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Composite Low-Speed Shaft Coupling

Enhancing Reliability and Reducing LCOE of Drive-Trains

Composite Low-Speed Shaft Coupling

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Advances in design, materials and drive-train testing have resulted in substantial improvements of wind turbine reliability, particularly in the 2–4MW class [1]. But with continuous growth in size of turbines, the risk of gearbox damage appears to be back on the agenda. Further upscaling of conventional drive-train designs is limited and alternative architectures might be required. A flexible element at the low-speed shaft allows the gearbox to be mounted rigidly to the main frame and relieves the gearbox from unnecessary stress and fatigue. The author of this article was part of a team that recently presented the results of a load study of such a system [2]. The focus of the current article is on a commercial study with the objective to identify the potential of reducing operational cost (OPEX) and enhancing levelised cost of energy (LCOE), using the example of a 6MW offshore wind turbine.

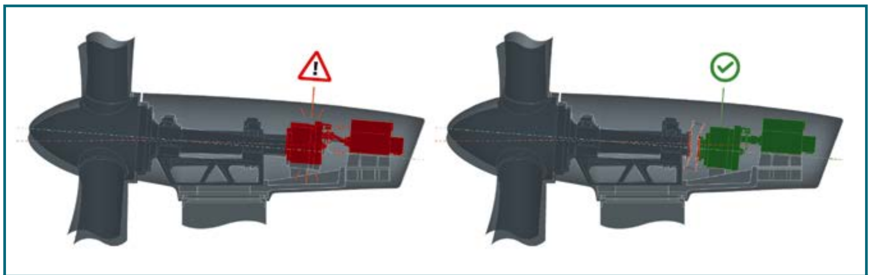

Figure 1. The operating principle of a standard drive-train with the gearbox mounted elastically (red) versus a gearbox mounted rigidly and a low-speed shaft coupling to absorb non-torque loads (green) (source: Geislinger)

This article is about a low-speed shaft coupling made of advanced composites. This coupling explicitly reduces non-torque loads, enhancing the dynamic system behaviour, and indicates the potential to reduce OPEX. Its weight-saving design is fatigue-resistant and maintenance-free and facilitates highly integrated next-generation drive-train architectures.

Non-Torque Loads

The size of the drive-train structure has a massive influence on effective distortions and its impact on excessive gearbox loads. Even in the days of 2MW turbines, non-torque loads were identified as a major root cause for deficient drive-train reliability. Avoiding parasitic loads by mounting the gearbox rigidly to the main frame and decoupling the rotor from the gearbox is valued as a potential way forward for drive-train layouts [1]. Figure 1 illustrates the difference between a state-of-the-art drive-train configuration and an advanced architecture with a low-speed shaft coupling.

Various examples of drive-train concepts confirm this trend [3] [4], as do the latest 8MW plus offshore wind turbines featuring high integrated drive-train architectures with a low-speed shaft coupling between the rotor and the gearbox instead of elastic gearbox mounts.

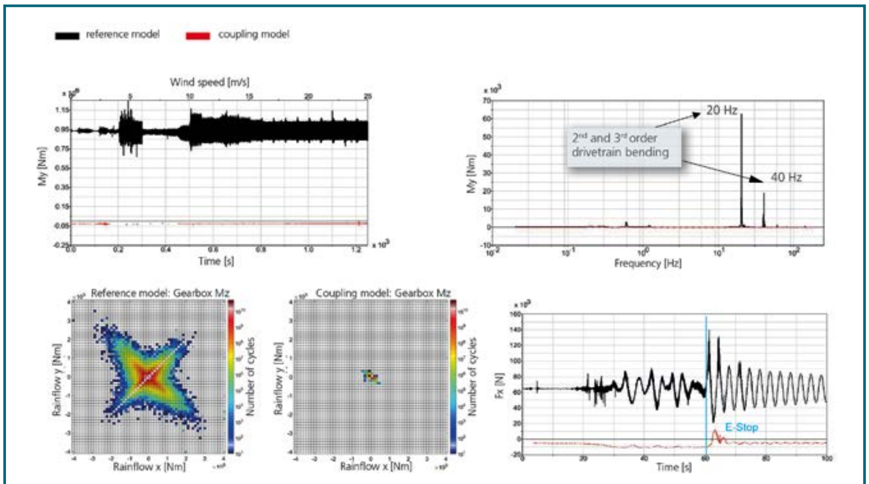

Figure 2. Design loads pitching moment My (top left) and modal analysis (top right); rainflow-counting thrust force Fx (bottom left and middle), emergency stop thrust force Fx (bottom right)

