Modelling approach of failures to improve structural health monitoring systems

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Abstract

Failures of the outer structure like the tower or rotor blades are not the most frequent cause for downtimes of wind turbines [5]. However, cracks in the rotor blades, attaching ice or damaged flange connections of the tower represent a high security risk and might lead to catastrophic failures. Structural health monitoring systems (SHM) are used to detected damages on the outer structure and securely shut down the turbine in case of damage identification. Additionally, an early detection can reduce the resulting downtimes. For SHM well known technics like acoustic emission, modal analyses, ultrasonic emission [1] are used as well as new approaches like passive radar [4] or lidar systems [3]. New sensors and analysis algorithm must be validated and their capability to detect certain damage types must be determined. The validation in the field is difficult, due to the low probability of occurrence of structural damages and the resulting high security risk of triggering the damages manually. Therefor, an approach based on simulation models is presented to quantify the change of the system behavior in case of a damage. Here models of failed screws at flange connection of the tower, attached ice on the tip of the blades and fatigue damage of one side of the spar cabs of the blade are investigated. The damage models can be scaled in their extent.

Methods

In a first step a detailed finite element method (FEM) and flexible multibody simulation (MBS) model of a 3.3 MW reference turbine is set up. The blades have a length of 54.7 meter and the material distribution of the composite layers are based on the NREL 61.5 meter reference blade [2]. The tower is fully flexible and based on detailed geometries parameters of the reference turbine tower. The drive train is represented by a two mass oscillator. Finally, the change of the natural frequencies of the system will be determined depending on the damage mode and its extent of damage.

Figure 1: Flexible MKS Modell

Damage mode: failed screws

Figure 2 shows the detailed modelled flange connection of the first two segments of the tower. The segments are connected with 100 preloaded flexible screws and contact interactions at the surfaces. The screws can be removed individually. The tower head mass is represented as a point mass and the soil stiffness is reduced by a rotational spring.

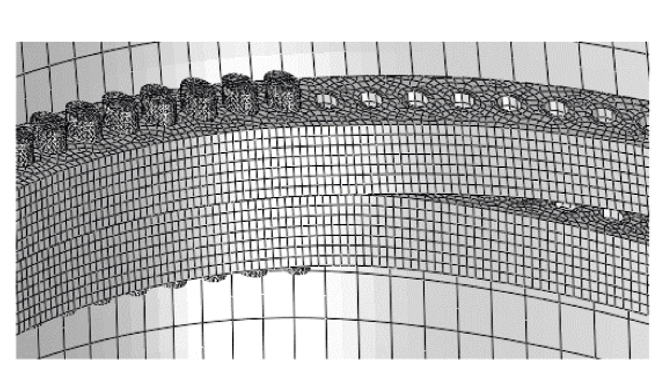

Figure 2: Modelled flange connection with removed screws

Damage mode: attached ice on the blade tips

Figure 3 shows the FE Modell of the rotor blade. The red area represent the position of the attached ice. The ice is modelled as an additional material layer, located irregular on the leading edge. That permits the stiffness and mass of the ice to be taken into account. The thickness and consequently the ice mass can be varied.

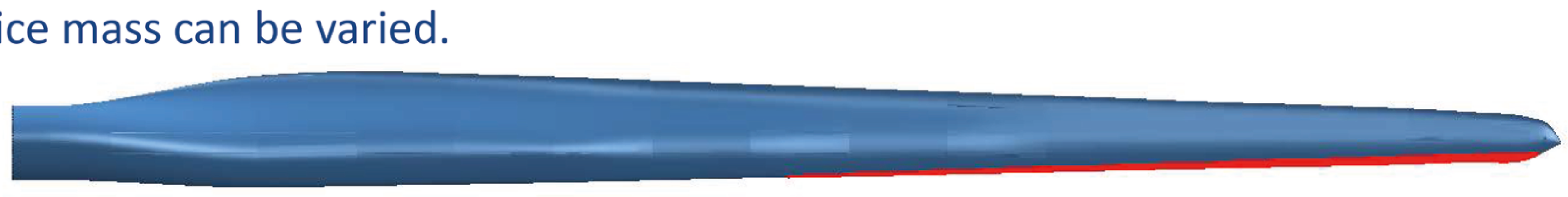

Figure 3: attached ice on the rotor blade

Damage mode: crack in the spar cabs of the blade

The spar cabs of the rotor blade is marked in red in figure 4. The green dot represent the position of the modeled crack. The progress of the crack is perpendicular to the fiber direction, and can be varied in length. The crack is modelled as a massive local stiffness reduction of the soar cabs material.

