

Gearbox Reliability Collaborative - Phase 1 and 2 Overview



NREL PIX # 19222

**Sandia Turbine
Reliability Workshop**

Aug 2-3, 2011

Hal Link

NREL/PR-5000-52463

Why GRC?

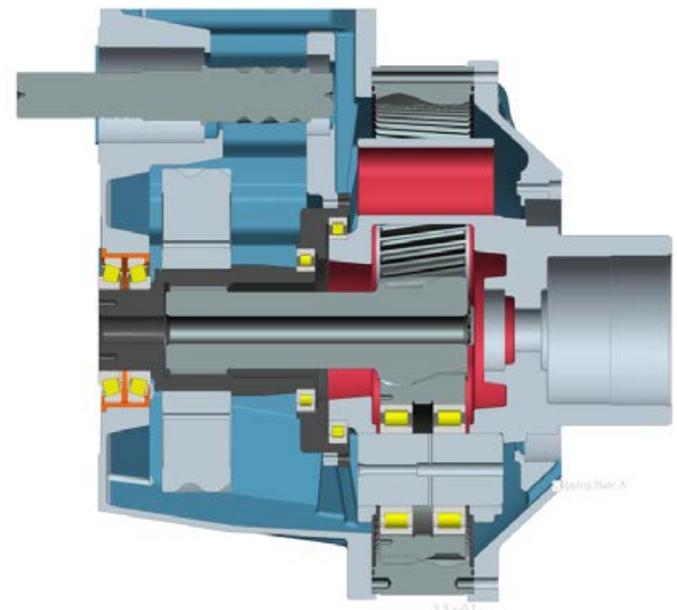
- Wind turbine gearboxes do not last their 20 year design life
- Designs must meet design, manufacturer, and testing standards and certification requirements
- Problems have occurred throughout the wind industry
- Problems range across the turbine design cycle
 - load characterization
 - design methods
 - model fidelity
 - testing/validation methods
- Competition inhibits communication and joint solutions

Major Elements of GRC

- **Collaboration** - form a team of stakeholders including manufacturers, owners, researchers
- **Generic drivetrain** - Identify and investigate “representative” test gearboxes
- **Testing** - model validation, load characterization, detailed gearbox, and subcomponent response
- **Modeling** - improve design tools and understanding
- **Failure Database** - document and analyze failures/modes
- **Condition Monitoring** - investigate use of continuous inspection as design and O&M (operation and maintenance) tool to improve reliability