Method for Load Study

An assessment of such a drive-train configuration was done by using one of the generic multi-body simulation models of the Center for Wind Power Drives, RWTH University of Aachen, allowing detailed investigations of the impact of different configurations on performance and dynamics of wind turbines [5]. The reference model was a generic 6MW offshore turbine with a four-point suspension and a three-stepped gearbox with hydraulic torque supports, while the gearbox of the coupling model is modelled rigidly to the main frame, stiffness and damping values of a composite coupling were included. Dynamic simulations considered design loads at steady wind loads (3–25m/s), turbulent wind fields and special events (grid failure, emergency stops, etc.). Together with statistical examinations (load duration distribution, rainflow-counting), comprehensive data on drive-train loads and dynamics were gathered and compared to the reference model, allowing identification of the coupling's contribution to load and fatigue reduction.

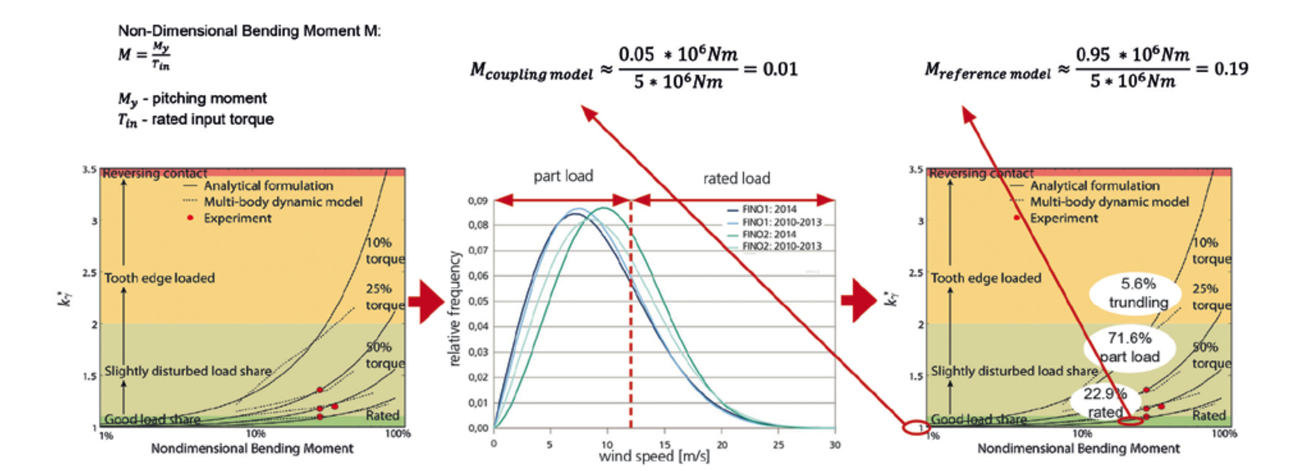

Figure 3. Load-sharing factor increases with non-dimensional bending moment M (left, source: NREL); Weibull distribution of wind speeds (middle, source: FINO, IWES Fraunhofer); part load operation increases in disturbed load share (right)

Results of Load Study

An abstract of the load study gives insight on the magnitude of load reduction and the potential to enhance the dynamic system behaviour. The comparison of pitching moments (My) shows a massive load reduction in the coupling model (Figure 2, top left). Modal analysis (Figure 2, top right) unveils severe drive-train bending Eigen modes in the reference model, explaining the dynamics and fatigue load (Figure 2, top left).

The comparison of yaw moments (Mz) clearly shows a high number of oscillating cycles and high amplitudes in the reference model, which is caused by alternating loads (Figure 2, bottom left). This dynamic effect does not occur in the coupling model thanks to the rigidly mounted gearbox (Figure 2, bottom middle). By comparing thrust loads (Fx) after the occurrence of an emergency stop, the massive improvement in dynamic system behaviour becomes obvious (Figure 2, bottom right).

Non-Dimensional Bending Moment

Wind turbines do not always meet their designed life since they are subject of non-torque loads, resulting in disturbed planetary load sharing. At high torque, bearings suffer from fatigue and gears pit, while at low torque bearings skid and smear (Figure 3, left) [1]. The Weibull distribution of wind speeds of a German offshore research location (Figure 3, middle) clearly demonstrates that turbines rarely operate at rated load [6], resulting in a load distribution of 22.9% at rated torque only, 71.5% under part load and 5.6% trundling.

