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Analysis of Pitch Gear Deterioration using Indicators

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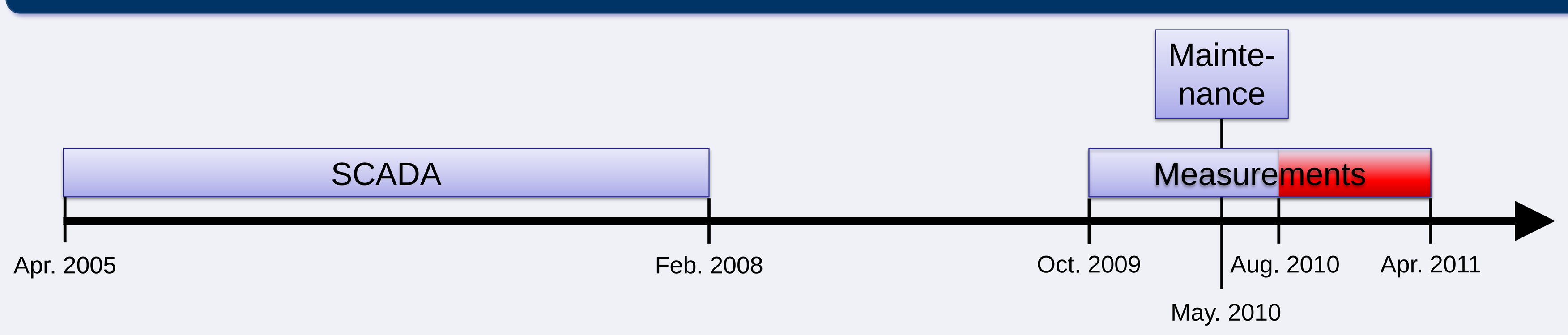
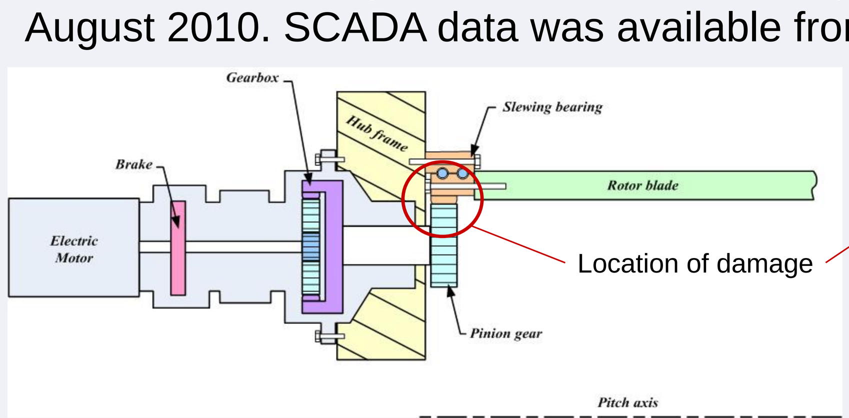
Abstract

This work concerns a case study in the context of risk-based operation and maintenance of offshore wind turbines. For turbines with electrical pitch systems, deterioration can generally be observed at the pitch gear teeth; especially at the point the blades are located during normal production. This deterioration is expected to cause larger loads, because increased play causes dynamic loads. At some point, the increased loads can be expected to cause a failure somewhere in the pitch system. If the loads increase with the size of the damage, the loads can be used as indicators of the size of the damage. This hypothesis was supported by results from a measurement campaign where measurements were available both before and after maintenance was performed. The loads dramatically decreased after the maintenance. However, after a few more months of measurements, and by including data from the SCADA system, it became obvious that seasonal changes in the temperature were the primary cause of the decrease. A model was established to remove the effect of the explained variation, and see if deterioration can be detected in the peak torque.

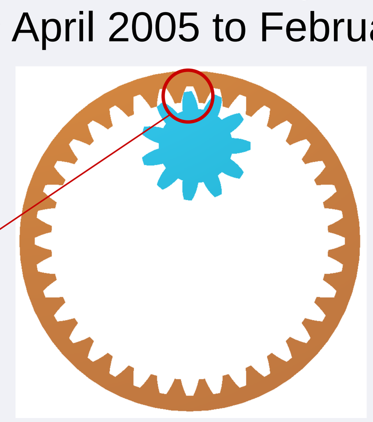
Data



The data used for this analysis comes from a commercially available multi-megawatt wind turbine on which ECN has performed measurements. For this turbine, deterioration of the pitch gear was observed, and preventive repair was performed in May 2010. Measurements were available from the period October 2009 to April 2011, but the system was not maintained after August 2010. SCADA data was available from April 2005 to February 2008.