Test Article Selection and Redesign

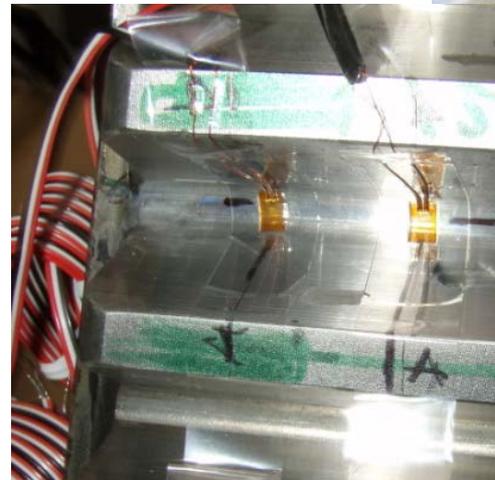
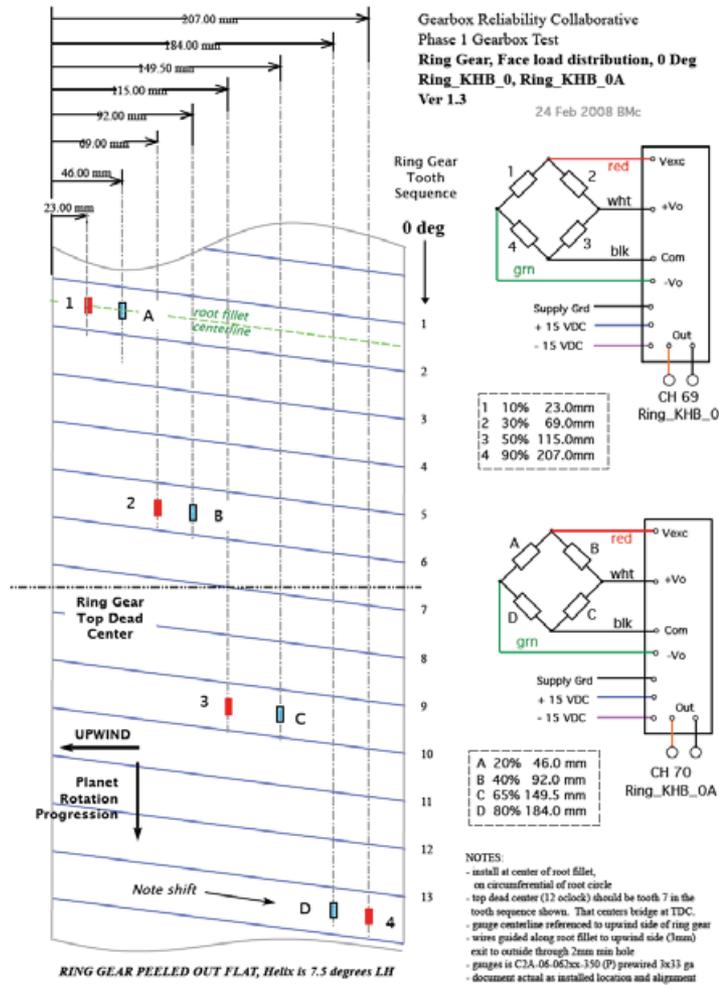
- 750kW - easy to test, representative, generic
- 2 gearboxes for field and dyno testing
- 3 point mount, 1 planet stage, 2 parallel
- Redesigned with expert input
- Upgraded using experience of design and rebuild experts
 - active lubrication with kidney loop
 - improved tooth profile and finish
 - improved bearing arrangements



Instrumentation (and lots of it)

- Planet load distribution (12 gauge pairs per planet)
- Planet race temperature (six sensors per planet)
- Planet rim movement (6 sensors on two planets)
- Mainshaft bending and torque
- Ring gear load distribution
- Carrier deflection/movement
- Sun radial movement
- Gearbox movement relative to mainframe
- High speed shaft (HSS) bearing temperatures
- HSS torque
- HSS / Generator alignment

Instrumentation – Ring Gear Tooth Load Distribution



Strain gauge installation
in ring gear of GRC
Gearbox .
NREL PIX #19495 (top).
NREL PIX #19494 (left).

