Wind Turbine Gearbox Vibration Condition Monitoring Benchmarking Datasets

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1 Background

The wind industry has experienced tremendous growth during the past few decades. By the end of 2013, the global installed capacity of wind power had reached more than 318 GW, according to the Global Wind Energy Council. Although this is very encouraging, the industry is still challenged by premature turbine component failures. With the increase in turbine size, these failures, especially those found in the major drive train components, i.e. main shaft, gearbox, and generator, have become extremely costly. To reduce the cost of wind energy, improvement in drive train reliability is critical.

Given that gearbox is the most costly component in the drivetrain to maintain throughout the expected 20-year design life of a wind turbine, the National Renewable Energy Laboratory (NREL) has investigated the root causes and loading conditions that result in the premature failure of wind turbine gearboxes [1] through a consortium called the Gearbox Reliability Collaborative (GRC). The GRC brings together different parties involved in the gearbox design, manufacture and operations process with the common goal of extending the lifetime of gearboxes. To achieve this goal, the GRC took a multitrack approach including extensive measurement of gear and bearing loads and displacements through dynamometer and field testing, modeling & analysis, condition monitoring, and development of a gearbox failure database. The condition monitoring (CM) and gearbox failure database had been two research areas under the GRC until October, 2012 and were combined to form a standalone wind plant operation and maintenance (O&M) project thereafter.

CM can potentially help the wind industry reduce turbine downtime and O&M cost. NREL CM research has investigated various techniques such as acoustic emission (AE – specifically stress wave), vibration, electrical signature, lubricant and debris monitoring based on the data gathered during GRC dynamometer and field tests [2], and other test turbines or resources accessible by NREL. During the past several years of the NREL CM research, it has been observed that there is a lack of validation and verification efforts on commercial wind turbine CM systems. One of the reasons might be limited benchmarking datasets accessible by stakeholders. To fill this gap, NREL executed a data collection effort. This document describes the data collection effort and the shared datasets. The targeted users of these datasets include those investigating vibration-based wind turbine CM research, evaluating commercially available vibration-based CM systems, or testing prototyped vibration-based CM systems.

The data was collected from a "healthy" and a "damaged" gearbox of the same design under the GRC dynamometer tests. Vibration data were collected by accelerometers along with high-speed shaft RPM signals. The "healthy" gearbox was only tested in the dynamometer. The "damaged" gearbox first finished run-in in the dynamometer and was later sent to a wind farm close to NREL for field testing. In the field test, it experienced two loss-of-oil events that damaged its internal bearings and gear elements. It was brought back to NREL at which point CM equipment was installed and then retested under controlled loading conditions that would not cause catastrophic failure of the gearbox.

By releasing these datasets along with real damage occurred to the "damaged" gearbox, the intension is to provide the wind industry some benchmarking datasets benefiting research, development, validation, verification, and advancement of vibration-based wind condition monitoring techniques.

The rest of the document will introduce the test article, the collected data, and the actual damage that occurred to the "damaged" gearbox.

2 Test Article

2.1 Test Environment

The NREL dynamometer test facility (DTF) was utilized for the benchmarking data collection.

2.2 Test Turbine

The test turbine (Figure 1) is a stall-controlled, three-bladed, upwind turbine with a rated power of 750kW. The turbine generator operates at 1800 rpm and 1200 rpm nominal on two different sets of windings depending on the power.

The complete nacelle and drivetrain was installed in the NREL DTF and hard fixed to the floor without the hub, rotor, yaw bearing or yaw drives. The actual field controller was used to provide start-up and system safety responses.

