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Validation of a Model of the NREL Gearbox Reliability Collaborative Wind Turbine Gearbox

By C. Halse, Z. Wright, and
A. Crowther, Romax Technology
Inc.

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Christopher Halse, Zachary Wright and Ashley Crowther, Romax Technology Inc.,

[The statements and opinions contained herein are those of the author and should not be construed as an official action or opinion of the American Gear Manufacturers Association.]

Abstract

Gearboxes in the wind industry have been suffering from a poor reputation due to major issues with reliability. There has been a long list of issues; e.g. grind temper, material inclusions, axial cracking in bearings, poor load sharing on shaft-bearing arrangements, significant gear misalignment, bearing ring creep, gear scuffing, gear and bearing micro-pitting; all of which are common and often serial problems. There has been improvement in the last few years for some of the products, yet it is not uncommon for wind sites built as recently as 2008 to have 20 - 40% of gearboxes requiring a component replacement (such as a high speed pinion or intermediate shaft bearing) already (by 2012) and 5-10% complete gearbox failures. An important program for the industry, "The Gearbox Reliability Collaborative" (GRC), has been funded by the US Department of Energy and run by the National Renewable Energy Laboratory for several years to aid the industry in improving the reliability of this key component. The collaborative has brought together manufacturers, academia, national laboratories, engineering consultants and gear and bearing software providers as part of a program to model, build, simulate and test gearboxes with a goal to improve reliability and reduce the cost of energy.

The team at NREL have instrumented two gearboxes with over 125 channels, for measurements such as planetary tooth load distributions, ring gear hoop strains, planet bearing load distribution, sun orbit and carrier deflection. They were then subjected to a rigorous testing regime, both up-tower and on the NREL 2.5MW dynamometer. Romax Technology has been a collaborator in the GRC Analysis Group and has developed detailed computer simulation models of the gearbox including gear macro and micro-geometry, bearing macro and micro-geometry, structural stiffness of gearbox housing, carrier and ring gear, system clearances and preloads, and surrounding boundary conditions (such as main shaft, rotor hub and bedplate). The model is used for accurate simulation of the whole system deflections and the prediction of the resulting gear and bearing contact conditions under various loading conditions.

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American Gear Manufacturers Association
1001 N. Fairfax Street, Suite 500
Alexandria, Virginia 22314

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Christopher Halse, Zachary Wright, and Ashley Crowther, Romax Technology Inc.

Introduction

Wind power has grown to be an important part of the energy mix in the U.S., contributing 35% of all new generating capacity constructed in the last 5 years, and with a total of 48,611MW of installed capacity and 8,900MW under construction as of May 2012 [American Wind Energy Association]. The state with the largest installed capacity, Texas, can sometimes generate over 20% of demand from wind [New York Times]. Wind power has the lowest “life cycle emissions” of all energy production technologies, paying back the energy used in turbine manufacturer, installation, operation, maintenance and decommissioning in three to six months [European Wind Energy Association].

Most wind turbines contain speed-increasing gearboxes to convert the slow main rotor speed into the 1000 rpm range for convenient generator operation. However, many wind turbine gearboxes have a poor reputation due to poor reliability. There have been many issues; grind temper, material inclusions, axial cracking in bearings, poor load sharing on shaft-bearing arrangements, significant gear misalignment leading to premature wear, bearing ring creep, gear scuffing, and gear or bearing micro-pitting. These are all common and often serial problems. There has been improvement in the last few years for some products as common failure modes have been addressed, yet it is not uncommon for wind sites built as recently as 2008 to have 20–40% of gearboxes requiring a component replacement (such as a high speed pinion or intermediate shaft bearing) by 2012 and 5–10% complete gearbox failures.

Some OEMs are manufacturing direct-drive wind turbines, where the generator rotor turns at the speed of the main rotor. This can lead to challenging structural engineering in maintaining a small generator air gap at a large diameter, inconvenient assembly and difficult transportation. Capital costs are high for direct drive and long term reliability is unknown. However, some manufacturers accept these increased risks as the reduction in operating expenditure from removing the gearbox is perceived to be so great. Without an improved understanding of gearbox failure modes and more reliable gearbox products, this important market for the gear industry is in danger of being eroded by growth in the use of direct drive machines.

An important program for the industry, “The Gearbox Reliability Collaborative” (GRC), has been funded by the Department of Energy and run by the National Renewable Energy Laboratory (NREL) for several years. The collaborative has brought together OEMs, component suppliers, academia, national laboratories, engineering consultants and software providers as part of a program to test gearboxes, validate software models and verify design assumptions. The overall goal is to improve gearbox reliability and reduce the cost of energy produced by wind turbines.

The NREL GRC team has delivered an extensive instrumentation and testing effort on two 750kW gearboxes, described further below. The contribution of the authors to the project has been as members of the Analysis Team as well as designers of revisions to the next gearbox (being built in 2013). The focus of this paper is a comparison between measurement and simulation of key parameters; gear load distributions, annulus deflection, carrier deformation and planetary gear load sharing. The simulation results that are robust and those that are sensitive to hard-to-predict parameters such as manufacturing and assembly variations will be outlined. Lessons learned in how best to apply computer-aided-engineering tools to improve wind turbine gearbox reliability will be described.

