PO.332

Statistical analysis of fatigue loads in a direct drive wind turbine

Håkan Johansson and Viktor Berbyuk
Department of Applied Mechanics, Chalmers University of Technology

CHALMERS

SWPTC
SWEDISH WIND POWER TECHNOLOGY CENTRE

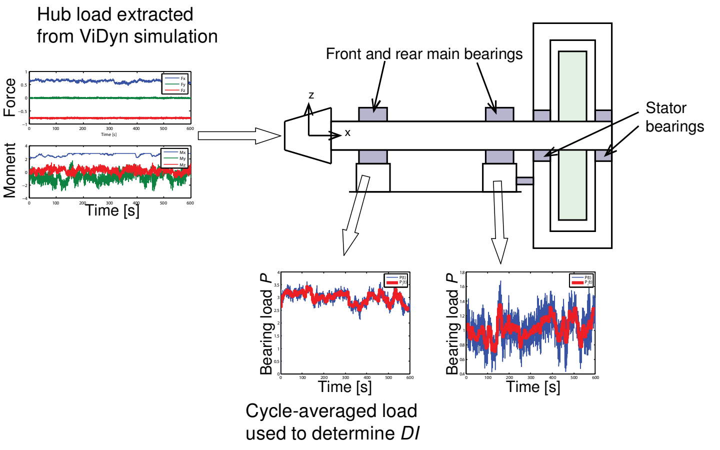
Abstract

In order to assess the fatigue life of drive train components, we seek to determine how the component damage index can be estimated, not only in terms of its expected value, but also its distribution due to a turbulent wind field introducing randomness. For assessing the fatigue life of main shaft bearings it was found that:

- A quasi-static drive train model may be sufficient for a direct drive concept in normal operation
- The average and variability of the damage index rate varies substantially with the mean wind speed
- The variability of the estimated total component damage index should be considered when estimating the total damage

Simulation model

As a basis for this investigation, we consider a simulation model for a commercial multi-MW direct drive wind turbine which was implemented in the software ViDyn [1] developed by Teknikgruppen AB. The simulation model is a structural model of the full turbine, including control system with individual pitch control, subjected to a 3-dimensional wind field, wind loads computed using Blade Element Momentum theory, implemented in code Aerforce [4]. The wind fields are random realizations based on the Kaimal spectra as described in the standard IEC-61400 [2] characterized by turbulence intensity for a specific mean wind speed. Each such wind field realization is used as input to the full-turbine model from which the forces at the hub are extracted. These forces are used as input for a drive train model based of Euler-Bernoulli beam theory implemented in Matlab.



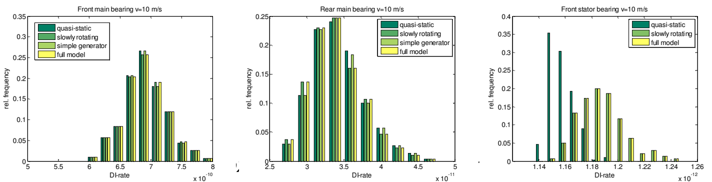
Simulation set-up

As the rate of bearing damage index *DI* [1/s] is estimated at four bearings along the main shaft; Front and Rear main bearings and Front and Rear generator stator bearings (results from the last is omitted below). The damage rate is computed using the Palmgren-Miner rule as rate other parameters specified by the bearing design, cf. [3]

$$DI = \frac{1}{T_{\text{sim}}} \sum_{i=1}^{N^{rev}} \frac{1}{L_i}, \qquad L_i = \underbrace{a_1 a_2}_{=1} a_3(P_i) \left(\frac{C}{P_i}\right)^p, \qquad P_i = aF_x + b\sqrt{F_y^2 + F_z^2}$$

Thus, each wind field realization (10 minutes) is mapped to one value of damage rate index *DI* per bearing, with the aim of assessing the distribution of calculated *DI*-values, It should be noted that this damage rate is for classical subsurface fatigue and not e.g. white etch cracking [5].

