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NATIONAL RENEWABLE ENERGY LABORATORY

Gearbox Reliability Collaborative Update: A Brief




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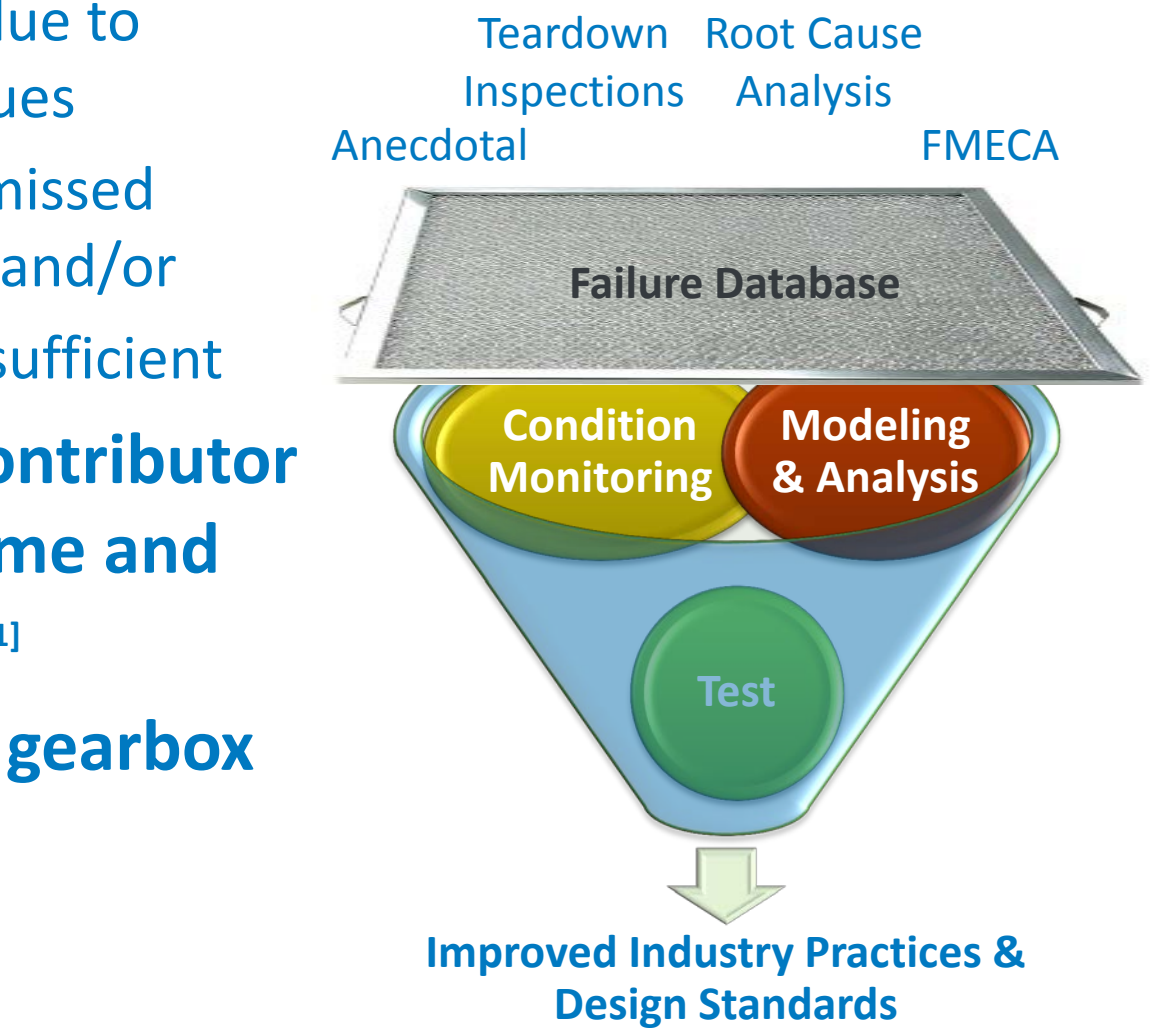
Outline

- Gearbox Reliability Collaborative (GRC)
- Failure Database
- GRC Test Gearbox 1 Damage
- Condition Monitoring
- GRC Status Update

