Diagnostic monitoring of drivetrain in a 5 MW spar-type floating wind turbine using Hilbert spectrum

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Abstract

The objective of this paper is to investigate the frequency-based fault detection in a 5MW spar-type floating wind turbine (WT) gearbox using the global response. It is extremely costly to seed managed defects in real WT gearbox; t using analytical tools, therefore, is one of the promising approaches in this regard. Forces and moments on the main shaft are obtained from the global response analysis using an aero-hydro-servo-elastic code, SIMO-RIFLEX-AeroDyn. Then, they are utilized as inputs to a high fidelity model developed using a multi-body simulation software (SIMPACK). The main shaft bearing is one of the critical components, since it protects gearbox from axial and radial loads. Six different fault cases with different severity in this bearing were investigated using power spectral density (PSD). It was shown that in severe degradation of this bearing the first stage dynamic of the gearbox is dominant in the main shaft vibration signal. Inside the gearbox, the bearings on the high speed side are those often with high probability of failure, thus, one fault case in IMS-B bearing was also considered. Based on the earlier studies, the angular velocity error function is considered as residual for this fault. The Hilbert transform was used to determine the envelope of this residual. Information in the amplitude of this residual properly indicate wear in this bearing.

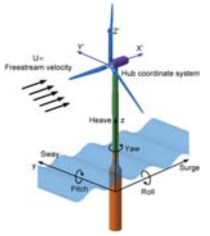
Introduction

- Wind energy is a rapidly growing renewable energy source, and the trend is toward applications further offshore in order to access higher wind and to avoid acoustic noise.
- Maintenance and repair costs constitute an important portion of the operating costs particularly for offshore wind turbines.
- Condition monitoring can play a crucial role in managing the operation and maintenance by:
  - ✓ Preventing component failure and system shutdown by early detection of incipient degradation.
  - ✓ Moving from planned maintenance to condition -based maintenance.
- Drivetrain, in particular, the gearbox, is among the most critical subsystems due its high repair downtime.
- This paper deals with fault detection of main shaft bearing of 5 MW gearbox, which its health is critical to other components, and one bearing inside the gearbox using:
  - ✓ Main shaft acceleration measurement and angular velocity error function
  - ✓ Power spectral density and The Hilbert transform

Wind turbine and drivetrain model

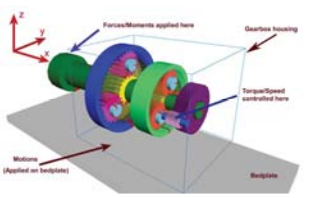
Fault detection in main shaft bearing of a 5-MW reference gearbox installed on the OC3 Hywind floating spar structure is studied using a de-coupled approach.

- De-coupled Approach & Environmental Condition
- The forces and moments on the main shaft are first obtained from the global response analysis using an aero-hydro-servo-elastic code, SIMO-RIFLEX-AeroDyn. Simulations are carried out at:
  - ✓ The rated wind speed (11.4 m/s)
  - ✓ Significant wave height HS = 5 m and peak period TP = 12 s The turbulence intensity factor is taken as 0.15 according to IEC 61400-1.



Global analysis in SIMO-RIFLEX-AeroDyn

Parameter	Value
Type	Upwind/3 blades
Cut-in wind speed (m/s)	3
Rated wind speed (m/s)	11.4
Cut out wind speed (m/s)	25
Hub height (m)	87.6
Rotor diameter (m)	126
Hub diameter (m)	3
Rotor mass (1000 kg)	110
Nacelle mass (1000 kg)	240
Hub mass (1000 kg)	56.8

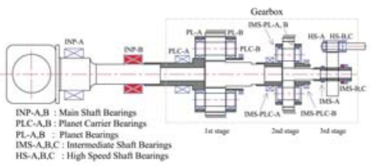


Global Loads are applied on a detailed gearbox model in Multibody Dynamics (MBD)

Parameter	Value
Type	2 Planetary + 1 Parallel
1st stage ratio	1:3.947
2nd stage ratio	1:6.167
3rd stage ratio	1:3.958
Total ratio	1:96.354
Designed power (kW)	5000
Rated input shaft speed (rpm)	12.1
Rated generator shaft speed (rpm)	1165.9
Rated input shaft torque (kN.m)	3946
Rated generator shaft torque (kN.m)	40.953
Total dry mass (1000 kg)	53
Service life (year)	20

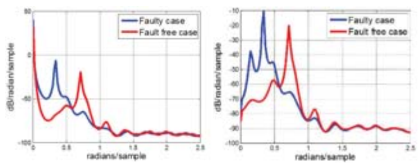
Simulation results

- Fault cases and fault detection results
- Physical meaning of fault cases in the main shaft bearing (INP-B) according to ISO 10816-1 standard:

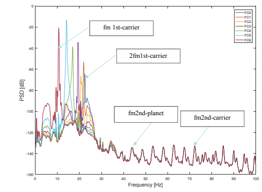


Fault cases	$\frac{K_{xf}}{K_{xnf}}\times 100\%$	r.m.s (mm/s)	vibration zone boundary
FC0	100	0.8	A
FC1	95	0.9	A
FC2	85	0.9	A
FC3	70	2.2	B
FC4	50	2.4	B
FC5	30	8.3	C
FC6	10	7.7	C

- Residual: Main shaft axial acceleration - nacelle acceleration

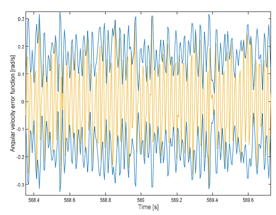


Subtraction acts similar to a high pass filer, making residual robust to wave and winds

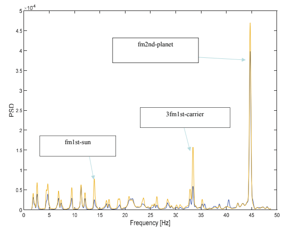


PSD of seven fault cases in the main shaft bearing

- Fault in IMS-B bearing
- Residual: Angular velocity error function



The angular velocity error function and its envelope



Envelope spectrum of the angular velocity error function.

Methodology

- Envelope analysis using the Hilbert transformation
- Unlike the Fourier transform and Laplace, Hilbert transform does not involve a change of domain. The Hilbert transform of a signal in time (frequency) is another signal in time (frequency). The Hilbert transform of a real value time-domain signal, x(t), is defined by:

$$H[\mathrm{x(t)}] = \frac{1}{\pi}\ \mathrm{p.v.}\int_{-\infty}^{\infty}\frac{x(t)}{t-\tau}\,d\tau$$

- H[x(t)] is a complex time series, where the magnitude of this complex signal represents the envelop of a signal, an estimate of the amplitude modulation.

Conclusion

- This paper has employed frequency analysis for fault detection in the main shaft bearing and a bearing inside gearbox. Relative axial acceleration and Angular velocity error function were the residuals, respectively.
  - ✓ Global analysis was obtained using SIMO-RIFLEX-AeroDyn
  - ✓ Global Loads were applied on a detailed gearbox model in Multibody Dynamics (MBD)
- Gearbox first stage dynamics and 2nd stage dynamics are dominant in the main shaft bearing and IMS-B bearing faults, respectively.

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