Wind Turbine Gearbox Reliability

Modeling, Instrumentation and Testing.

Travis Histed and Chad Glinsky, Romax Technology, Inc.

A high number of wind turbine gearboxes do not meet their expected design life, despite meeting the design criteria of current bearing, gear, and wind turbine industry standards and certifications. This, in turn, increases the cost of energy generated by wind turbines. To investigate the root causes of these reliability issues, the U.S. Department of Energy and National Renewable Energy Laboratory (NREL) established the Gearbox Reliability Collaborative in 2007, now called the Drivetrain Reliability Collaborative (DRC), of which Romax Technology is an active partner. The collaborative is focused on improving reliability by better understanding loads, improving design tools, and refining testing practices.

A series of gearbox designs have been tested on the NREL 2.5 MW dynamometer in Colorado as part of this effort, with each iteration containing strategic design elements used to validate certain assumptions. Romax Technology and Romax InSight have been involved in the modeling, analysis, design, and testing of these gearboxes since 2008. The final iteration of the test program was Gearbox 3 (GB3), which was tested in late 2016.

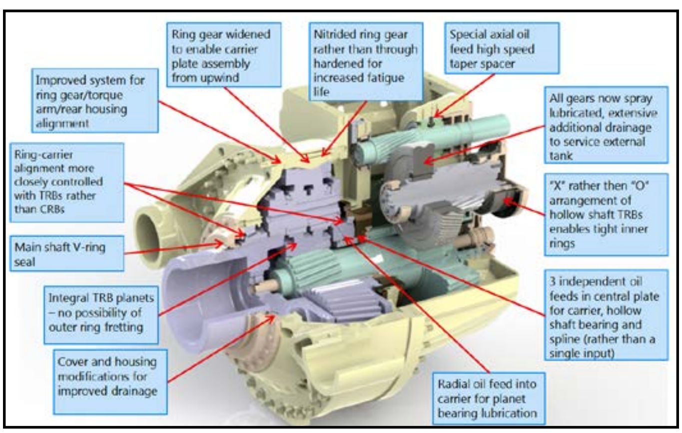

Figure 1 As the wind industry seeks to reduce costs, improvements in gearbox reliability will improve the bottom line.

The 2.5 MW dynamometer at the NREL National Wind Technology Center allows for accurate replication of field conditions encountered by wind turbines such as transient loading, rotor off-axis non-torque loads (NTL), and grid interface conditions. Romax carried out an engineering assessment of the GB3 test article, focusing on the planetary stage modelling, instrumentation, gearbox assembly, and data analysis.

The gearbox was fully modeled in *RomaxWind* as part of the design effort. *RomaxWind* is a drivetrain system modeling tool developed over the last twenty years for wide usage in the rotating machinery industry, particularly in wind turbine gearbox design, automotive and off-highway vehicle drivetrain design. The Romax simulation tools allow the complete gearbox system to be analyzed in a fully coupled 6-DOF environment, including the mechanics and stiffness of gears, bearings, housings, shafts, planet carriers and supporting structures. This allows the prediction of misalignment of the gears and bearings, which is one of the key inputs that affect the durability of these components.

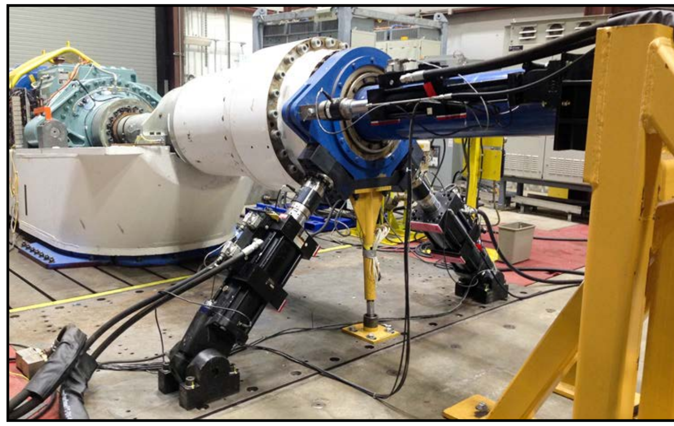

Figure 2 NREL 2.5 MW test stand with GB3 in background, and NTL hydraulic system in the foreground. The NTL system is used to impart non-torque loads into the hub flange of the test article, simulating wind turbine rotor hub loads.

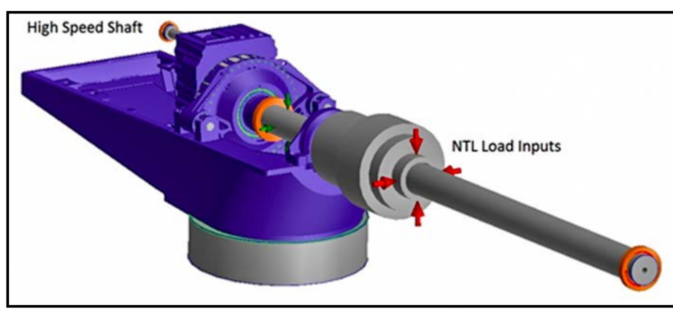

Figure 3 ***RomaxWind*** **analysis model of GB3, including NREL 2.5 MW dynamometer shafting and NTL system.**

The test article was heavily instrumented with strain gauges on the ring gear both internally and externally, strain gauges on the planet bearing inner rings, and proximity sensors to measure carrier alignment to the housing as well as housing alignment to the bedplate. The strain gauges placed within the planet bearings (a pair of tapered roller bearings with the outer races integral to the gear blank) were of particular interest, as this is rarely done. Ten gauges were bonded to the inner races of the bearings (both upwind and downwind) in custom machined grooves. This allowed for the analysis of the variation of the load zone during testing, and correlation with *RomaxWind* predictions created in the design phase of the project.