Gearbox Reliability Collaborative (GRC)

- **Disparity between expected and actual gearbox life**
  - Widespread, not due to manufacturing issues
  - Critical elements missed in design process, and/or
  - Analytical tools insufficient
- **Gearbox largest contributor to turbine downtime and costliest to repair**[1]
- **How do I design a gearbox for reliability?**



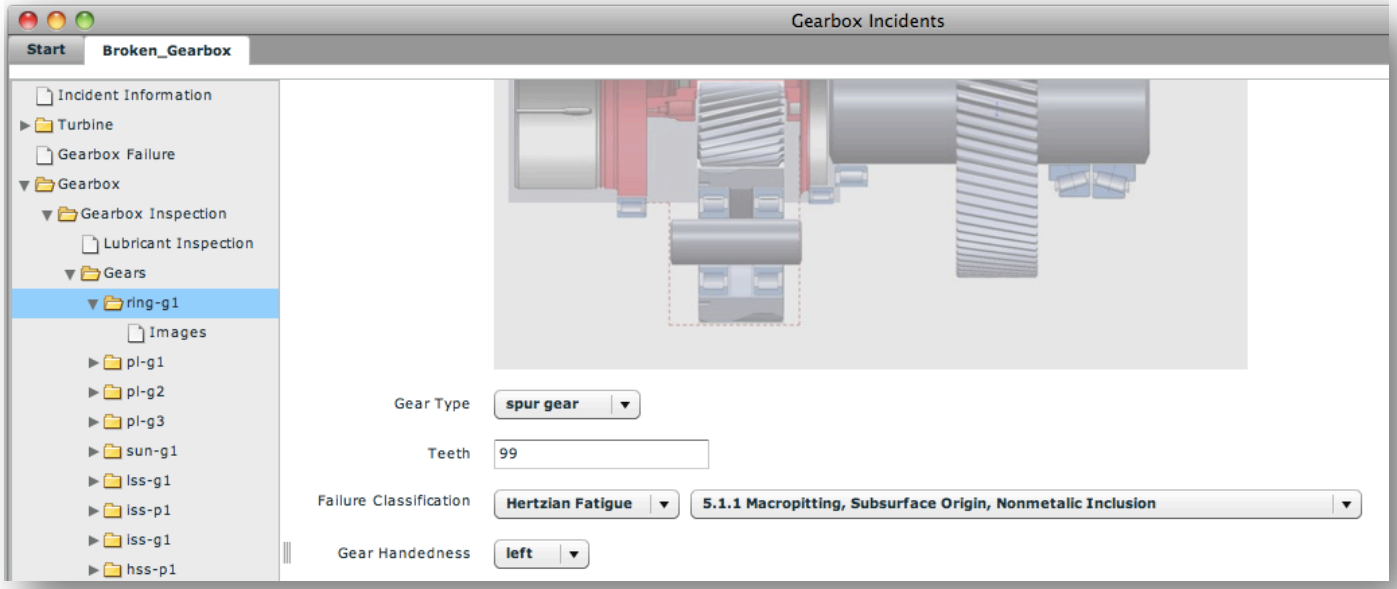
[1] WindStats Newsletter, Vol. 16 Issue 1 to Vol. 22 Issue 4, covering 2003 to 2009

Failure Database

- **Collect information on gearbox rebuilds**
  - In shop and on tower
  - Existing data from papers, Excel spreadsheets
- **Quantify magnitude and cost of gearbox problems**
  - Expensive uncertainty
- **Focus research accurately**
  - Aid root cause analysis and correction
- **Provide objective record of improvements**
  - Analyze and close loop when solutions found
- **Sanitized data shared among GRC members**

Failure Database Software

- **Structured data collection**
  - Navigation tree
- **Visually oriented**
  - Wireless image from camera to software fields
- **Embedded failure codes**