Testing

Early tests

- Field test: torque and modal characterization

- Planet bearing calibration

- Trunnion stiffness characterization

Phase 1

- Dyno Gearbox 1: run-in and instrumentation checkout

- Field Gearbox 1: loads, responses, events

- Dyno Gearbox 2: run-in, limited non-torque loading

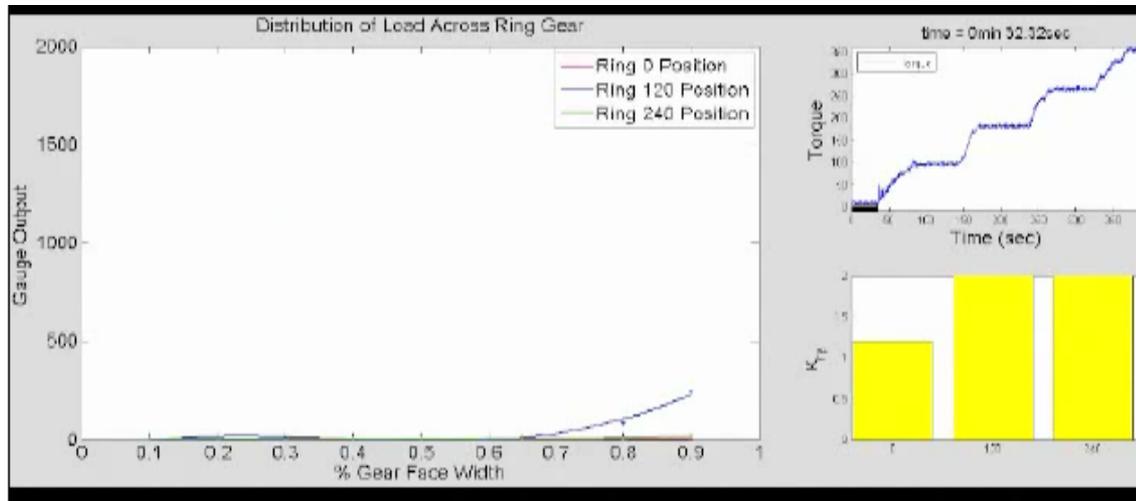
Phase 2

- Dyno Gearbox 2: extensive Non-Torque Loads (NTL), dynamics, HSS misalignment

- Dyno Gearbox 1: NTL, condition monitoring

Data Analysis

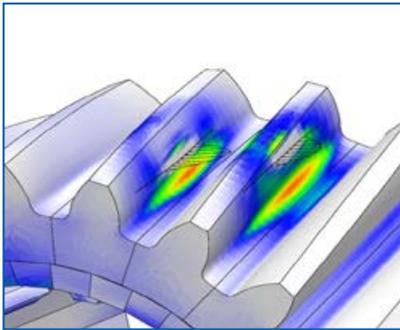
- Did we measure what we wanted accurately?
- Did we achieve the test conditions we wanted?
- What data are available and where?
- Can the data be released for model validation?
- Were unexpected loads observed?



Gearbox Modeling

Gearing Analysis

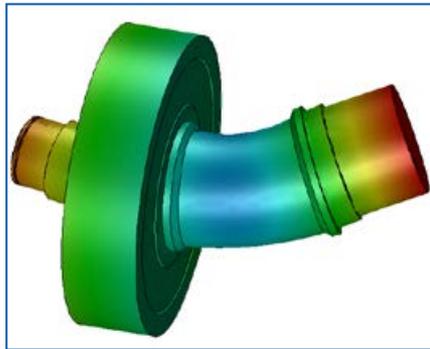
- Gear tooth loading
- Gear mesh stiffness
- Gear tooth contact stress



Source: Ansol (Calyx)

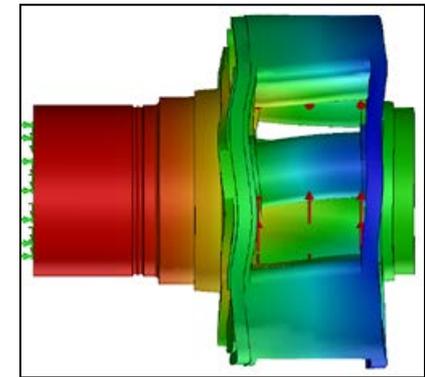
Shaft Analysis

- Torsional deflections
- Bending deflection and misalignment



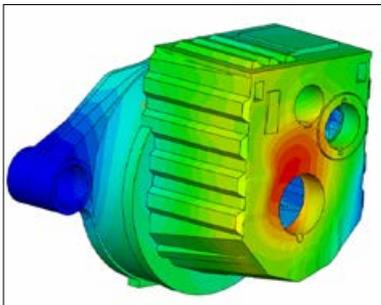
Planet Carrier Analysis

- Torsional deformation of the planet carrier
- Misalignment the planet pin
- Planet carrier and pin interaction