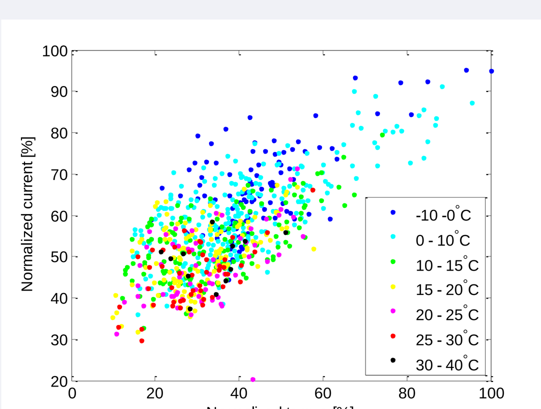
Overview of pitch system, including side view of pitch gear. [1,2]



Pitch gear, front view (sketch).

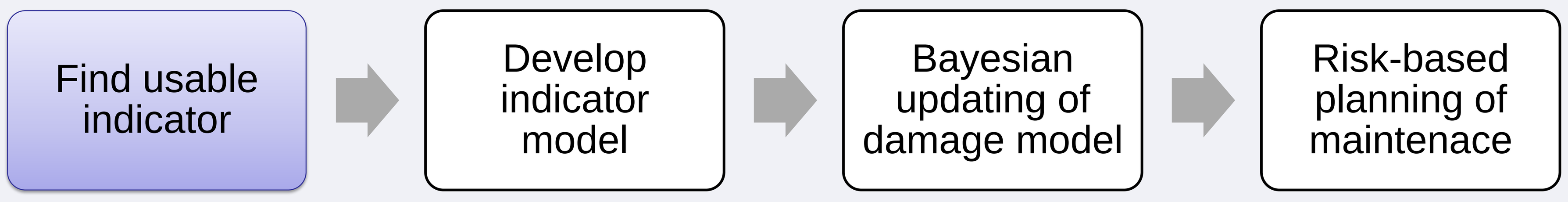
Picture of the damage in the internal gear.

The idea is to use the peak pitch motor torque, when the turbine went from running to idling, as damage indicator. This peak torque is approximately proportional to the peak pitch motor current, which is part of the SCADA data. Therefore, the peak pitch motor current, when going from running to idling is used in the following.



Model

This model is developed to investigate if the pitch motor current is a usable indicator of damage. This is a first step to create a model for risk-based maintenance planning:



For a perfect linear indicator, the indicator is a linear function of the size of the damage D:

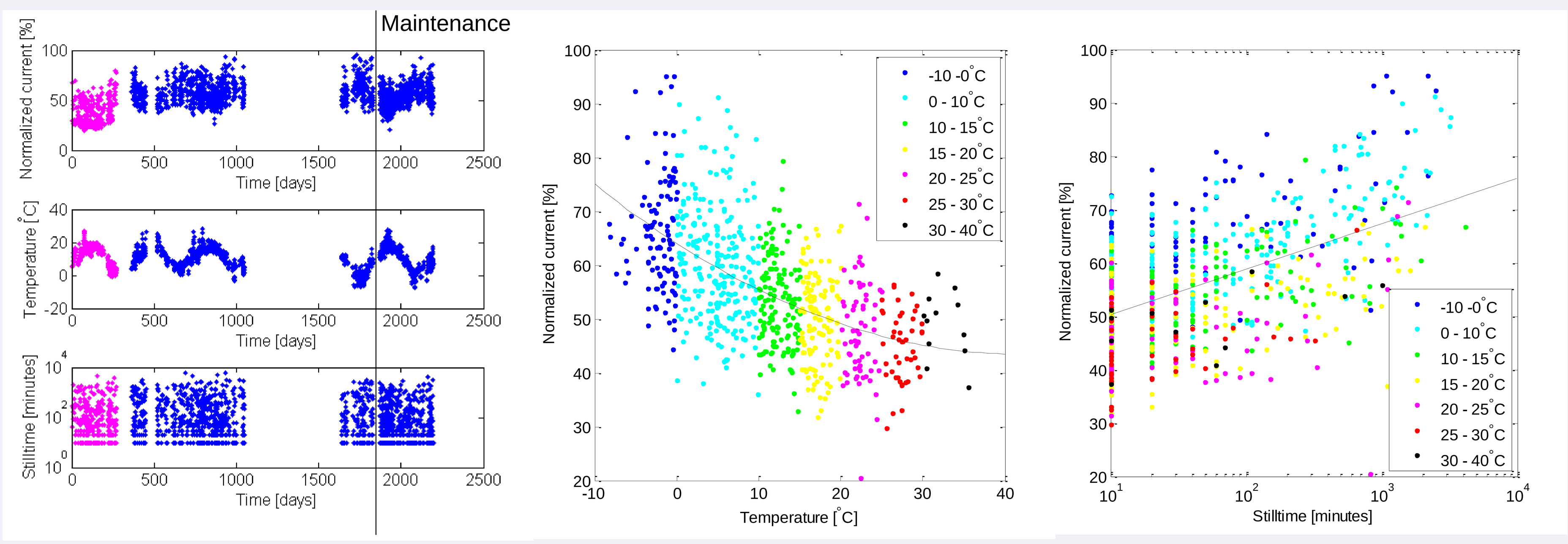
current(i) = $k_1 + k_2 \cdot D(i)$ (1)

