between droplet size and rain rate. For higher rain rate the number of large raindrops increases (see Fig. 5). The relative impact velocity depends on wind speed and is often higher than the velocity of free falling droplets. Fig. 5 shows typical distributions of raindrop diameters for different rain intensities.

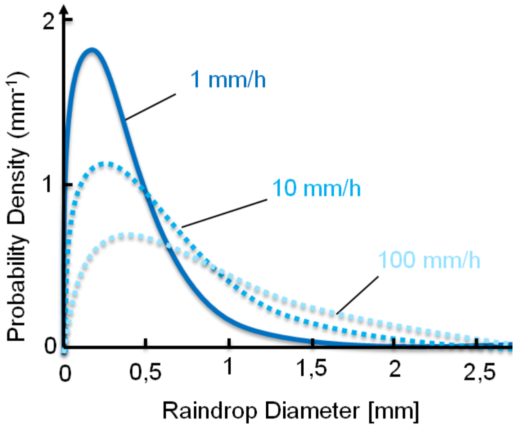

Fig. 5Distribution of probability density and rain drop diameter for different rain intensities [6].

3. Modeling Test Scenarios for Rotor Blades

The test scenarios are based on real weather conditions of wind turbine sites and include rain droplet as well as particle application. Concerning droplet erosion it has to be considered, that the rotor blade is exposed to a higher amount of rainfall than the projected area on the ground due to the rotational speed.

There are more influences to the erosion process like site conditions (hail, moisture, sun radiation, temperature gradients, salt and other aggressive substances), material as well as mechanical support structure and the dynamics (bending, strain) of the rotor blade itself. For rotor blades the high tip speed of approximately 80m/s is the most critical aspect.

To receivethe most realistic results from the erosion tests, it is necessary to keep shape and material conditions preferably unchanged from the free field conditions. In Fig. 6 an example of the test specimen with realistic geometry of the leading edge is shown. Since the leading edge is oriented vertical like the axis of rotation the full length of the specimen represents one blade element at a certain radius.

It is essential to do erosion tests faster than in real time, to receive results in reasonable time. It is therefore intended to use a time-lapse factor as high as possible without changing the damage mechanisms. A time-lapse factor of approximately 10,000 is strived for. Thereby it would be possible to simulate the specimens' lifespan within a few hours.

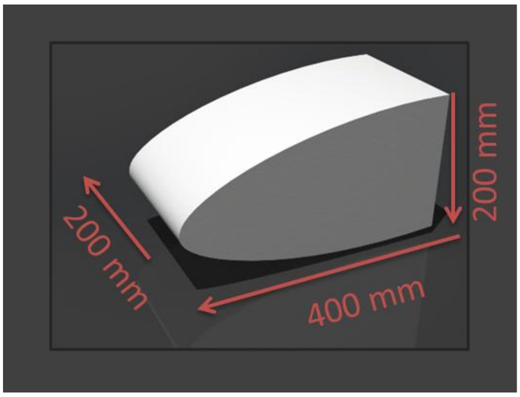

Fig. 6 Shape and dimensions of the erosion test specimen

4. Test chamber and testing conditions

A mobile erosion test facility (MET) with a rotating arm that can carry two specimens at once (Fig. 7)will be used for the tests. Furthermore it will be equipped with a

recirculation for water and particles to increase the ecological efficiency.
The upcoming tests will serve as a basis for consistent testing to provide comparable findings for customers and manufacturers.

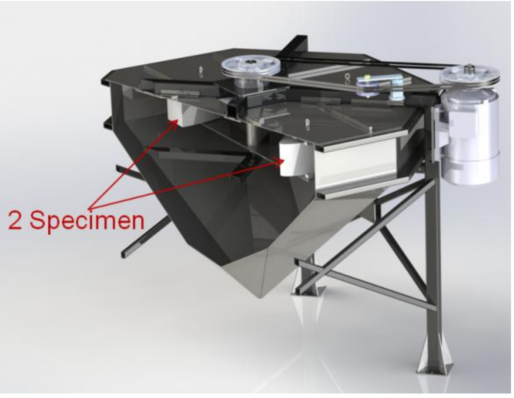

Fig. 7 Mobile erosion test facility, sectional view with two specimens

The MET is required to beindependent from manufactures interests and aims for reasonable test scenarios, repeatable, universal test results and realistic test conditions. The MET is motor-operated (11 kW / 20 kW) and uses a vertical rotating axis. The rotational speed will be adjustable from zero to approximately 1400 cycles per minute which corresponds to a circumferential speed of 100 m/s. Moreover the MET is able to test the specimen under rain and particle erosion conditions. Droplet sizes form 0-3 mm and particle sizes above 10µm will be supported.
The MET is covered by a common 20”-container, which is part of the safety concept of the MET. Around 40% of the space is needed for the test rig, other space is free for supporting devices and the work station for preparatory work.

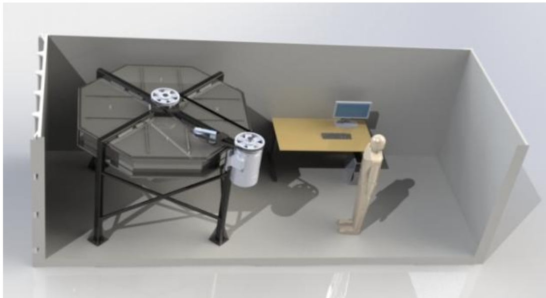

Fig. 8 MET lab container with work station

5. Conclusion & Outlook

The theoretical approach of understanding erosion at rotor blades is done. The different test scenarios for different sites are defined. Testing campaigns are set up and will start when the construction of the MET is finished.
With upcoming comparison between field experience and test results it is possible to improve damage propagation methods. Test scenarios will be adjusted and enhanced.

6. Final Remarks

This work is a cooperation of Key Wind Energy GmbH, Seilpartner Windkraft GmbH and Chair Fluid Dynamics (FSD) of TU Berlin supported by the German Federal Ministry of Economics and Technology, grant no.: KF3167502DF3

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