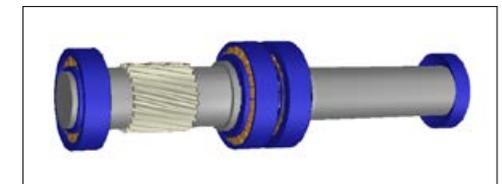
Housing Analysis

- Deflections
- Misalignment
- Tolerance stack up
- Virtual modal testing

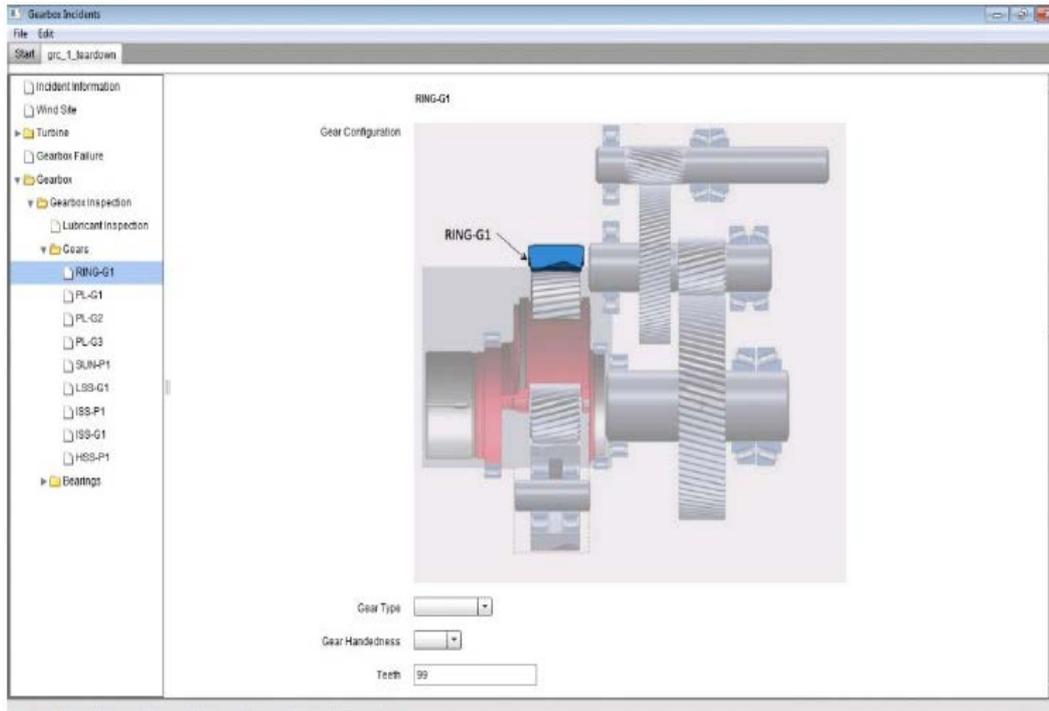


Bearing Analysis

- Bearing stiffness
- Roller contact stress
- Roller load distribution
- Bearing life



Gearbox Failure Database



Why?