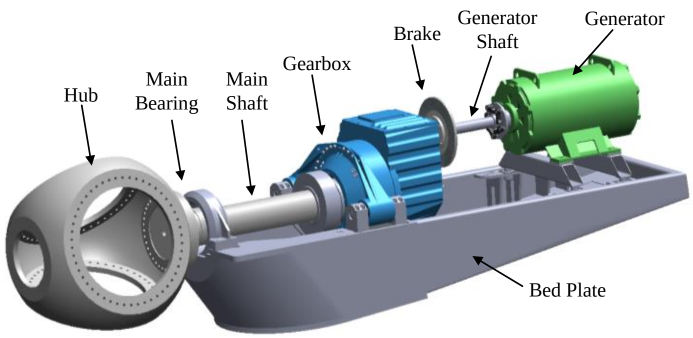

Figure 1: Test turbine drive train configuration

2.3 Test Gearboxes Description

The two test gearboxes were originally taken from the field and redesigned with the same configuration, rebuilt and instrumented with over 125 sensors. Both gearboxes have an overall ratio of 1:81.49. Each

gearbox is composed of one low speed (LS) planetary stage and two parallel stages as shown in the expanded view in Figure 2. Nomenclature for the internal elements of the test gearboxes is described in Figure 3, and the gear dimensions, teeth number and helix are listed in
Table 1.