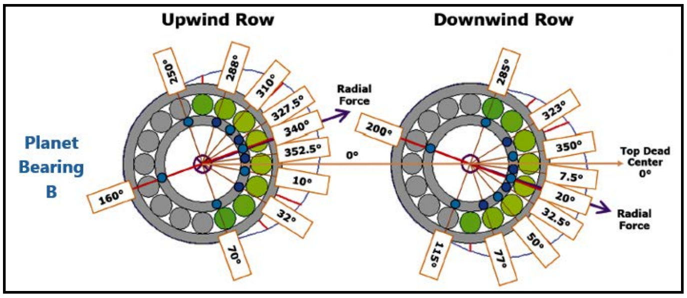

Figure 3 **Instrumentation Layout.**

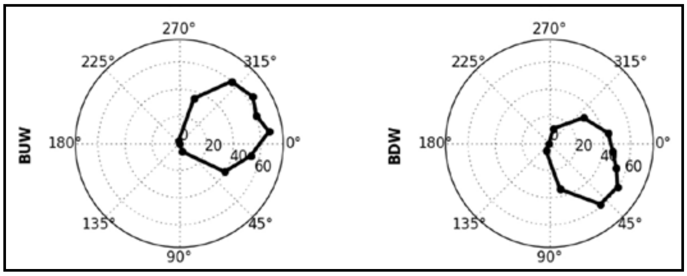

Figure 4 **Experimental Results 100% torque (360 kNm), no NTL.**

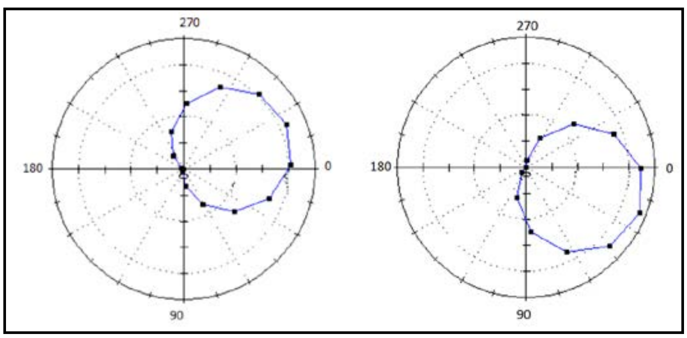

Figure 5 ***RomaxWind* Prediction 100% torque (360 kNm), no NTL.**

As can be seen by comparing the experimental results with *RomaxWind* analysis, load zones are shifted 20 degrees between the upwind bearing and the downwind bearing rows as a result of the tipping moment created by the axial thrust generated from the helix angle on the planetary gear set.

By employing this more rigid pre-loaded TRB pair in each planet of GB3, compared to the more traditional double row cylindrical bearings used in the predecessor gearbox GB2, great increases in planet bearing reliability are realized.

This more rigid arrangement allows for better load share between the upwind and downwind bearings, which in turn leads to increased L10 life, as predicted in *RomaxWind* analysis.

It is this combination of advanced analysis tools yielding insight to the design process, backed by innovative testing to confirm these assumptions, that is closing the gap between design-estimated and actual wind turbine gearbox field reliability. Knowledge gained from the Drivetrain Reliability Collaborative is publicly available to facilitate reliability improvements, and ultimately result in improved gearbox design standards and practices.

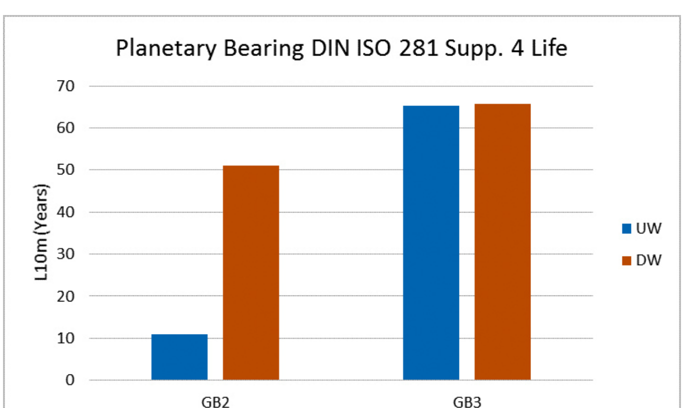

Figure 6 **Planetary bearing L10 life predictions show improved life for GB3 planet bearings as a result of improved load share between the upwind and downwind row. This is a result of the increased rigidity of the pre-loaded TRB pair, compared to the more traditional double row cylindrical roller employed in GB2.**

For more information:

Romax Technology, Inc.
Phone: (970) 397-5253
www.romaxtech.com

Travis Histed is an engineering analyst at Romax and is responsible for delivering project work and assisting customers with solutions. Having joined Romax in 2014, Travis' prior experience includes hydro-turbine analysis and design, natural gas engine fuel delivery systems, and manganese mining in South America before joining Romax in 2014. He graduated from Colorado State University in 2011 with a degree in mechanical engineering.

Chad Glinsky graduated from Michigan State University with a master of science degree in mechanical engineering. His research experience is in drivetrain dynamics and controls of continuously variable transmissions. Prior industry experience includes automotive quality engineering, electromechanical design, and noise and vibration testing. He joined Romax in 2012 as an engineering analyst and is now the Engineering Manager for the US.