Incidents Summary

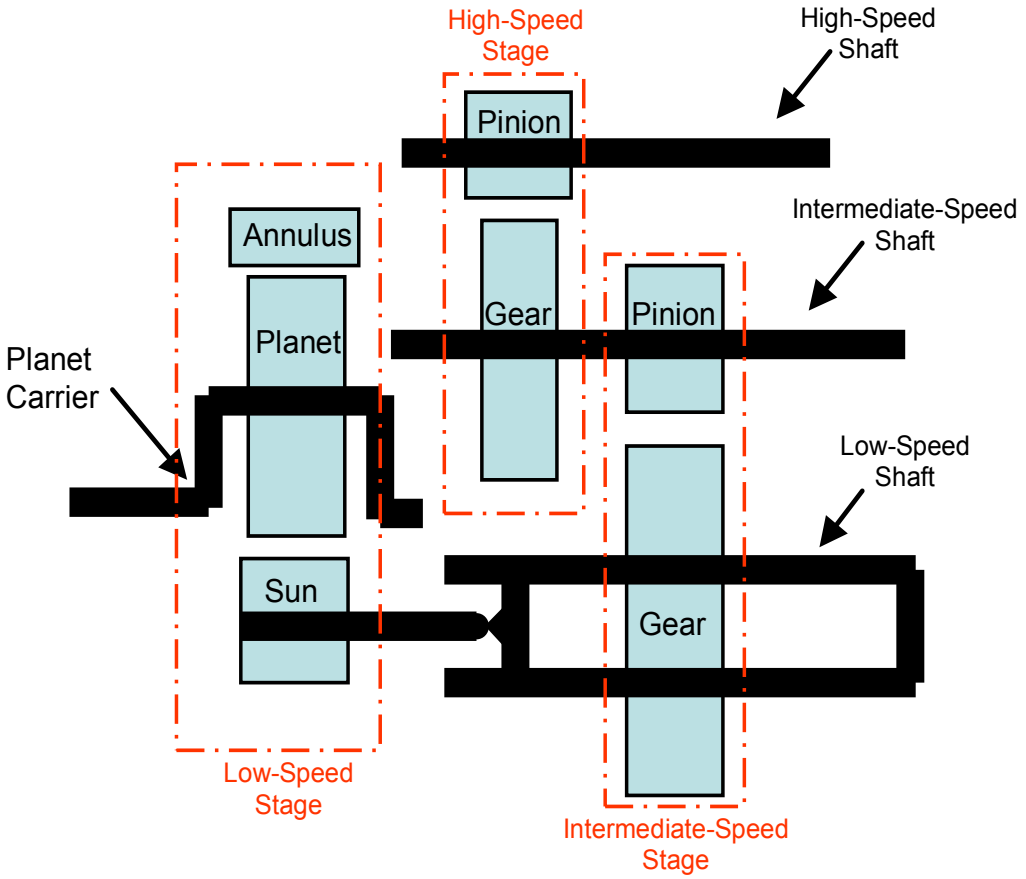
- 37 incidents: 36 involving bearings and 22 gear failures[2]
  - Top modes highlighted in RED

Quantity	Component	Code	Description
1	bearing	5.4.3	Hertzian Fatigue, Micropitting, Edge of Raceway
1	bearing	6.1.1	Wear, Adhesion, Mild
3	**bearing**	**6.1.3**	**Wear, Adhesion, Severe (Scuffing)**
4	**bearing**	**6.2.1**	**Wear, Abrasion, Two-body**
10	**bearing**	**6.2.2**	**Wear, Abrasion, Three-body**
1	bearing	6.2.3	Wear, Abrasion, Polishing
14	**bearing**	**8.1.1**	**Cracking: Roller and Ring Cracks, Hardening Cracks**
2	bearing	8.1.2	Cracking: Roller and Ring Cracks, Grinding Cracks
1	gear	3.1	Overload, Fracture, Brittle
1	gear	4.1	Bending Fatigue, Low Cycle
2	gear	5.3	Hertzian Fatigue, Subcase Fatigue
6	**gear**	**6.4**	**Wear, Fretting-Corrosion**
2	gear	4.2.1	Bending Fatigue, High Cycle, Root Fillet Cracks
3	**gear**	**4.2.2**	**Bending Fatigue, High Cycle, Profile Cracks**
2	gear	6.1.1	Wear, Adhesion, Mild
1	gear	6.2.2	Wear, Abrasion, Moderate
4	gear		not found