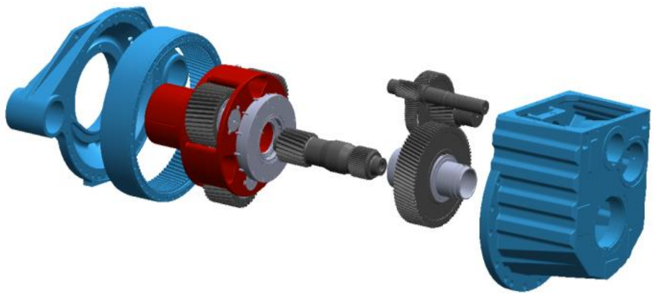

Figure 2: Test gearbox internal components view

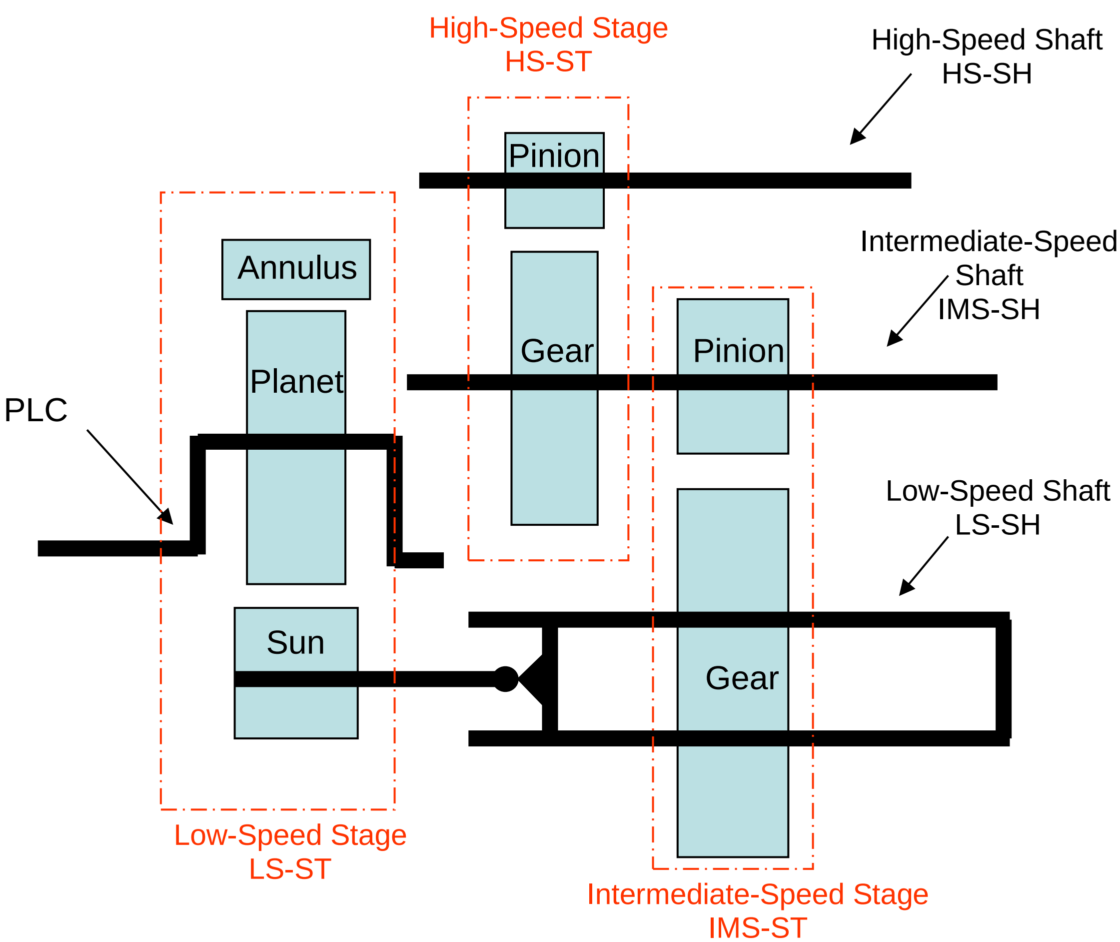

Figure 3: Test gearbox internal nomenclature and abbreviations

Table 1 Gear element dimensions and details

Gear Element	No. of Teeth	Mate teeth	Root diameter (mm)	Helix angle	Face width (mm)	Ratio
Ring gear	99	39	1047	7.5L	230	
Planet gear	39	99	372	7.5L	227.5	
Sun pinion	21	39	186	7.5R	220	5.71
Intermediate gear	82	23	678	14R	170	
Intermediate pinion	23	82	174	14L	186	3.57
High-speed gear	88	22	440	14L	110	
High-speed pinion	22	88	100	14R	120	4.0
					Overall:	81.49

2.4 Bearing Arrangements

Several bearing types are employed in each of the two gearboxes according to the loading conditions and gearbox life requirements. The planet carrier is supported by two full-complement cylindrical roller bearings (fcCRB) and each planet gear is supported by two identical cylindrical roller bearings (CRB). Each parallel shaft in the gearbox is supported by a (CRB) on the upwind side of the assembly, and by two back-to-back mounted, tapered roller bearings (TRB) on the downwind side. Table 2 provides the location and bearing manufacturer part number of all bearings in the gearbox and Figure 4 is a graphic illustration of the bearing nomenclature and location. The letter following the abbreviation indicates the position of the bearing according to the component from upwind (A) to downwind (B, C).

Table 2: Bearing type, number and location

Location	Location Designation	Type	Provider	Part Number
Planet carrier	PLC-A	fcCRB	INA	SL 18 1892E
	PLC-B	fcCRB	INA	SL 18 1880 72/K10
Planet	PL-A	CRB	FAG	NJ2232E.M1.C3
	PL-B	CRB	FAG	NJ2232E.M1.C3
Low-Speed Shaft	LS-SH-A	fcCRB	INA	SL 18 1856E
	LS-SH-B	TRB	SKF	32948*
	LS-SH-C	TRB	SKF	32948*
Intermediate-Speed Shaft	IMS-SH-A	CRB	FAG	NU2220E.M1.C3
	IMS-SH-B	TRB	SKF	32032 X
	IMS-SH-C	TRB	SKF	32032 X
High-Speed Shaft	HS-SH-A	CRB	FAG	NU2220E.M1.C3
	HS-SH-B	TRB	SKF	32222 J2
	HS-SH-C	TRB	SKF	32222 J2

