

Interactive comment on “Comparison of Planetary Bearing Load-Sharing Characteristics in Wind Turbine Gearboxes” by Jonathan Keller et al.

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The authors thank the reviewer for their comments.

Comment #1: “Page 2, lines 1-4; One sentence states that “wind turbine gearboxes are not achieving their expected design life” and the next sentence seems to negate this by stating “Although planet gear and bearing failures are not predominant...”. Re-phrase by stating specifically what is the problem that is being addressed here.”

Authors’ response to comment #1: For clarity, the latter sentence has been changed to:

Planet bearing failures, although not the most frequent type of failure (Sheng, 2017), are extremely costly because they typically require replacement of the entire gearbox

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with a large crane and thus merit investigation.

Comment #2: “Page 2, lines 15-16, “Rotor moments and gravity result in once-per-revolution effects...”. Are rotor moments only 1P in frequency? Don’t you have any higher frequency components from the rotor passed to the main shaft?”

Authors’ response to comment #2: It is certainly true that rotor moments vary in time and in frequency. This sentence was originally intended to explain the simplest situation where even steady-state rotor moments (in the fixed frame, like those applied in dynamometer testing) and gravity (naturally constant in the fixed frame) result in 1P effects (in the carrier frame). Steady moments are the only ones that have been examined in this literature review section. For clarity, the sentence has been changed to:

Steady-state rotor moments and gravity result in a once-per-revolution variation in bearing load in the rotating carrier frame, that both increases fatigue and could cause wear or skidding (Guo et al., 2014, Gould and Burris, 2016).

Comment #3: “Page 5, Line 2, “Representative rotor pitch and yaw moments up to ± 300 kNm...”. Under what situations is this a representative load? Are these for normal operating conditions under turbulence?”

Authors’ response to comment #3: The moments are based on a 3-month field test of this drivetrain when it was installed in a NEG Micon 750/48 turbine at a wind plant in Wyoming, USA. Moments this high were measured, but not frequently – the majority were under ± 300 kNm. This is accounted for later in the L10 life calculations. Stating that these highest 300 kNm moments are “representative” might imply that they are common, which is not the case. This sentence has been revised to include some additional clarification and detail as follows:

Vertical and lateral forces were applied with hydraulic actuators to an adapter in front of the main bearing, resulting in bending moments up to ± 300 kNm measured on the

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main shaft. This range of moments was derived from measurements on the same drivetrain when installed in a NEG Micon NM 750/48 turbine at an operational wind plant (Link et al., 2011).

Comment #4: "Page 6, Line 7, "The entire drivetrain is represented as deformable bodies...". Is this really required? Provide some explanation on what role do the housing stiffness, ring gear stiffness etc. play on the loads on the bearing?"

Authors' response to comment #4: The "entire drivetrain" being modeled with deformable bodies is a mistake that has been fixed. Other clarifications were also made, changing these sentences to:

The Transmission3D software application implements a three-dimensional, contact-mechanics model (Transmission3D, 2018). The gearbox is represented with deformable bodies, including the ring gear and gearbox housing as their flexibility can affect gear misalignment and load sharing characteristics. Gear and bearing contacts, including piece-wise clearance nonlinearities, are modelled with a hybrid of finite elements to predict far-field displacements and a Green's function model to predict displacements in the contact region.

Comment #5: "Page 7, Line 10, "load zones for the pure torque condition are compared to those for extreme positive and negative pitch moments". Where do you get the extreme pitch moments from? I don't think 300 kNm are extreme moments, if that is what is referred to here."

Authors' response to comment #5: As stated earlier, the range of main shaft moments were derived from field tests. For clarity, the sentence has been changed to:

The load zones for the pure torque condition are compared to those for the highest pitch moments.

Comment #6: "Page 9, Figure 7: Why should the loads on the upwind and downwind bearing be out of phase for a pure torque condition that is shown here? The explanation

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given is due to clearances, but possibly there is additional loading than pure torque?"

Authors' response to comment #6: The gravity load is the additional load. The difference in phase between the upwind and the downwind loads is a direct result of the difference in size of the load zones in Fig. 5. At the 180 degree location, the larger upwind load zone results in a higher load while the smaller downwind load zone results in a lower load. The authors are actually developing a separate journal manuscript which examines this behavior analytically, but for now just refer to previous modeling studies. For additional clarification, the sentence has been changed to:

The CRB loads fluctuate over the rotation and are also out of phase because of the combined effect of planet and carrier bearing clearances and gravity and the resulting gear misalignment (LaCava et al, 2013).