For a linear damage model, where the load causing the damage is evenly distributed with time, the following damage model can be assumed:

$D(i) = k_3 + k_4 \cdot \text{time}(i)$ (2)

Therefore, if the current is a valid indicator, and the damage is increasing linearly with time, i.e. c_1 is different from 0 in the following model which combines (1) and (2):

current(i) = $c_0 + c_1 \cdot \text{time}(i)$, where $c_0=k_1+k_2 \cdot k_3$ and $c_1=k_2 \cdot k_4$ (3)



Data analysis showed that the peak current was dependent on the outside temperature (temp) and the duration since last time the turbine was pitching (still time). Therefore, the data should be corrected for the variation explained by the temperature and still time, and then, if the peak current is a valid indicator for the damage, it should be possible to see an increase of the current with time and an instantaneous decrease after maintenance.

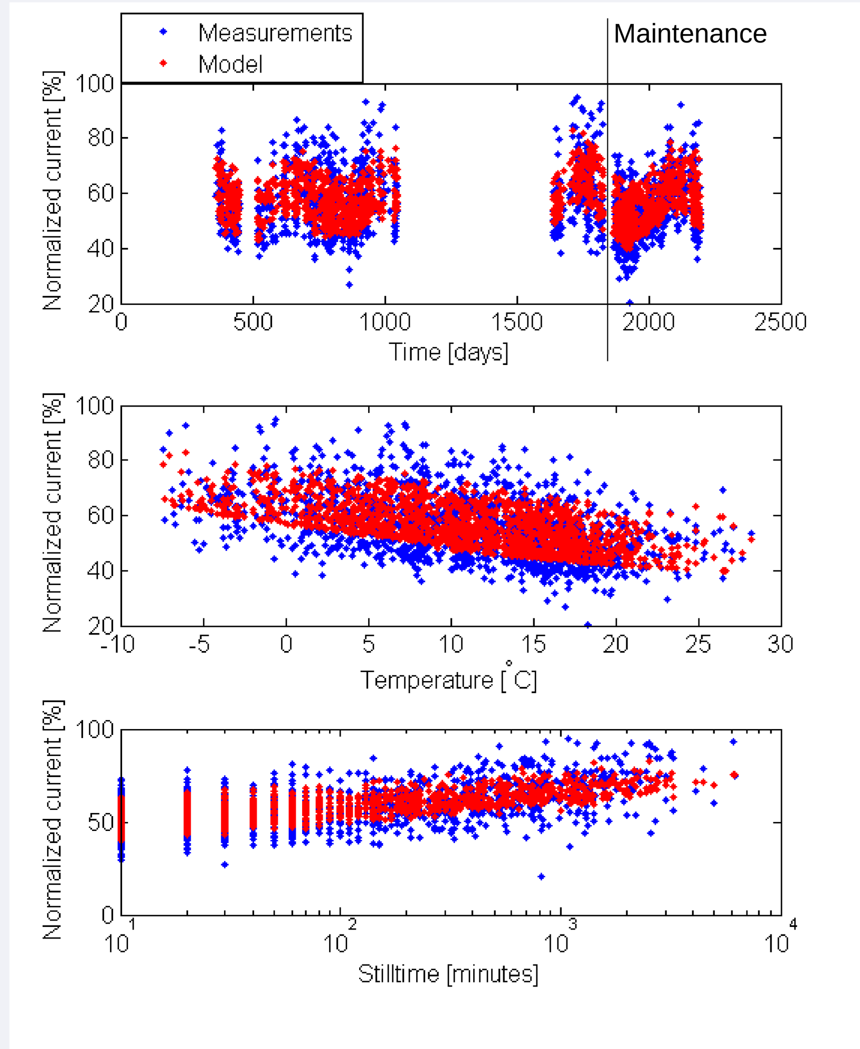
The following model is used, where the constants, c_0 and c_1 have different values before and after maintenance, and all constants are modeled as stochastic variables to include uncertainties:

$$\text{current}(i) = c_0 + c_1 \cdot \text{time}(i) + c_2 \cdot \ln(\text{stilltime}(i)) + c_3 \cdot \text{temp}(i) + c_4 \cdot \text{temp}(i)^2 + \epsilon(i) \quad (4)$$

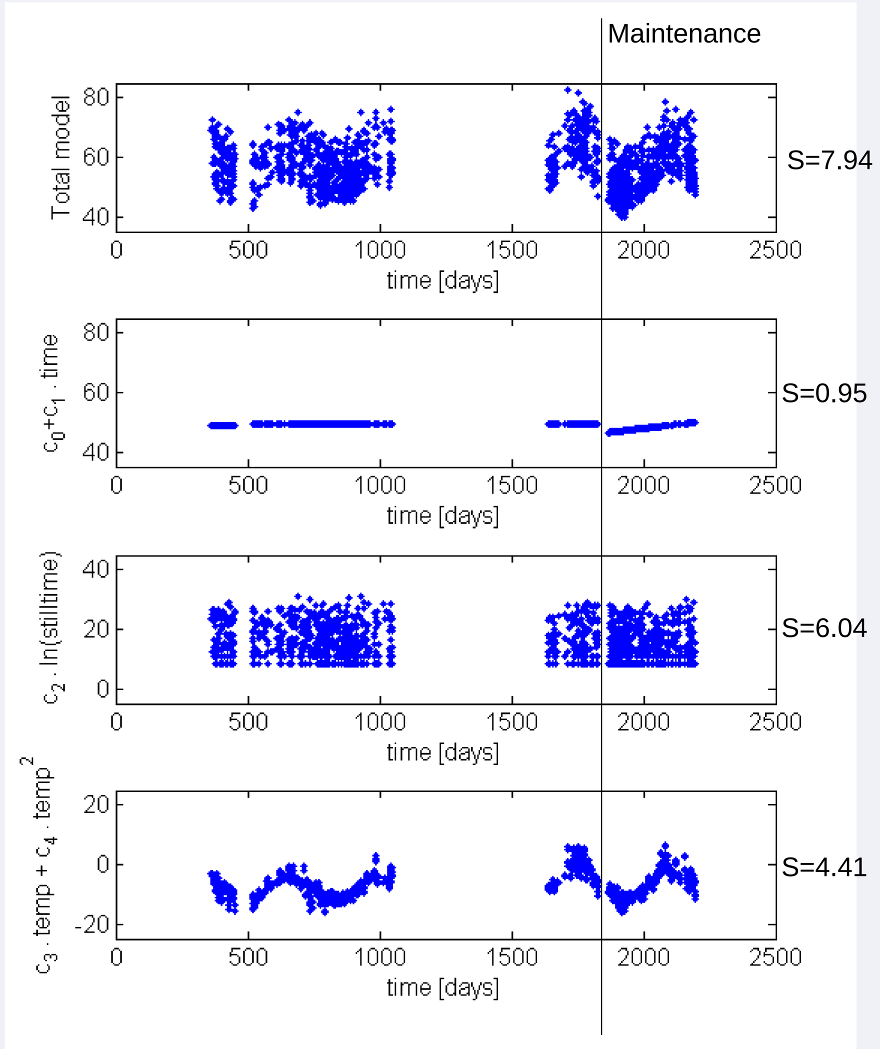
$\epsilon(i) \sim N(0,\sigma)$

The model was built in the program OpenBUGS, a program for Bayesian analysis of complex statistical models using Markov Chain Monte Carlo techniques [3]. Non-informative priors were used for the constants. The data, consisting of coherent values of time, pitch motor current, temperature, and still time was loaded into the model, and the posterior distributions for the constants were found. The data for the first year of operation (magenta) was discarded after initial analyses, because a large instantaneous increase was observed; probably caused by a system update.