Anticipating the simulation results of Figure 2 top left, which shows the pitching moment My [2], the calculated non-dimensional bending moment (M) in the reference model is 0.19 (=19%) and planet load share will be disturbed with decreasing torque (Figure 3, left). The almost linear restoring forces of low magnitude of a composite coupling always ensure good load sharing, independently of bending moment, torque level and other operating conditions (Figure 3, right).

Commercial Study Method

The commercial study was carried out under the assumption that the integration of a composite coupling has the potential to reduce non-torque loads applied at the gearbox input shaft and thus may have positive effects on OPEX as gearbox failures reduce and the number of gearbox exchanges is decreased. Furthermore, reduced gearbox failures lead to higher availability of the turbine and therefore the annual energy production (AEP) might be increased. OPEX (shipping, material, labour) and AEP values were compared using the example of a 6MW offshore wind turbine. Another major assumption is based on a GE publication [7], revealing that 61% of gearbox replacements are due to failure within the planetary stage (36% planet bearings and 25% planetary stage gear) (Figure 4). Together with an assumed failure reduction of 90%, a realistic best-case reduction potential of a gearbox exchange results in 55%.

Results of the Commercial Study

Potential OPEX savings of 876,000 € for a 6MW offshore wind turbine (Figure 5) were calculated using the following assumptions: 4,500 full load hours AEP, 271GWh over its lifetime, an offshore LCOE reference value of 12.8ct/kWh (source: Prognos Fichtner 2013), a probability of 55% for a gearbox exchange due to a failure in the first planetary stage [7], a day rate for a jack-up vessel at 80,000 € [8], average cost for a gearbox exchange taking six days at 480,000 € [8], and the number of major replacements at 0.154 annually [8]. The LCOE is calculated by the net value of energy generation over the entire lifetime of a wind turbine (Figure 5).

Taking into account that a gearbox replacement at difficult and rarely accessed offshore locations might take much longer than six days, the potential savings could be significantly higher than the results illustrated above.

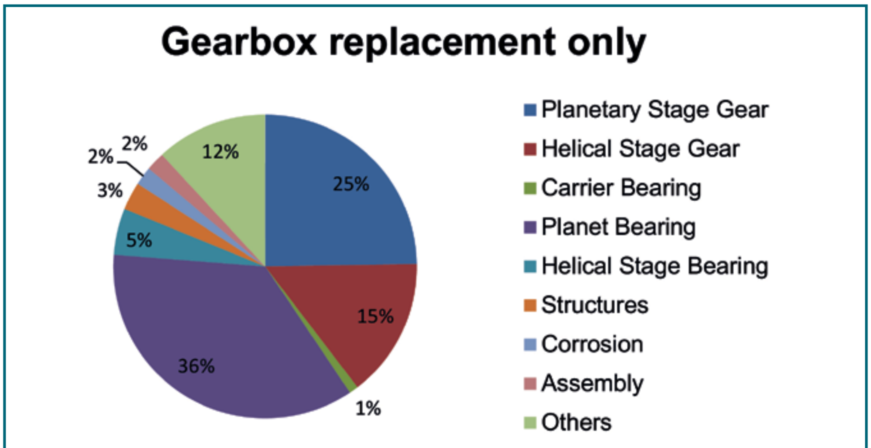

Figure 4. Reasons for gearbox exchange (source: GE)

	Savings due to reduced failures 1st planetary stage:	100%	50%	10%
Total OPEX Savings	Cumulative savings shipping [€]	407.495	203.750	40.750
	Cumulative savings material & labor [€]	441.504	220.750	44.150
	Cumulative additional AEP [€]	27.129	13.565	2.713
	Total OPEX Savings over Lifetime [€]	**876.128**	**438.065**	**87.613**
Total LCOE Reduction	**Reduction of LCOE [ct/kWh]**	**0.30**	**0.16**	**0.024**
	Reduction of LCOE relative	**2.4%**	**1.2%**	**0.19%**

Figure 5. Total OPEX savings and LCOE reduction potential over lifetime (source: CWD Aachen)

Summary

A low-speed shaft coupling made of advanced composite allows the gearbox to be mounted rigidly to the main frame. The almost linear restoring forces of very low magnitude ensure that the coupling absorbs almost 95% of non-torque loads which are unnecessarily stressing and fatiguing gearbox components. This technology not only possesses the ability to explicitly reduce gearbox peak loads and fatigue but also to reduce the size, weight and cost of the gearbox. From another perspective, this technology facilitates next-generation highly integrated drive-train architectures, capable of being upscaled to 14MW and more. The commercial study delivers an indication on the potential of OPEX reduction and enhancement of LCOE if a drive-train features a low-speed shaft coupling made of advanced composites.

Further Reading

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