Comment #7: "Page 10, Figure 9, What about the main bearing load? Does the main bearing hold a part of this pitch moment load?"

Authors' response to comment #7: Rotor moments can certainly be carried by both the main bearing and low-speed stage of the gearbox, depending on their relative clearances and stiffnesses. As mentioned in the response to comment #3, the moments discussed herein were actually measured on the main shaft and so are related but not equal to the rotor moments. The authors have made minor changes in the manuscript text to distinguish between the rotor moment itself, which then results in the main shaft pitch and yaw moments that were used during the tests. Note that the figures in question use this easily measurable quantity, "Main Shaft Pitch Moment" and "Main Shaft Yaw Moment", on the x-axis. The main spherical bearing in this case most likely supports a minor and unknown moment, but this uncertainty is not relevant as all moments were measured on the main shaft – including the field tests.

No changes were made to the manuscript.

Comment #8: "Page 11, line 11: "The upwind carrier CRB does not carry any load

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regardless of the pitch moment and neither does the downwind carrier CRB for pitch moments within ± 100 kNm because of their clearances". This is not clear."

Authors' response to comment #8: The authors agree that this sentence was confusing. The section has been modified and also better linked to the previous result:

To better understand the planet bearing load-sharing behaviour shown in Fig. 10, the effect of pitch moments on carrier bearing loads is explored in Fig. 11. Here only the predicted loads from the model are available; measurements of the carrier bearing loads were not acquired in tests. Carrier bearing loads are also nondimensionalized by the average of the assumed total planet bearing load. Beyond ± 100 kNm pitch moment, the downwind carrier CRB load increases while the planet CRB load does not. The downwind carrier CRB supports essentially all the additional load. Within ± 100 kNm pitch moment, the planet CRBs carry any load while the carrier CRBs are both unloaded. For this gearbox, the upwind carrier CRB does not carry any load regardless of the pitch moment. This behaviour is a direct result of the relative clearances of all the carrier and planet CRBs.

Comment #9: "Page15. Effect of bearing clearances: Overall all load effects shown are explained through the effect of clearances. If this is indeed the case, then the initial sections of this manuscript should explain the clearances over the different parts of the gearbox and discuss their modeling in the software."

Authors' response to comment #9: The planetary bearing types and clearances were described earlier in the paper in Table 1. The description of the "piece-wise" CRB clearance modeling has been added to the modeling section as mentioned in the response to comment #4.

Comment #10: "Page 16, line 5: 15 μ m tangential pin position error is investigated. How is this done in practice? Is this simulated or measured? Why are the load results in Fig. 17 said to negligible? They seem significant for such a small error."

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Authors' response to comment #10: Pin position error was simulated in the model. There is no direct measurement of the error itself. Pin position error commonly exists during the manufacturing process, as stated in the introduction. The authors agree that describing the effect of pin position error as "negligible" is an overstatement, so this sentence has been changed to:

This effect is much smaller than the load fluctuations caused by other factors,...

Comment #11: "Page 18, Line 3: The conclusions state that "resulted in a modified L10 life 3.5 times greater for the gearbox" . I don't think the cases simulated here are representative enough to compute the L10 life directly. If they are claimed to be so, then that should be substantiated with some load simulations of normal operation. Otherwise the conclusions should just focus on the effects of clearances and gravity on loads and not extrapolate to the L10 life."

Authors' response to comment #11: As mentioned earlier, the loading conditions were measured in field tests over a 3-month field test. Although brief, this test period was used to calculate a representative duty cycle for the turbine. It was this duty cycle that was then used to make the L10 life calculations. The life calculations are based on this whole duty cycle, not just the extreme load cases presented here. The duty cycle is actually comprised of mostly low or near pure-torque conditions, and indeed the gearbox with CRBs shows disturbed load-sharing even in what is thought of as this "benign" (or even best case) condition. Regardless of how accurate the duty cycle may be, what is important to quantify is the relative difference in L10 life between the two gearboxes (which is significant) rather than just stopping at an examination of the difference in planet bearing loads.

No changes were made to the manuscript

Please also note the supplement to this comment:

<https://www.wind-energ-sci-discuss.net/wes-2018-36/wes-2018-36-AC2->

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