Figure 4: Position of the spar cabs and the applied crack

Results

The natural frequencies of the whole turbine model are validated using strain gauges in the blade root and accelerometers in the tower. An accuracy of the simulation model of 2% deviation could be reached.

Damage mode: failed screws

Loose or fractured screws, resulting in a reduced stiffness of the flange connection. To analyzed its influence on the natural frequency adjacent screws were removed step by step. Figure 3 displays the reduction of the first natural tower frequency in relation to the amount of failed screws.

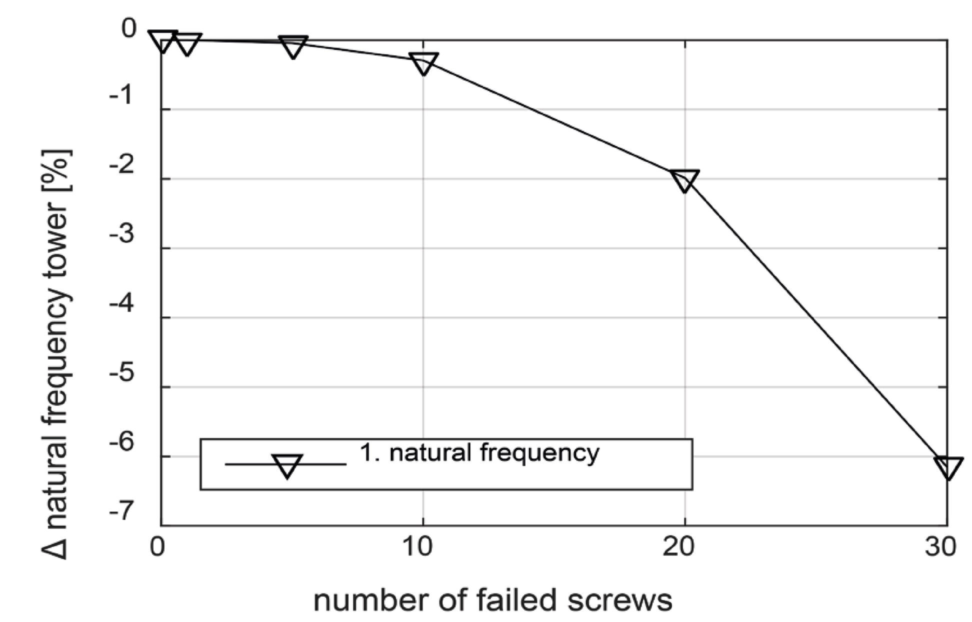

Figure 5: Simulated change of the natural frequency depending on the amount of failed screws

Damage mode: attached ice on the blade tips

Attached ice changes the mass distribution of the blade and therefore the natural frequency of the blade. Figure 2 shows the reduction of the edge- and flap wise first natural frequency of the blade depending on the mass of the ice. Both bending modes are infected equally.

