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Effects of bearing configuration in wind turbine gearbox reliability

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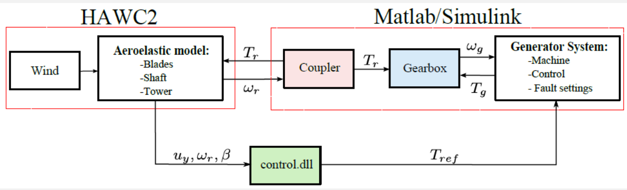
This paper investigates the impact on the reliability of different configurations of planet bearings. The studied bearings are located in the low-speed planetary stage of a wind turbine gearbox. The bearing stiffness matrix for each kind, cylindrical and tapered roller bearing (CRB and TRB), is included in the electro-mechanical drive-train simulation tool presented here. The system defined in Matlab/Simulink is co-simulated along with a wind turbine defined in an aeroelastic software. Moreover, the normal production design load case (DLC 1.1) is used to compute the bearing response to different turbulence seeds. From this, the fatigue and reliability of the bearings is calculated using the damage equivalent load and the first-order reliability method (FORM), where the L_{10h} life is used as a limit state. The results indicate a relation between the reliability index and the bearing dynamic rating. However, when the actual parameters from the manufacturer are used, the TRB shows higher reliability even though its damage equivalent load is higher across the wind speed range.

METHODOLOGY AND MODELS

Wind turbine system

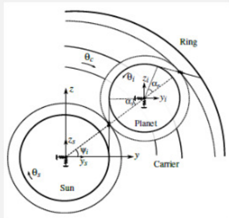
1. Co-simulation approach between HAWC2 and Matlab/Simulink
   a. **HAWC2**: wind, aero-servo-elastic model of the turbine.
   b. **Matlab/Simulink:** gearbox, generator and machine controller.

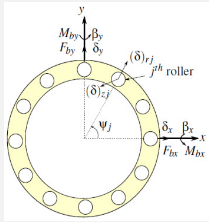


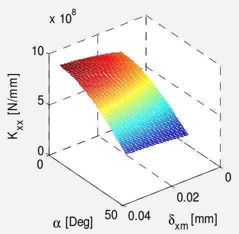
$$T_r = K_s \int (\omega_r - \omega_c)dt + C_s(\omega_r - \omega_c)$$

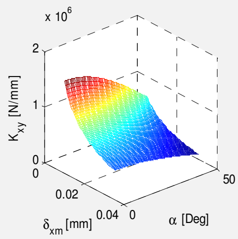
Drive-train model

1. **Gearbox**
   a. 2D Translational/rotational..
   b. Pre-processor to find bearing stiffness matrix.
2. **Generator**
   a. Permanent magnet synchronous generator.
   b. Machine controller uses the torque demand from the turbine controller as reference.





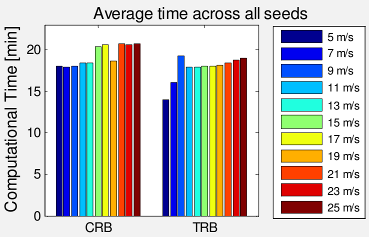




HAWC2 SIMULATION SETUP

DLC 1.1

1. Wind speed range: 5 m/s-25 m/s; 2 m/s bins.
2. Six seeds, 66 total number of simulations.
3. 10 min of simulation time.



RELIABILITY ANALYSIS

Let the limit state equation describe the failure of the bearing depending on the bearing life computation:

$$g(x) = \frac{10^6}{60n}\left(\frac{C}{P(x)\chi_{aero}\chi_{dyn}\chi_{stat}}\right) - 10^5$$

Therefore, failure might be described by:

$$P_f = \int_{g(\mathbf{X})\leq 0} f_x(\mathbf{x})dx$$

where $f_x(\mathbf{x})$ is the probability density function of the random variables $\mathbf{x}$

FORM:

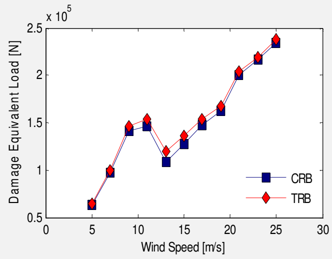
The input variables are transformed into the normal space and the Hasofer-Lind's reliability index is found:

$$U_i = \Phi(F(X_i)) \qquad \beta = \min_{g(\mathbf{u})=0} \sqrt{\sum_{i=1}^{n} \mathbf{u}_i^2}$$

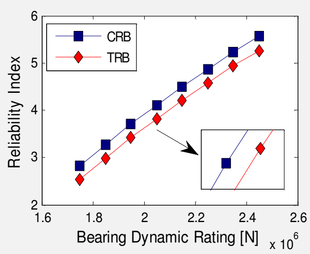
RESULTS

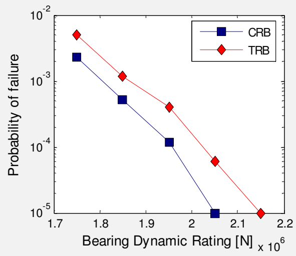
The damage equivalent load shows the effect of the different bearing stiffness:

$$S_{eq} = \left(\sum_{i=1}^{N_b} \frac{n_i S_i^m}{N}\right)^{1/m}$$



The reliability index is calculated for different values of the bearing dynamic rating (C) in order to show the effect on the reliability:





For the manufacturer value of C for each bearing used in the model simulations, the reliability analysis shows that the **TRB is more reliable** (by small margin).

Type of bearing	Reliability index, β	Probability of failure, p_f	Importance factors, α			
			χ_s	χ_{aero}	χ_{dyn}	χ_{stat}
Cylindrical roller bearing	3.83	9.0×10^{-5}	0.121	0.809	0.405	0.045
Tapered roller bearing	3.97	6.0×10^{-5}	0.121	0.809	0.405	0.045

ACKNOWLEDGEMENT

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http://www.rewind.mek.dtu.dk/