Model fidelity

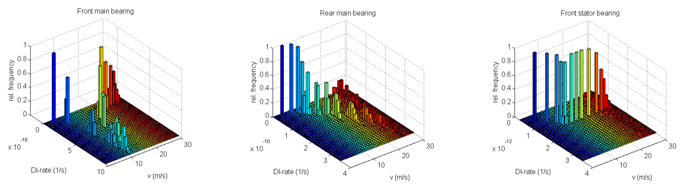


for front main bearing (left), rear main bearing (middle) and stator bearing (right), comparison of different drive train models

Observations:

- Quasi-static assumption sufficient to predict damage index rate for main bearings.
- Inertia effects should be considered to predict the damage index rate of the stator bearings.

Mapping of damage index rate



Histogram of damage index rate for front main bearing (left), rear main bearing (middle) and front stator bearing (right) at different mean wind speeds

Plotting the damage index rate distribution versus mean wind speed, it is observed that:

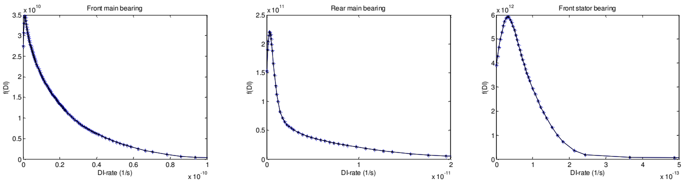
- For front main bearing the largest damage rate, as well as the largest variability arise at 11 m/s, likely related to rotor blade pitch control.
- For the rear main bearing, the damage and variability increase with higher mean wind speeds

Total accumulated damage index rate

Assuming the mean wind speed varies according to a Rayleigh distribution, the total average damage rate can be approximated

$$f(DI_{tot}^k) = \int_{v_{min}}^{v_{max}} f(DI^k(v))\mathcal{W}(v)\mathrm{d}v \approx \int_{v_{min}}^{v_{max}} \mathcal{N}(\mu(v), \sigma(v))\mathcal{W}(v)\mathrm{d}v$$

which has been evaluated numerically



Distribution of average total damage index rate for front main bearing (left), rear main bearing (middle) and front stator bearing (right) at different mean wind speeds

Observation: For the main bearings, a "tail" extends to higher damage index rates, indicating that a substantial safety factor is needed if the variability is not properly considered.

Conclusion and outlook

- Model detail can for some cases affect the estimated damage rate.
- The main result of the present investigation was that the not only the mean, but also the variance of damage rate depend on mean wind speed, and that this carries over to the predicted accumulated damage index. An important future work is to investigate the generality of these conclusions with respect to other drive train designs.
- Future work will in more detail study the efficient sampling of wind turbine simulations to estimate mean and variability of predicted damage index in the turbine drive train components with sufficient accuracy.

Acknowledgement

This project is financed through the Swedish Wind Power Technology Centre (SWPTC). SWPTC is a research centre for design of wind turbines. The purpose of the centre is to support Swedish industry with knowledge of design techniques as well as maintenance in the field of wind power. The Centre is funded by the Swedish Energy Agency, Chalmers University of Technology as well as academic and industrial partners.

References

[1] H. Ganander. The use of a code-generating system for the derivation of the equations for wind turbine dynamics. *Wind Energy*, 6(4) 333-345, 2003
[2] International electrotechnical commission (IEC) Standard. *61400 Wind turbines – part 1: Design requirements*, 2005
[3] Harris, T.A.. *Rolling Bearing Analysis*. John Wiley & Sons, Inc., fourth edition, 2001
[4] Björck, A. *AERFORCE: Subroutine Package for unsteady Blade-Element/Momentum Calculations.* The aeronautical research institute of Sweden FFA, tn 2000-07
[5] Kotzalas, M. and Doll, G. Tribological advancements for reliable wind turbine performance. *Phil. Trans. R. Soc. A* 368, 4829-4850, 2010