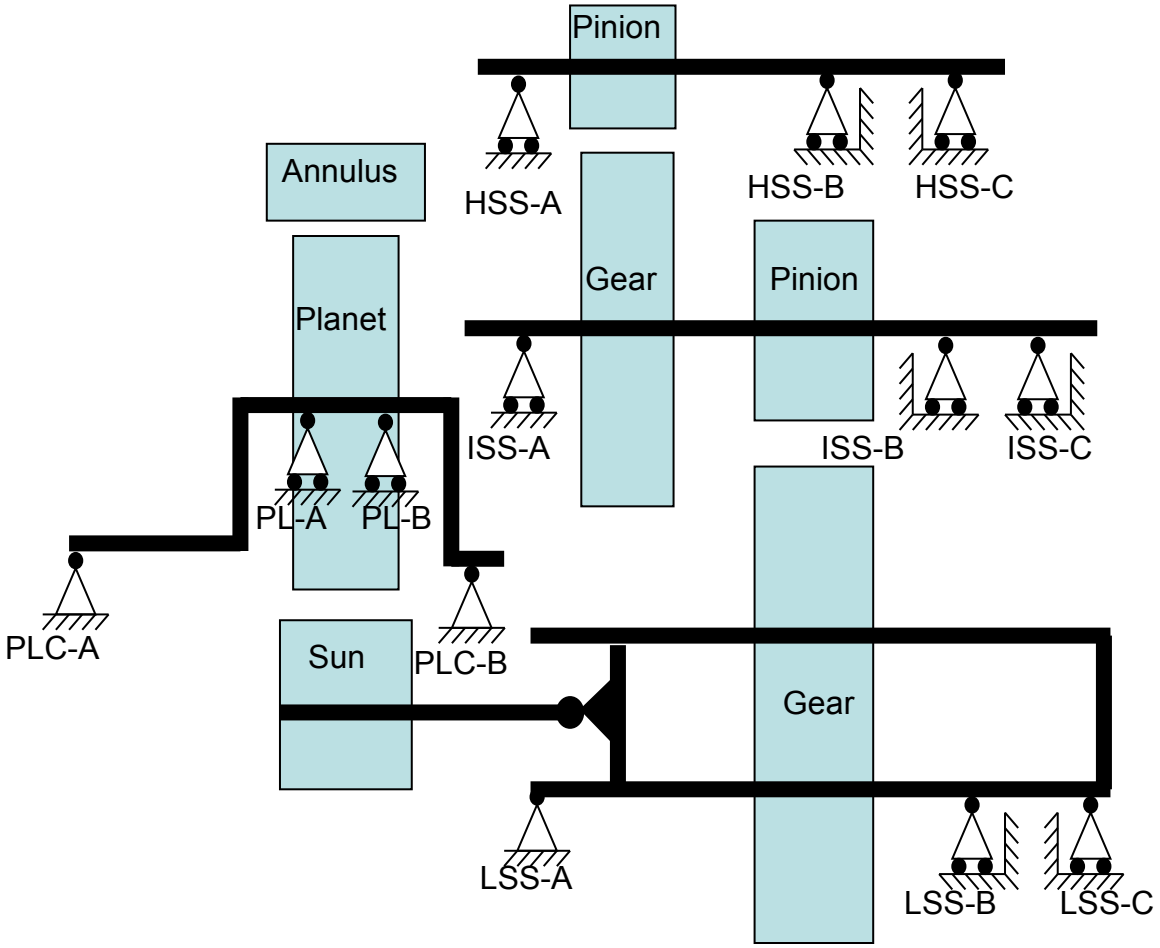
[2] Wind Turbine Failure Modes – A Brief, ASME/STLE 2011 International Joint Tribology Conference, NREL PR-5000-53084.