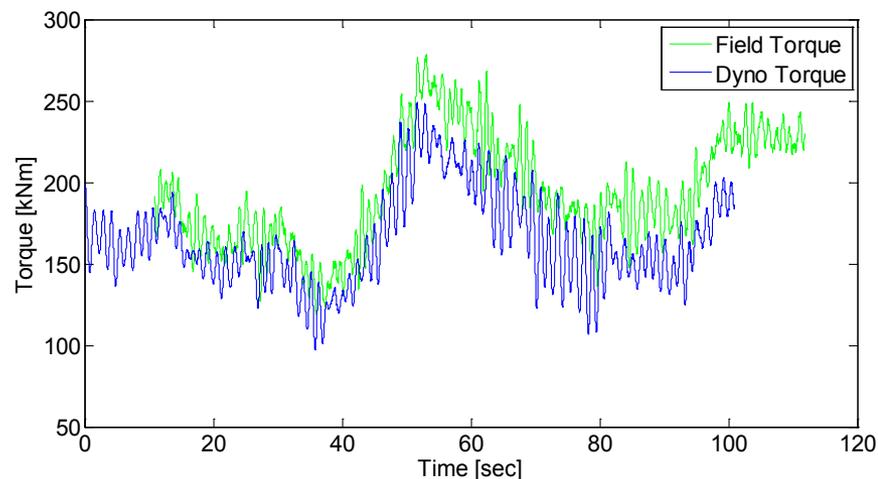
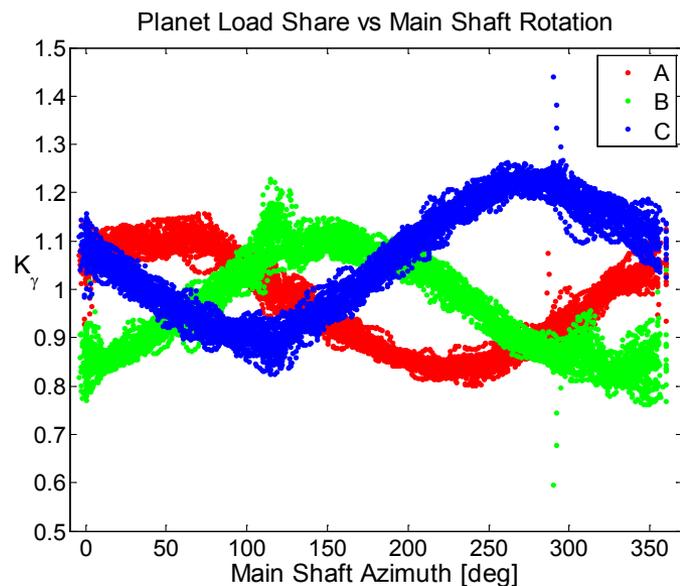
- Connects testing and simulations to actual failures
- Helps to identify root causes of failures
- Sanitized data can be shared among GRC members

Status

- Development of standardized collection software
- Signed partners: 17% of US generating capacity represented

Findings

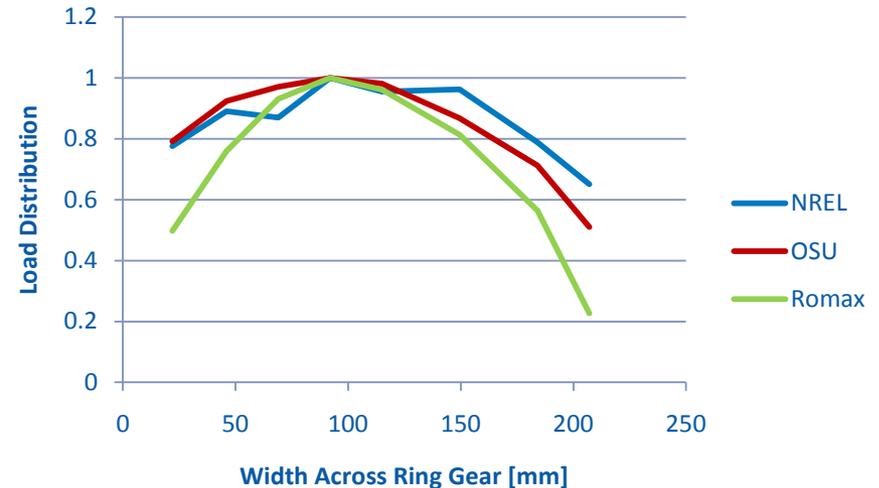
1. NTL (bending) affects planet/ring mesh
2. On-line particle counting for run-in
3. Controller adjustments to reduce torque spikes
4. NTL (thrust) affects carrier position
5. Planet bearing load share varies significantly
6. External gauges can indicate tooth contact pattern