Test articles

Tests were carried out on two 750kW wind turbine gearboxes obtained by NREL. They were modified to have typical wind turbine bearing arrangements and using typical design practices. The aim of this original

modification was not to solve all problems in the design, rather it was to create gearboxes that were similar to the fleet of modern wind turbine gearboxes in operation. One of the gearboxes was tested in the NREL dynamometer, the other was operated in the field in a wind turbine.

The gearboxes are speed increasers, with the input shaft attached to the wind turbine rotor and the output shaft attached to a high speed coupling which in turn drives a generator. The first (input) stage is a planetary helical gear stage with three planets, with input on the carrier, the ring fixed and the output on the sun. The sun is splined into a hollow shaft to allow some float, and then the second and third stages are parallel helical gears. The carrier bearings and planet gear bearings are cylindrical roller bearings, whilst each of the hollow shaft, intermediate shaft and high speed shaft are supported by a double-row taper roller bearing and a cylindrical roller bearing. Oil is fed into the rotating carrier and rotating hollow shaft via “oil feed rings” to enable oil to reach the planet bearings and the sun to hollow shaft spline. The labels used for the gears and bearings are shown in Figure 1.

Measurement campaign

NREL’s measurement campaign was extensive with particular focus on measurement of system deflections and load distributions in planet-ring meshes and planet bearings. The gearboxes were instrumented with over 125 channels, for measurements including planetary tooth load distributions, ring gear hoop strains, planet bearing load distribution, sun gear orbit and carrier deflection. They were then subjected to a rigorous testing regime, both up-tower and on the NREL 2.5MW dynamometer. The measurements used so far for the validation work are briefly described below, but for more details of these and all the other measurements the full GRC report is from Phases 1 & 2 is publicly available [<http://www.nrel.gov/docs/fy11osti/51885.pdf>, NREL/TP-5000-51885 Gearbox Reliability Project Report: Findings from Phase 1 & Phase 2 Testing].

The ring gear strain was measured in the tooth roots at several positions across the face width and at three positions around the circumference to simultaneously capture the loading on each planet.

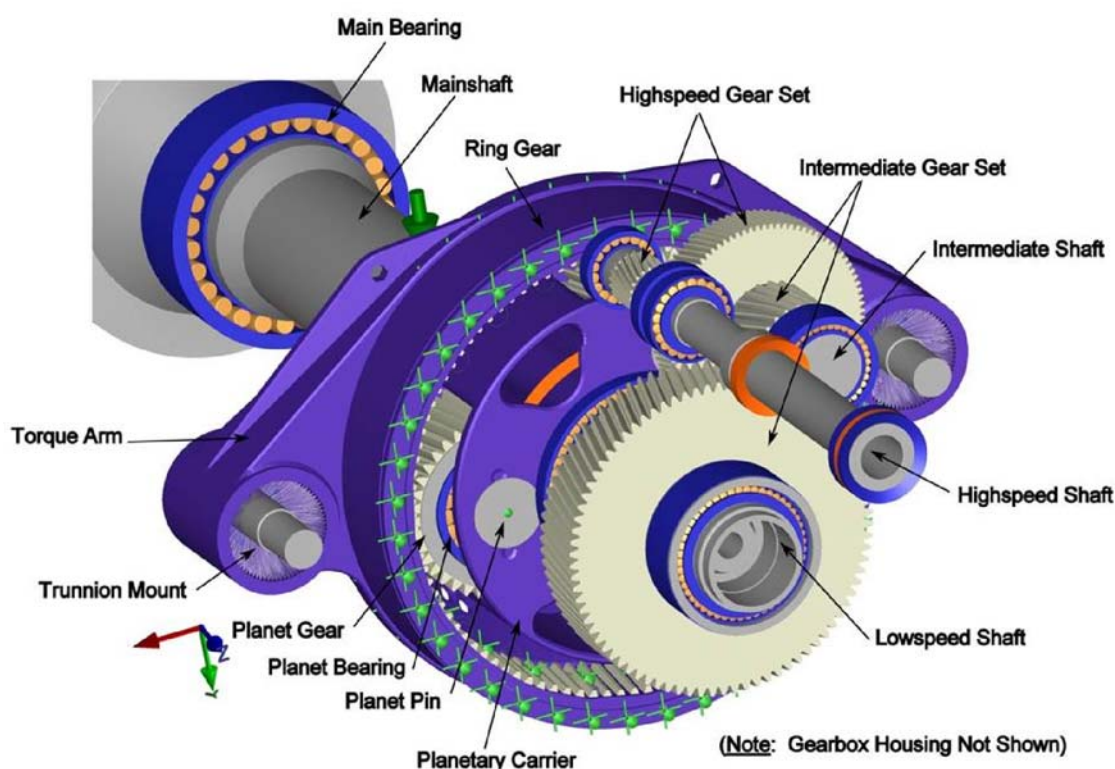


Figure 1. Illustration of gearbox model with part labels (gearbox housing hidden)