One GRC Test Gearbox

- A 750-kW wind turbine gearbox
- One planet and two parallel stages, floating sun
- Pressurized lubrication for all but the planet gears and the ring gear



Bearing Nomenclature



Acronym	Definition
PLC	Planet Carrier
PL	Planet
LSS	Low-Speed Shaft
ISS	Intermediate-Speed Shaft
HSS	High-Speed Shaft

Bearing PLC-A Outer Raceway (Severe Fretting Corrosion) *Photo from GEARTECH, NREL/PIX 19748*

Real Damage [2]

- Severe damage highlighted in **RED**

Failure #	Component / Location	Mode	Severity
1	HSS Gear Set	**Scuffing**	Severe
	(HSS Gear and HSS Pinion)		
2	HSS Downwind Bearings	Overheating	Mild
	(IR and Rollers)		
3	ISS Gear Set	**Fretting Corrosion**	Severe
	(ISS Gear and Pinion)	**Scuffing**	
	(All Teeth)	**Polishing Wear**	
	(Sun Spline)		
4	ISS Upwind Bearing	Assembly damage	Moderate
	(IR)	Plastic deformation	
		Scuffing	
		False brinelling	
		Debris dents	
		Contact Corrosion	
5	ISS Downwind Bearings	**Assembly damage**	Severe
	(OR Spacer for both Bearings)	Plastic deformation	
		Dents	
6	Annulus/Ring Gear, or Sun Pinion	Scuffing and polishing	Moderate
		Fretting Corrosion	Severe
7	Planet Carrier Upwind Bearing	**Fretting Corrosion**	Severe
	(Container and OR)		

Real Damage (*Cont.*)

9	Oil Transfer Ring for Planet Carrier	Polishing	Mild
	(Bore)		
10	LSS	**Scuffing**	Severe
	(Shaft and O-ring Seal Plate)		
11	LSS Downwind Bearings	**Abrasion**	Severe
	(Locknut)		
12	HSS Shaft	Misalignment	Mild

- Two main root causes
  - Oil starvation
  - Assembly damage
- Simple triggers may lead to complex damage

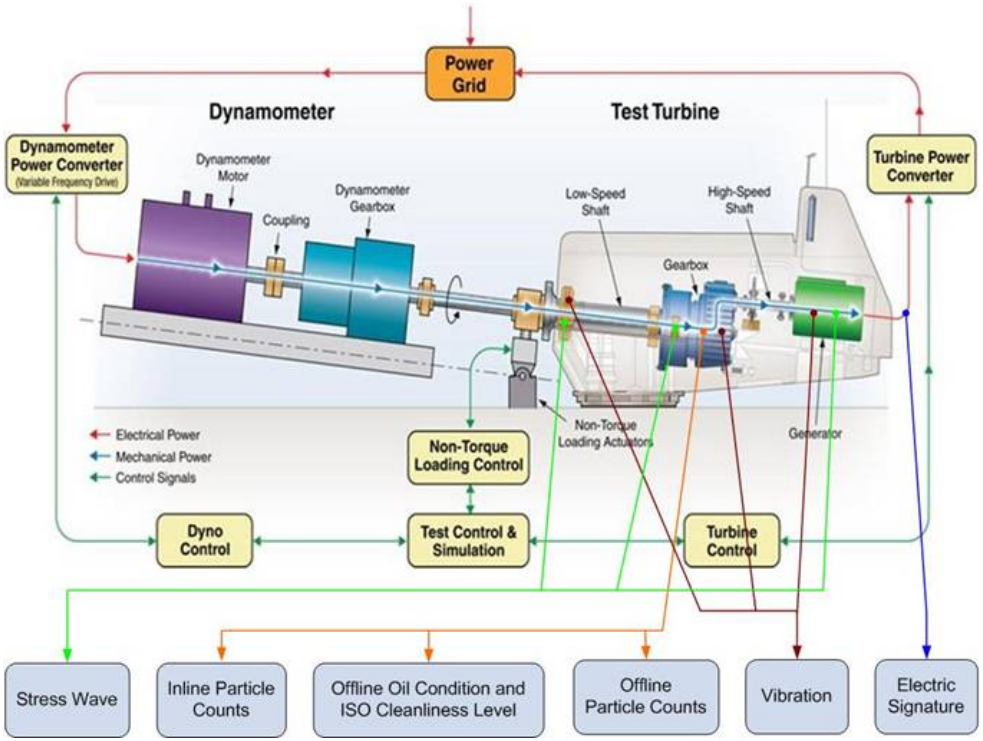
High-Speed Stage Pinion (Severe Scuffing)
Photo from GEARTECH, NREL/PIX 19743