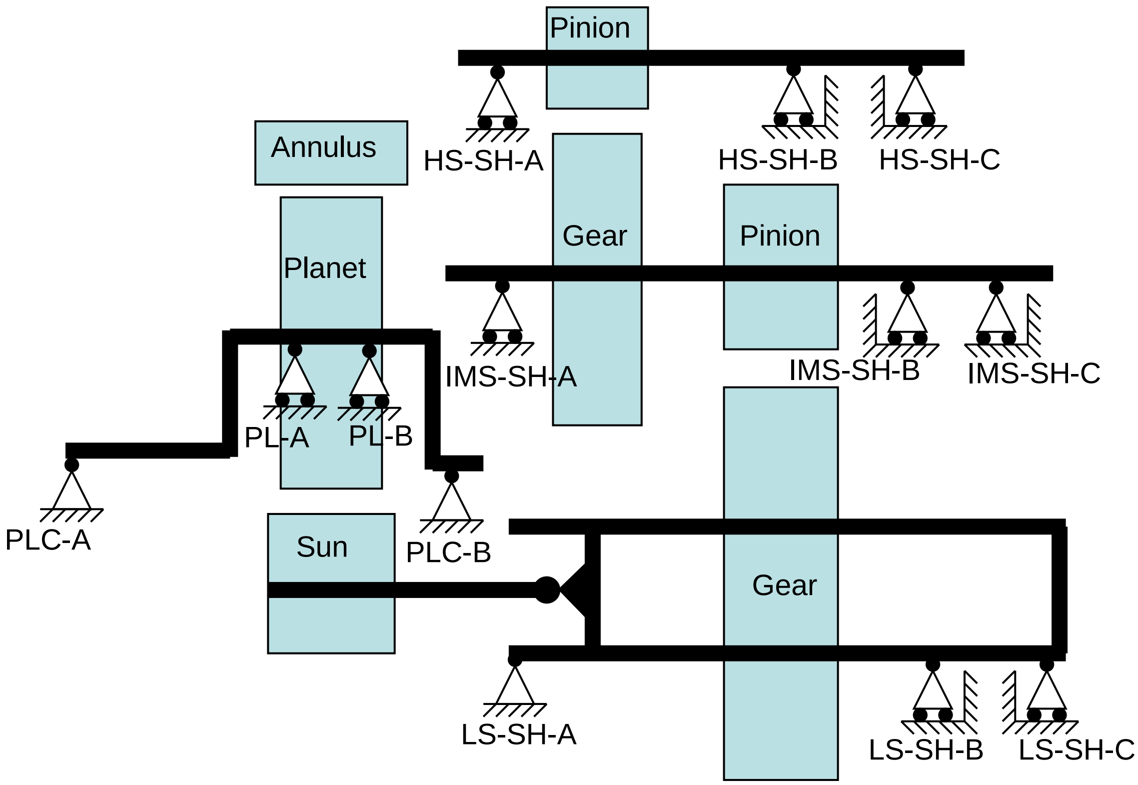

Figure 4: Test gearbox bearing nomenclature and location

2.5 Kinematics

The operating gear mesh and bearing characteristic frequencies can be determined based on the data in Table 2 and catalogue information from bearing suppliers.

3 Vibration Data

3.1 Description

Accelerometers were mounted on the outside of the gearbox to sense vibratory acceleration.

3.2 Instrumentation

Data was collected at 40 kHz per channel using a National Instruments PXI -4472B high speed data acquisition system (DAQ). Generator speed was recorded in addition to the accelerometer data.

3.3 Sensor Locations

The accelerometers were mounted as listed in

Table **3** and as shown in Figure 5 and Figure 6. Signal descriptions, signal labels, sensor model and units are also included.

