Investigating Bearing Failures in Wind Turbine Drivetrains

Jonathan Keller*, Benjamin Gould and Aaron Greco****
*National Renewable Energy Laboratory, Golden, CO, USA, jonathan.keller@nrel.gov
**Argonne National Laboratory, Lemont, IL, USA, bgould@anl.gov
**Argonne National Laboratory, Lemont, IL, USA, agreco@anl.gov

Abstract
The most prevalent failure modes in wind turbine drivetrains are main bearing failures stemming from micropitting, white etching or axial cracks in gearbox bearings, and generator bearing failures. These failures are neither well understood nor accounted for in design standards; consequently, the mitigation strategies being developed and fielded may only partially address the physics of failure and can take years to assess. The U.S. Department of Energy continues to support research programs to investigate the influence of rotor loads on planetary gear and bearing load-sharing, rolling element sliding on the formation of bearing axial cracks and main bearing micropitting.

Keywords: *gearbox, bearing, load-sharing, micropitting, axial crack, white etch crack*

Introduction
Although the cost of energy from wind has declined tremendously during the past three decades, wind power plant operation and maintenance (O&M) costs remain an appreciable contributor to the overall cost of wind energy. Wind plant O&M averages $10 per megawatt-hour at recently installed wind plants, accounts for 20% or more of the wind power purchase agreement price and generally increases as the wind plant ages. Approximately 50% of the total wind plant O&M costs are related to wind turbine O&M, and a sizeable portion of these higher than anticipated costs is related to reliability of the wind turbine drivetrain [1]. The most prevalent failures in wind turbine drivetrains are main bearing failures stemming from micropitting, so-called axial cracks or “white etching” cracks (WECs) in gearbox bearings, and generator bearing failures prior their expected design life [1]. This paper summarizes key research findings to date into planetary load-sharing characteristics and the importance of rolling element sliding on bearing axial cracks. Ongoing research and full-scale testing of the causes of main bearing micropitting and bearing roller sliding is also discussed.

Approach
The U.S. Department of Energy established the Gearbox Reliability Collaborative (GRC) with the goal of understanding the root causes of premature gearbox failures and improving gearbox reliability in 2007. Since that time, the focus has expanded to include the main bearing and renamed the Drivetrain Reliability Collaborative (DRC). The program conducts research and testing ranging from benchtop tests of materials and tribological effects at the scale of 100 μm at Argonne National Laboratory to full-scale wind turbine tests with rotor diameters of approximately 100 m at the National Wind Technology Center.

Results
Although planet gear and bearing failures are not predominant, they are extremely costly when they occur as they typically require replacement of the entire gearbox with a large crane. In planetary gearboxes, design life can only be achieved if the loads are distributed equally among the planet gears. It is generally agreed that a three-planet gear set with a floating central member has equal load sharing regardless of manufacturing errors; however, in wind turbines the combination of bearing clearance, gravity and rotor moments can cause unequal load sharing and increase bearing loads and contact stresses. The planetary load-sharing characteristics of 750 kilowatt wind turbine gearboxes supported by cylindrical roller bearings (CRBs) and preloaded tapered roller bearings (TRBs) when subjected to rotor moments was investigated [2]. The measured load in the gearbox with CRBs was found to be as much as 47% more than assumed, compared to only 14% more in the preloaded TRBs as shown in Figure 1. Consequently, the predicted planetary TRB fatigue life is 3.5 times greater than the CRB fatigue life.

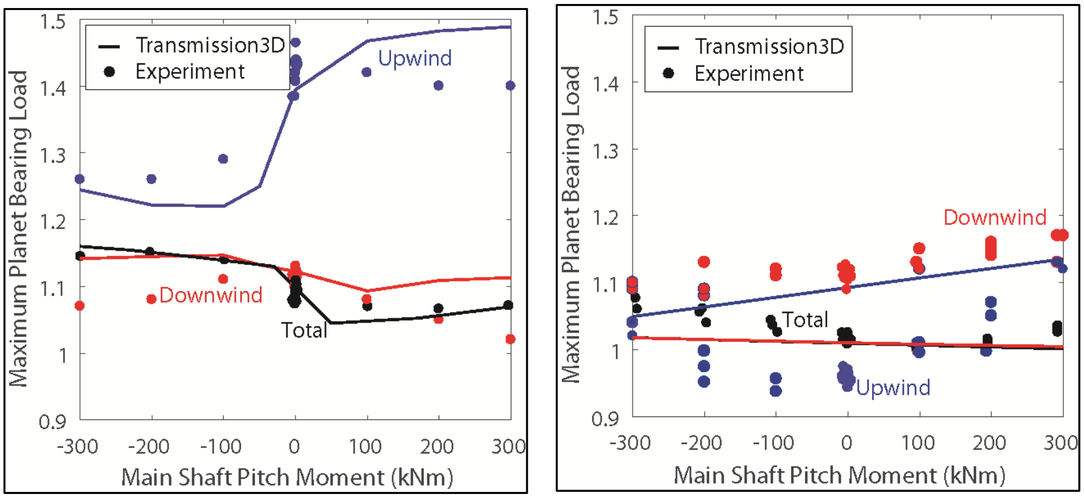

Figure 1. Maximum planet bearing loads in CRBs (left) and TRBs (right) [2]

Although planetary failures have high repair costs, the most commonly damaged components in wind turbine gearboxes are the rolling element bearings in the intermediate and high-speed parallel stages due to WECs. Although these types of cracks have been reported for over a decade, the conditions leading to WECs, the process by which this failure culminates, and the reasons for their apparent prevalence in wind turbine gearboxes are all highly debated. WECs have been generated on a three-ring-on-roller benchtop test rig in highly-loaded sliding conditions as shown in Figure 2. Both loads and sliding at full scale will be measured in planned uptower drivetrain testing and their contribution to WECs assessed [3].

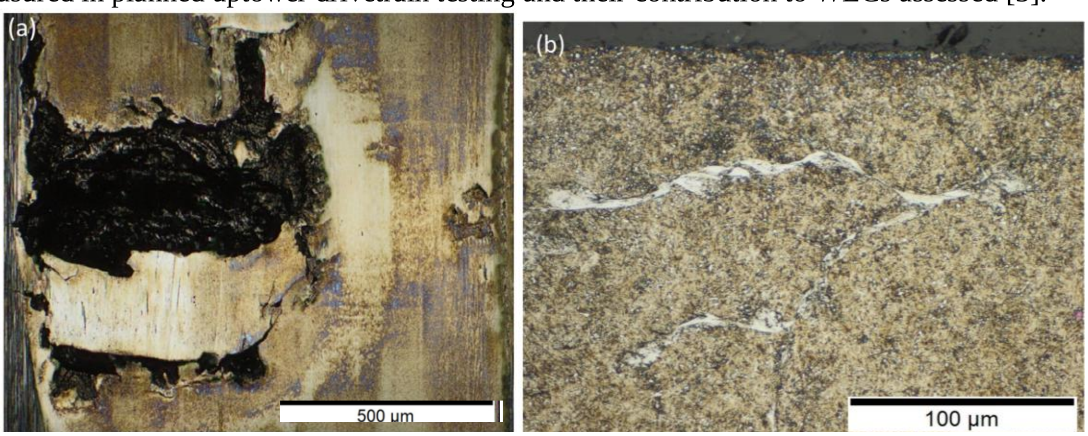

Figure 2. View of roller race spall (left) and cross section with WECs (right) [3]

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