Response to Reviewer 1

Title of paper: Structural monitoring for lifetime extension of offshore wind monopiles: Can strain measurements at one level tell us everything?

Dear Reviewer,

Thank you for the review of our submitted paper. We appreciate your constructive feedback and valuable comments on the topic. Please find below our suggestions, how we plan to modify the manuscript.

Please let us know if the suggested revisions fulfil your expectations.

Kind regards,

Lisa Ziegler - on behalf of the authors

03/07/2017

Review comments

The revision comments are organized as follows: The review comments are repeated in *italic*, responses are stated in normal black, and suggestion for revisions of the manuscript are shown in red.

Specific comments

Comment 1: Potentially the largest errors come from situations in which the DELs calculated from the measured strains are inaccurate (since these form the basis for the extrapolation). This will be the case even for relatively low signal-to-noise ratios. It is suggested to investigate the effect of commonly encountered noise levels on the DEL calculation in order to give a more nuanced image of the accuracy that can be obtained with the proposed method.

We plan to add a new test case in Chapter 3.1, which includes artificial measurement noise: For the new test case, artificial noise was imposed on the time series of bending moments at tower bottom extracted from the simulation model to represent potential measurement errors from strain sensors. The measurement noise was modelled as white Gaussian noise with zero mean and a signal-to-noise ratio of 40 dB. The procedure of rainflow counting and DEL calculation was performed equally to the previous test cases without artificial noise.

The extrapolation will then be performed as the following (Chapter 3.2 Extrapolation results): For the test case 'design with artificial measurement noise', the extrapolation model was calibrated with the computed T-DELs and M-DELs without noise. The noise affected 'measured' T-DELs were then used to predict corresponding M-DELs. Adding artificial noise on the simulated time series of bending moments at tower bottom increased the prediction error of lifetime M-DELs and damage by 1-2% in this case study.

We believe that further evaluation of sources of measurement noise and its magnitude is only meaningful with actual measurement data and out of scope of this brief communication paper. This should be investigated in future work.

Comment 2: A review of existing literature on the subject is presented in the Introduction. It would be interesting to also see a comparison of the proposed methodology to the methods reviewed.

We plan to add the following comparisons in Chapter 3.3 Discussion: Reference is made to Perisic and Tygesen (2014) for a comparison between existing approaches for structural health monitoring and our suggested approach. Perisic and Tygesen (2014) compare Kalman filter based methods and modal expansion for criteria including computational complexity, operation in real time, and structural model complexity. Kalman filter based methods have a low computational complexity, use reduced order FE models and can thus operate in real time. The complexity of structural models and computations for modal based algorithms is high resulting in an operation of near-real time (Perisic and Tygesen, 2014). Once the simulation data basis of the methodology presented here is set up, predictions can be performed with almost no computational effort. This makes it possible to analyse large data sets in retrospect also. Algorithms based on artificial intelligence show similar computational performance. These algorithms, however, need sensors at every location for a training period. Perisic and Tygesen (2014) state that Kalman filter based methods and modal expansion perform similarly in terms of accuracy and sensitivity towards measurement noise. Future work with measurement data is needed to evaulate the sensitivity of the proposed methods to measurement noise.

Perišić N, & Tygesen UT. 2014. Cost-Effective Load Monitoring Methods for Fatigue Life Estimation of Offshore Platform. *In ASME 2014 33rd International Conference on Ocean, Offshore and Arctic Engineering.* American Society of Mechanical Engineers.

Comment 3: It is presumed that the model updating mentioned on p2/line 23 is rather important for the accuracy of the estimates obtained with the proposed method. For this reason it might be good to give more detail regarding the proposed updating procedures.

We also believe that the FE model updating is very important for good estimations with the method. We inserted a new Chapter 2.3 to give further information on this:
The process of FE model updating should verify that the global dynamic behaviour of the structure is captured correctly in the simulation model. Typical model updating techniques try to match natural frequencies, mode shapes, and damping. Devriendt et al (2014) use data from distributed accelerometers for operational modal analysis of on offshore wind turbine. Maes et al. (2016) show that the first and second fore-aft and side-side natural frequencies of a monopile are identifiable from strain gauge measurements at the tower in operating conditions of the wind turbine by transforming strain time series into power spectral densities. Modern turbines are often equipped with accelerometers in the nacelle whose measurements can be beneficial for the model updating procedure. After identification of the relevant modal properties, a sensitivity analysis should reveal which parameters in the original design model are uncertain and influential on the mismatched modal properties. For the case of the monopile support structure, these parameters can be, for instance, soil properties, manufacturing tolerances, grouted connection (early designs of transition pieces) and secondary steel elements if omitted in the initial FE model. Several methods exist to update the finite element model through minimization of an objective function addressing the selected parameters as described in standard literature (e.g. Friswell and Mottershead, 1995). The updating procedure should be repeated in time to identify possible changes on natural frequencies of the structure. Such changes could occur, for instance, due to scour or soil stiffening over time. Future work with measurement data is necessary to address FE model updating based on strain measurements for a monopile and the sensitivity of the extrapolation algorithm to this.

Devriendt, C., Weijtjens, W., El-Kafafy, M., & De Sitter, G. (2014). Monitoring resonant frequencies and damping values of an offshore wind turbine in parked conditions. *IET Renewable Power Generation, 8*(4), 433-441.

Friswell, M.I. and Mottershead, J.E. (1995). *Finite Element Model Updating in Structural Dynamics.* Netherlands: Kluwer Academic Publishers.

Comment 4: p8/line 1: "The algorithm also provides an estimate of the extrapolation uncertainty. This can be used for probabilistic assessment and potentially reduction of design safety factors." Care should be taken with statements like these since only uncertainties related to the ideal case (perfectly accurate structural model) are now considered.

Thanks for this comment. We plan to delete the two sentences since they might be misleading.

Technical corrections

Thanks for the technical corrections. We will implement this.