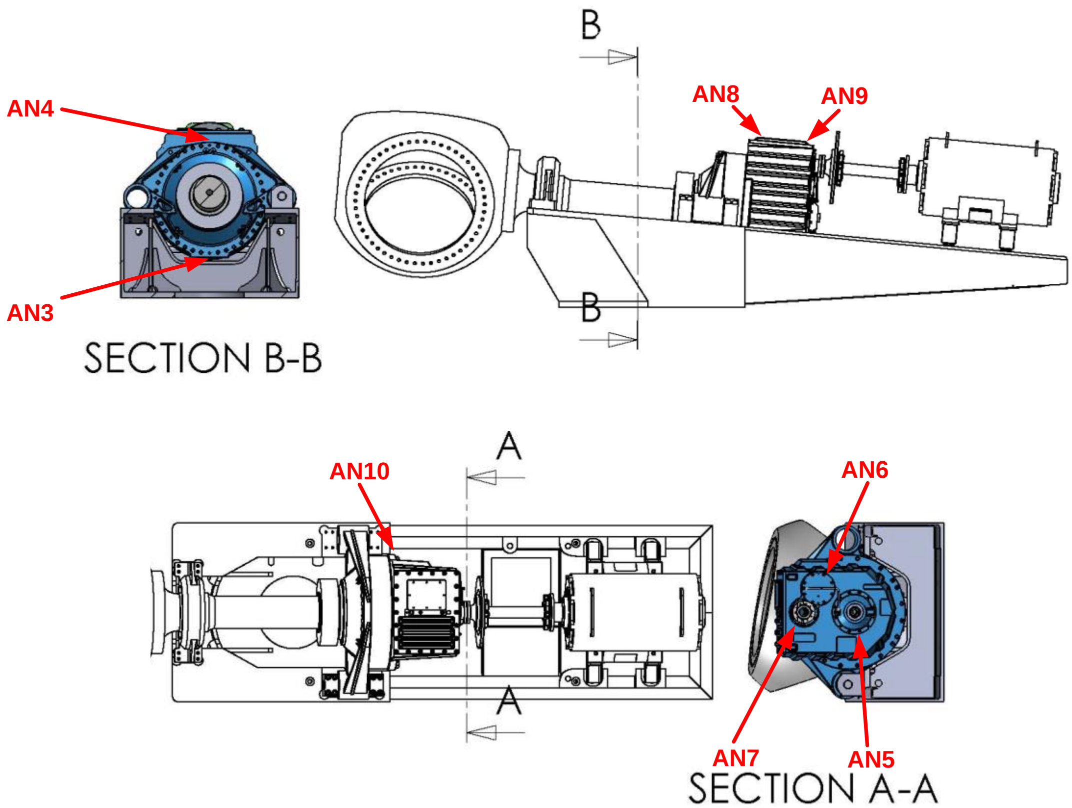

Figure 5: Vibration sensor locations

(a) AN3 to AN6 (Left to Right)

(b) AN7 to AN10 (Left to Right)

Figure 6: Vibration sensors physical installations

Table 3: Sensor locations and descriptions

Sensor Label/Signal Name (see Figure 5**)**	**Description**	**Sensor Model**	**Units in Data File**
AN3	Ring gear radial 6 o'clock	IMI 626B02	m/s^2
AN4	Ring gear radial 12 o'clock	IMI 626B02	m/s^2
AN5	LS-SH radial	IMI 622B01	m/s^2
AN6	IMS-SH radial	IMI 622B01	m/s^2
AN7	HS-SH radial	IMI 622B01	m/s^2
AN8	HS-SH upwind bearing radial	IMI 622B01	m/s^2
AN9	HS-SH downwind bearing radial	IMI 622B01	m/s^2
AN10	Carrier downwind radial	IMI 626B02	m/s^2
Speed*	HS-SH		rpm

*Format is not the same for data collect from the "healthy" test gearbox.

3.4 Test Data

Data is provided in engineering units and does not have to be adjusted, scaled or modified.

3.5 Data File Description

The data files are provided in the following format:

a. Matlab packed binary format for direct import into Matlab (*.mat). Header information is included that identifies signals (variables). File converters/importers should be readily available for large data handling.
b. Ten 1 minute data sets for the test condition described in Table 4. Files are labeled, for example, as H1.mat for the first 1 minute of test data on the "healthy" gearbox.
c. 40 kHz data provided in 10 one dimensional arrays, no time channel is included.

Table 4: Test Condition

Main Shaft Speed (rpm)	**Nominal HSS Speed** (rpm)	**Electric Power** (% of rated)	**Duration** (min)
22.09	1800	50%	10

4 Actual Gearbox Damage

The "damaged" gearbox experienced two oil-loss events in the field and was later disassembled and a detailed failure analysis was conducted [3]. Table 5 gives a compiled list of the actual damage occurred to the test gearbox and also deemed detectable through vibration analysis.

Table 5: Actual Gearbox Damage Deemed Detectable through Vibration Analysis

Damage #	Component	Mode
1	HS-ST gear set	Scuffing
2	HS-SH downwind bearings	Overheating
3	IMS-ST gear set	Fretting corrosion, scuffing, polishing wear
4	IMS-SH upwind bearing	Assembly damage, scuffing, dents
5	IMS-SH downwind bearings	Assembly damage, dents
6	Annulus/ring gear, or sun pinion	Scuffing and polishing, fretting corrosion
7	Planet carrier upwind bearing	Fretting corrosion

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References

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