Fatigue Reliability-Based Inspection and Maintenance Planning of Gearbox Components in Wind Turbine Drivetrains

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Abstract

This paper introduces a reliability-based maintenance plan for wind turbine gearbox components. The gears and bearings are graded based on their fatigue damage and a maintenance map is developed to focus on those components with higher probability of fatigue damage and lower level of reliability. The main aim of this paper is to propose a method for developing the "vulnerability map" which can be used for maintenance team to identify the components with lower reliability. The fatigue damage for gears and bearings are calculated at rated wind speed by SN curve approach. The load duration distribution (LDD) method is used to obtain the stress cycles for gears and load cycles for bearings from the load and load effect time series. During routine inspection and maintenance, the vulnerability map can be used to find the faulty component by inspecting those with highest probability of failure rather than examining all gears and bearings. Such maps can be used for fault detection during routine maintenance and can reduce the down time and efforts of maintenance team to identify the source of problem. The proposed procedure is exemplified by 750 kW NREL gearbox and a vulnerability map is developed for this case study gearbox.

Methodology

In this paper, the 750 kW NREL GRC gearbox is used. The loads on gears and bearings are obtained from the decoupled analysis. The global loads on the drivetrain are measured using a NREL dynamometer test bench. Next, these loads are used as inputs to a multi-body (MBS) drivetrain model in SIMPACK. See Fig. 1 for an illustration of drivetrain. The main shaft loads, or the forces and moments, are applied at the end of the main shaft where the rotor hub is connected.

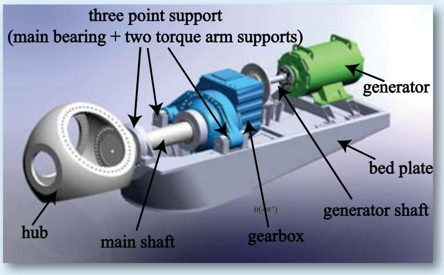

Figure 1: NREL 750 kW wind turbine.

In Fig. 2 the decoupled approach is presented.

Step I:

NREL dynamometer test bench.

Torque time series

Step II:

Torque time series are applied on Gearbox MBS model.

Step III:

Loads on gears and bearings are measured.

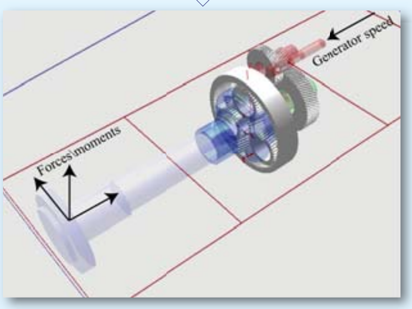

Figure 2: Decoupled analysis method.

Results

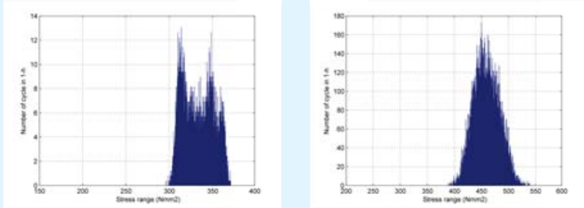

Figure 3: Stress range and number of stress cycles, planet gear (left); 3rd stage gear (right).

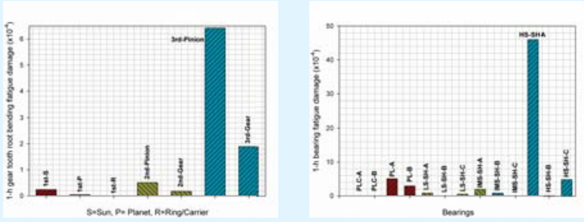

Figure 4:1-h fatigue damage of gears (left); bearings (right).

The fatigue damages of gears and bearings in the 750 kW case study gearbox are calculated and shown in Table 1 and Fig. 5.

Table 1: Gears and bearings sorted based on 1-h fatigue damage at rated wind speed.

Rank	Gear or Bearing	Name	*Damage* x 10^{-4}
1	Bearing	HS-SH-A	46.00
2	Gear	3rd Pinion	6.423
3	Bearing	PL-A	5.064
4	Bearing	HS-SH-C	4.846
5	Bearing	PL-B	2.921
6	Bearing	IMS-SH-A	1.954
7	Gear	3rd Gear	1.893
8	Bearing	LS-SH-A	0.812
9	Bearing	IMS-SH-B	0.777
10	Gear	2nd Pinion	0.509
11	Bearing	LS-SH-C	0.507
12	Gear	1st Sun Gear	0.241
13	Gear	2nd Gear	0.171
14	Bearing	HS-SH-B	0.096
15	Gear	1st Planet Gear	0.039
16	Bearing	IMS-SH-C	0.021
17	Bearing	LS-SH-B	0.020
18	Gear	1st Ring Gear	0.004
19	Bearing	PLC-A	0.000
20	Bearing	PLC-B	0.000

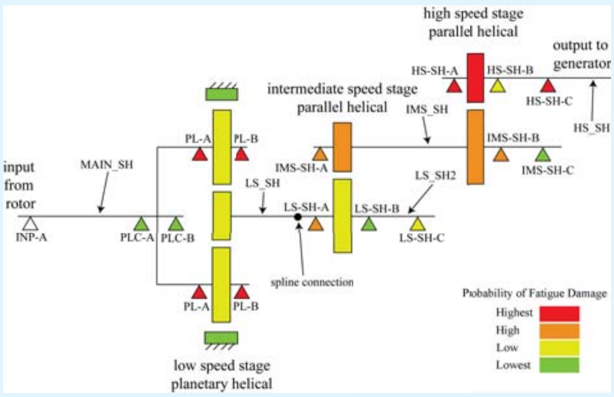

Figure 5: "Vulnerability map" of 750 kW case study gearbox based on component fatigue damage ranking.

Conclusions

In this paper an inspection and maintenance planning map based on the fatigue damage of gears and bearings is presented. The procedure for calculating the short-term fatigue damage for gears and bearings is described and exemplified for the NREL GRC 750 kW gearbox. The gearbox components are then sorted based on their fatigue damage. A "vulnerability map" is constructed indicating the components with highest to lowest fatigue damage. This maintenance map can be used for maintenance planning and inspection of components during routine preventive maintenance inspections. This approach can give the advantage of detecting the source of fault in shorter time. By using this plan, the maintenance inspector looks for defects from those with higher probability of failure, instead of examining all gears and bearings.

EERA DeepWind'2014, 11th Deep Sea Offshore Wind R&D Conference