Observations

- **Gear failure database incidents**
  - 37 incidents: 36 related to bearings and 22 related to gears
    - ✓ may need to pay attention to both bearings and gears
  - Top bearing failure modes: hardening cracks, abrasion (scratching of surfaces), adhesion (scuffing, welding and tearing of materials)
  - Top gear failure modes: fretting corrosion, high-cycle bending fatigue
  - Be careful with generalization of the database results
    - ✓ the population is still small
- **GRC test gearbox damage**
  - Simple causes may lead to complex damage
  - Operation and maintenance improvements are necessary to minimize the possibility of oil loss
  - Additional attention to assembly is needed to avoid damage

Condition Monitoring (CM)

- **Multiple CM systems demonstrated in Phases 1 and 2**
- **Various vendors and techniques (27 partners)**
  - Vibration
  - Stress Wave
  - Electrical Signature
  - Oil Condition
    - ✓ Particle count
    - ✓ Moisture/Quality
- **Compared capability to detect gearbox fault in dynamometer test**



CM Key Findings [3]

- ISO cleanliness measurements could be used to monitor and control the run-in of wind turbine gearboxes

- Recommend an integrated approach when conducting wind turbine condition monitoring
  - At a minimum, a combination of vibration or acoustic emission, with oil debris monitoring techniques, is recommended.

- If the sensor mounting location is appropriate, similar trends in wear debris counts can be obtained between the offline filter loop and the inline filter loop

[3] Wind Turbine Drivetrain Condition Monitoring During GRC Phase 1 and Phase 2 Testing, NREL TP-5000-52748.

GRC Accomplishments

- **Failure database software deployed**
  - Partners see business value for themselves and customers
- **Designed, built, instrumented, and tested two gearboxes**
  - Generated unprecedented public domain test data from both field testing and dynamometer testing
  - Different responses from ‘identical’ gearboxes
  - Demonstrated importance of non-torque loading and modeling approach
- **Active collaborative, with wide industry support, leveraging DOE funding**
  - Modeling round robin
  - Condition Monitoring round robin

GRC Recent Activities

- **Deployed Failure Database software**
  - Users represent 17% of installed U.S. capacity
- **Continued Modeling and Analysis**
  - Model-to-model-to-test comparisons for dynamic data
  - Effect of carrier and planet bearing clearances/gravity on loads
- **Planning Phase 3 Testing**
  - Field representative loading tests of Gearbox 2
  - Design and eventual tests on Gearbox 3
- **Meetings**
  - Hosted Condition Monitoring Workshop
    - ✓ 46 speakers, 11 sessions, and about 150 attendees
  - Hosted Tribology Seminar
    - ✓ 21 speakers and about 110 attendees

GRC Recent Publications and Presentations

- **Failure Database**
  - Wind Turbine Failure Modes – A Brief, ASME/STLE 2011 International Joint Tribology Conference, PR-5000-53084
- **GRC General**
  - Gearbox Reliability Collaborative Project Report: Findings from Phase 1 and Phase 2 Testing, 2011 Sandia Wind Turbine Reliability Workshop, TP-5000-51885 & PR-5000-52463
  - Wind Turbine Tribology Seminar presentations & TP-5000-53754
- **Testing, Modeling and Analysis**
  - NREL Gearbox Reliability Collaborative: Comparing In-Field Gearbox Response to Different Dynamometer Test Conditions, WINDPOWER 2011, CP-5000-51690
- **Condition Monitoring**
  - Investigation of Various Condition Monitoring Techniques Based on a Damaged Wind Turbine Gearbox, 8th International Workshop on Structural Health Monitoring, CP-5000-51753
  - Wind Turbine Drivetrain Condition Monitoring During GRC Phase 1 and Phase 2 Testing, 2011 Sandia Wind Turbine Reliability Workshop, TP-5000-52748 & PR-5000-52352
  - Condition Monitoring Workshop presentations

Thank You!

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Photo from HC Sorensen, Middelgrunden Wind Turbine Cooperative, NREL/PIX17855

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