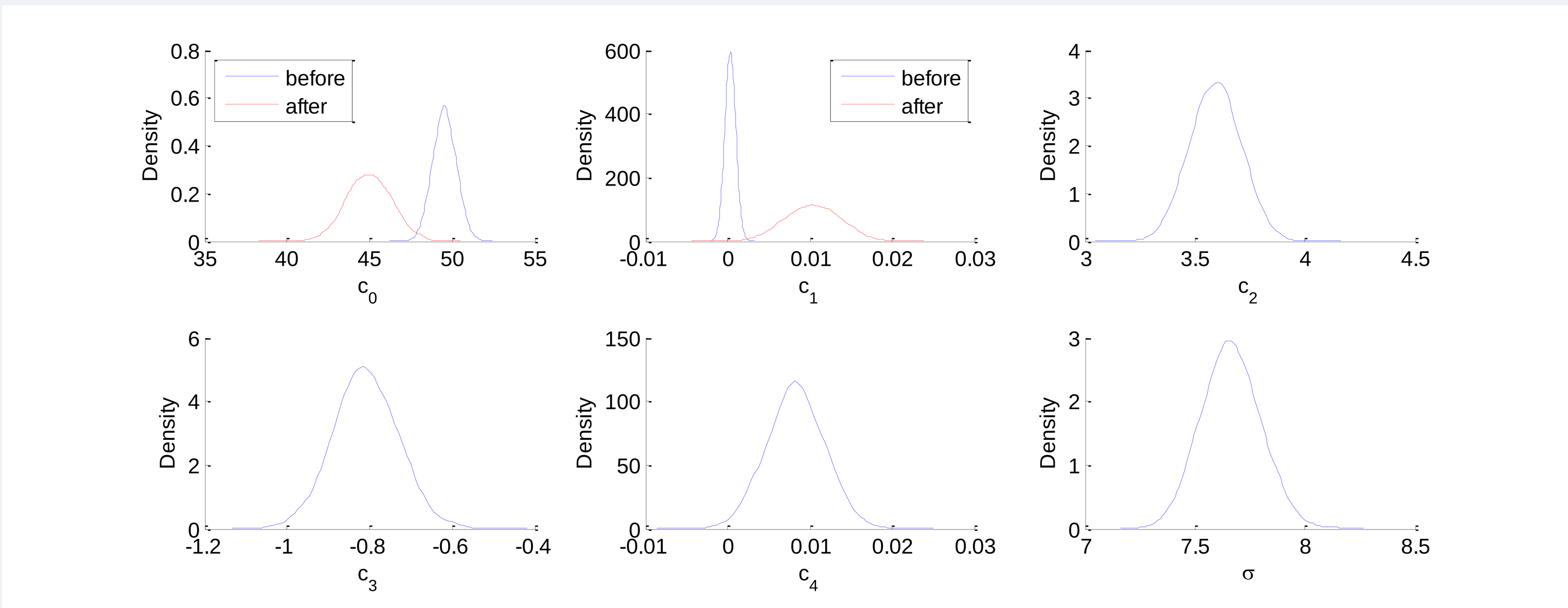
Results



Blue: measured values; Red: predicted values from deterministic model with mean values.



Contributions to the total current from time, still time, and temperature. The contribution from time shows a change after the maintenance. S denotes standard deviation.



Posterior distributions for the constants.

There is a clear difference on the mean value for the constants c_0 and c_1 before and after the maintenance. Before the maintenance, no significant increase can be seen (c_1 not significantly different from 0), but after the maintenance there was a small reduction followed by an increasing trend. However, it is not obvious whether the increase is caused by deterioration of the pitch gear. The standard deviation of the measurements of the current is 11.03, and for the residuals it is 7.65. This confirms that the model explains some of the variation. The terms including temperature and still time explains most of the variation.

Conclusions

The factors mainly affecting the peak pitch motor current are the outside temperature and the time since last pitching (still time). A small increase with time can be observed after the maintenance, but it is not necessarily caused by pitch gear deterioration, as no change could be observed before the maintenance, where deterioration was actually detected. For this damage type, the peak current does not seem to be a suitable indicator of the size of the damage, as the uncertainties are too large.

Acknowledgements

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