The Operation and Maintenance Planning Based on Reliability Analysis of Fatigue Fracture of a Wind Turbine Drivetrain Components

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Abstract

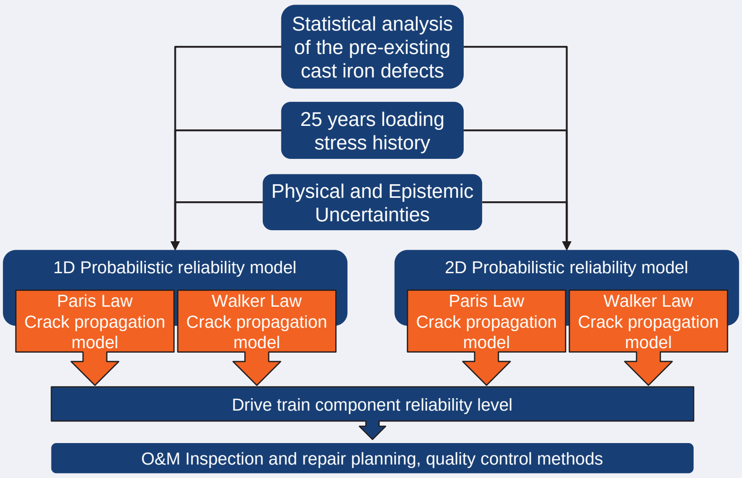
Offshore wind turbines located in deep waters are exposed to harsh environmental conditions including extreme winds, temperatures, waves and lightning storms. These severe conditions significantly increases the cost of offshore wind project installation, operation and maintenance (O&M) and reduces the reliability of the wind turbines. Therefore, the levelized cost of energy (LCOE) produced by offshore wind turbines is relatively high. The increased energy costs are due to the fact that the offshore O&M is quite expensive and contributes up to 30% of the COE.

The cost of offshore O&M is caused by the dependency on the weather condition, vessel availability in addition to the energy loses due to the down time of the turbine. Eventual failures in the wind turbine drivetrain module result in around 25% of the total down time, hence resulting in significant lost revenue.

The following research addresses the influence of the pre-existing defects on the reliability of the wind turbine drive train and the utilization of developed methods for O&M planning and quality control. The wind turbine main shaft is regarded as a main component of interest. Crack propagation models are developed with the assumption that the pre-existing defects are located in the main shaft and consequently subjected to lifetime loading history of the component.

Probabilistic models, based on Paris and Walker crack propagation laws, are developed and applied to estimate the probability of failure. The reliability analysis was conducted by the use of first order reliability method (FORM). The results gained form the probabilistic reliability analysis, provide a basis for O&M inspections and repair planning methods with additional potential for new quality control methods for casted iron components.

Graphical representation of the model



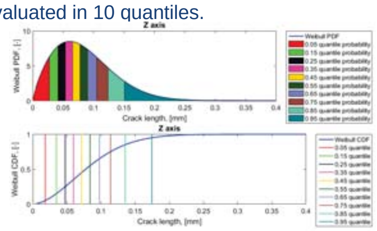
Objectives

- Present a general framework for the probabilistic reliability models.
- Present the results gained.
- Discuss model utilization for O&M and quality control.

Methods

- **Statistical analysis of the pre-existing cast iron defects**

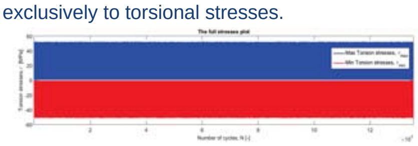
The statistical analysis was performed on the defects gained by scanning the sand casted specimens of cast iron. An Weibull distribution was fitted to the defects data, which was evaluated in 10 quantiles.



The values gained were used as deterministic values in combination with stochastic a_0/c_0 ratio of initial crack sizes for the probabilistic reliability models.

- **25 years loading stress history**

The internal reaction moments gained from the HAWC2 in combination with the wind speed distribution, was utilized as the basis to create the 25 years loading stress history of the main shaft. In this research the main shaft is subjected exclusively to torsional stresses.



Probabilistic reliability models and results

- **Crack propagation models**

Two crack propagation models were utilized for the probabilistic reliability models, namely Paris and Walker laws. $\frac{da}{dN} = C(\Delta K)^m$; $\frac{da}{dN} = \frac{C(\Delta K)^m}{(1-R)^{m(1-\lambda)}}$;

- **1D Probabilistic reliability model**

The one dimensional reliability model is formulated around the stress intensity factor ΔK exceeding the fracture toughness value K_{IC}. The model limit state equation:

$$g(t) = K_{IC} - X_{dyn}X_{exp}X_{aero}X_{str}X_{sif}K_I(t)$$

- **2D Probabilistic reliability model**

The two dimensional reliability model is based on the ultimate limit state, investigating the reduced cross-section ability to resist the loading stresses. The model limit state equation:

$$g(t) = \sigma_y X_R A_{reduced}(t) - X_{dyn}X_{exp}X_{aero}X_{str}X_{sif}\tau A(t)$$

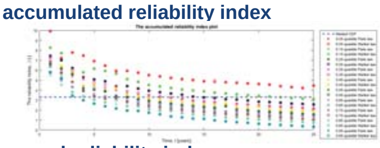
- **Total reliability index**

The reliability index in a critical volume part V_C is approximately by:

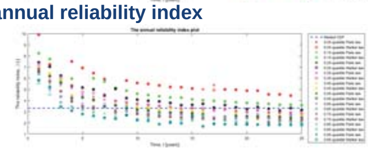
$$P_F(t) = \sum_i P(g(t)|c_0 = x_i)P_{Existence}P_{oriantation}$$

$$\beta = -\Phi^{-1}(P_F(t))$$

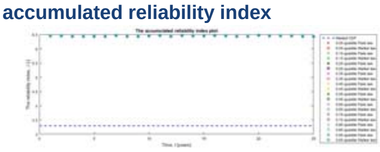
- **1D accumulated reliability index**



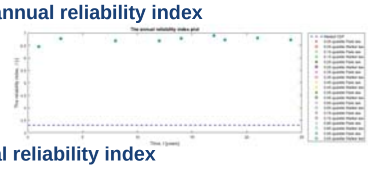
- **1D annual reliability index**



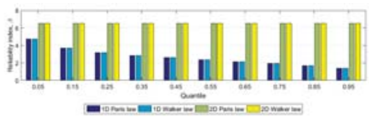
- **2D accumulated reliability index**



- **2D annual reliability index**



- **Total reliability index**



Acknowledgments

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Conclusions and future work

Based on the results gained via the one dimensional probabilistic reliability simulation, it can be observed that 60% of the simulated models fall under the design reliability index value of 3.3 after 10 years. Hence, the O&M inspections should be planned around this time. Additionally, the total reliability indexes reveal that seven largest of quantiles analyzed fails the design requirement β=3.3 over the 25 year lifetime. It can be noticed from the two dimensional model that the crack growth does not reduce the reliability of the main shaft significantly throughout the lifetime of the component. Future work will include expanding the reliability models to incorporate the Failure Assessment Diagram model. In addition, expanding the probabilistic models to contain stochastic variables regarded to material properties of the considered casted component.