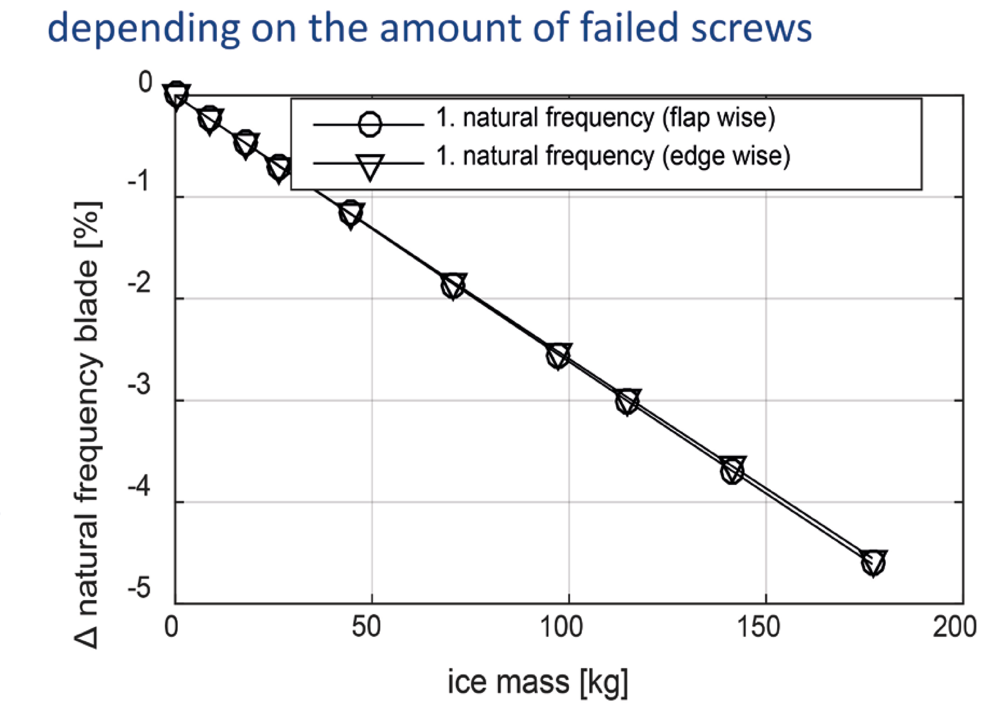

Figure 6: Simulated change of the natural frequency of the blade depending on the ice mass

Damage mode: crack in the spar cabs

Figure 3 shows the reduction of the first edge- and flap-wise natural frequency with respect to the relative crack length (crack length/ belt wide). It can be observed that the influence on the flap-wise mode is higher due to the fact that the stiffness of the spar cabs is higher in flap-wise direction.

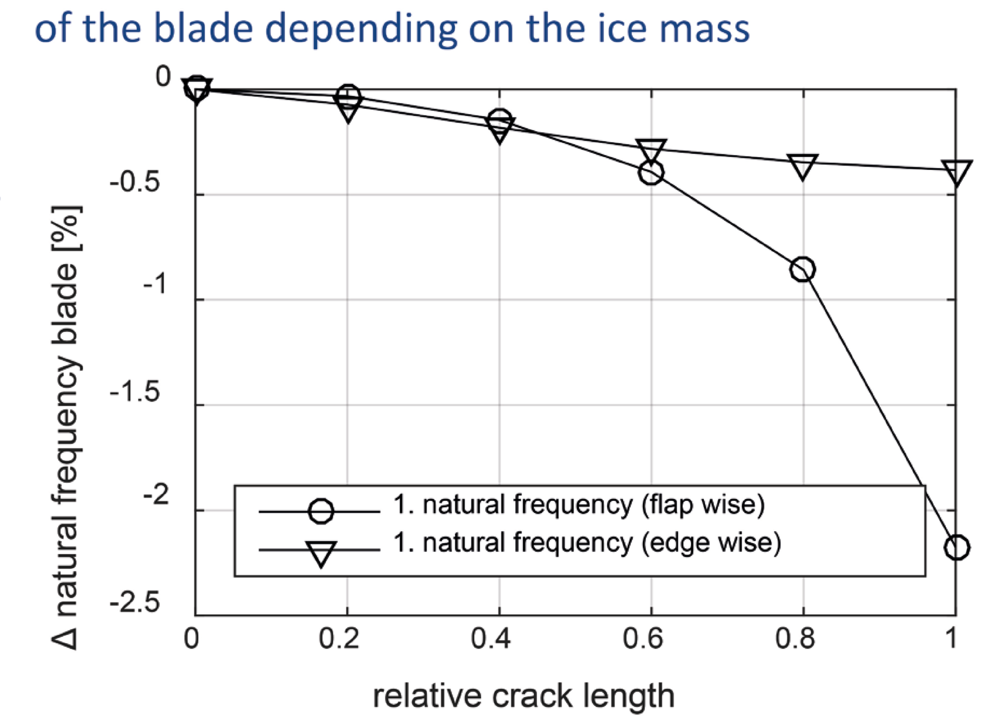

Figure 7: Simulated change of the natural frequency of the blade depending on the relative crack length

Conclusions

Validated simulation models can be used to quantify the effect of different failure modes on the system behavior. A variety of different damage parameters like crack position, crack size or affected component can be considered. This information can be used to evaluate the suitability of a SHM system or help to optimize the sensor positioning or analysis algorithm of the measured data. In this abstract modelling approaches for lose screws in the flange connection, cracks in the rotor blade and attached are presented as well as the percentage changes of the lower natural frequencies of the turbine in case of damage are shown.

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