External Gauges Facilitate Tooth Load Measurements

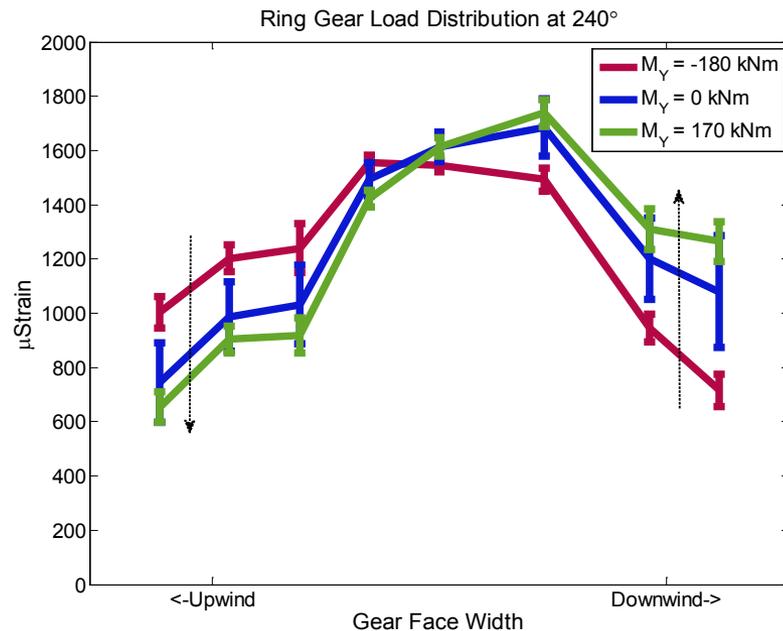
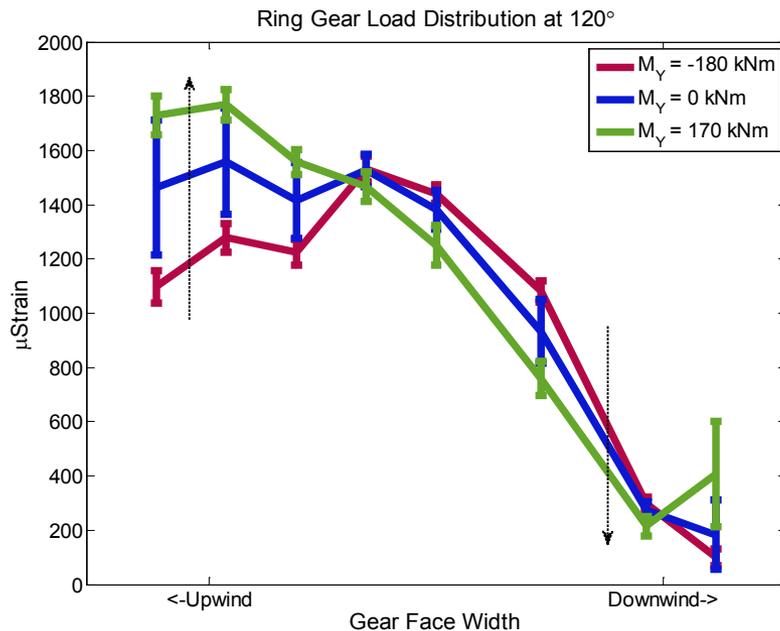


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- External gauges are MUCH easier to install
- Last longer and are repairable
- They accurately indicate the centroid of the contact area and, potentially, edge-loading
- They distort measurement of the important design parameter, $K_h\beta$

Non-Torque Loads Affect Gearing



- Non-torque loads DO affect the gearbox
- Mainshaft bending loads up to 180 kNm in all azimuths simulating unbalanced rotor loads
- Caused significant increase in tooth edge loads

Next Steps in GRC

- Continue data validation and analysis
- Use data and experience to identify design sensitivities for next re-design
- Redesign and rebuild damaged Gearbox 1
-> Gearbox 3
- Start Phase 3 testing in the dyno and field
- Convene a tribology / lubrication workshop in November 2011 with experts and shared WTG experiences from field

Questions / Comments?



<http://www.nrel.gov/docs/fy11osti/51885.pdf>

Gearbox Reliability Collaborative Project Report: Findings from Phase 1 and Phase 2 Testing

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