NREL
NATIONAL RENEWABLE ENERGY LABORATORY

# 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**

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

# Why GRC?

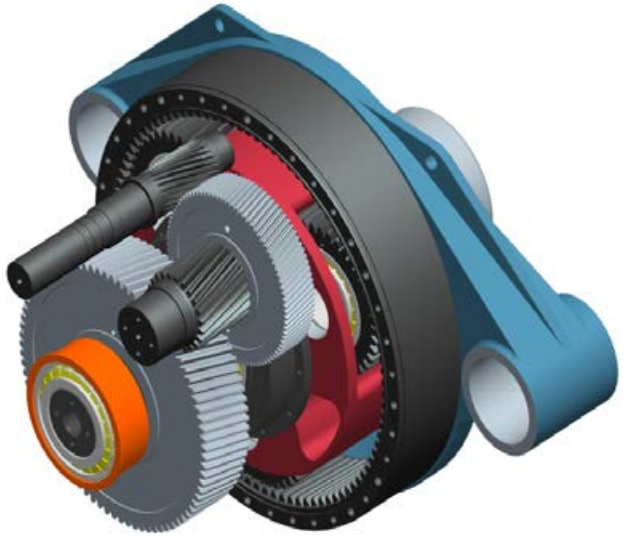
- Wind turbine gearboxes do not last their 20 year design life
- Designs must meet design, manufacturer, and testing standards and certification requirements
- Problems have occurred throughout the wind industry
- Problems range across the turbine design cycle
  - load characterization
  - design methods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

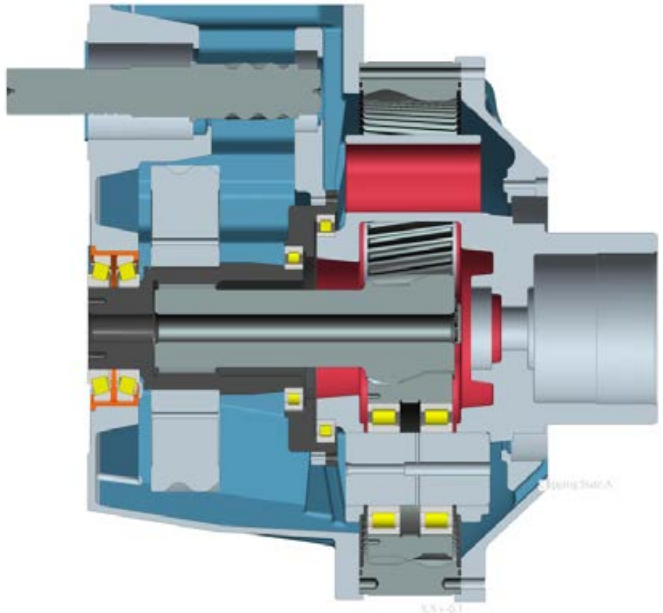
# Major Elements of GRC

- **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

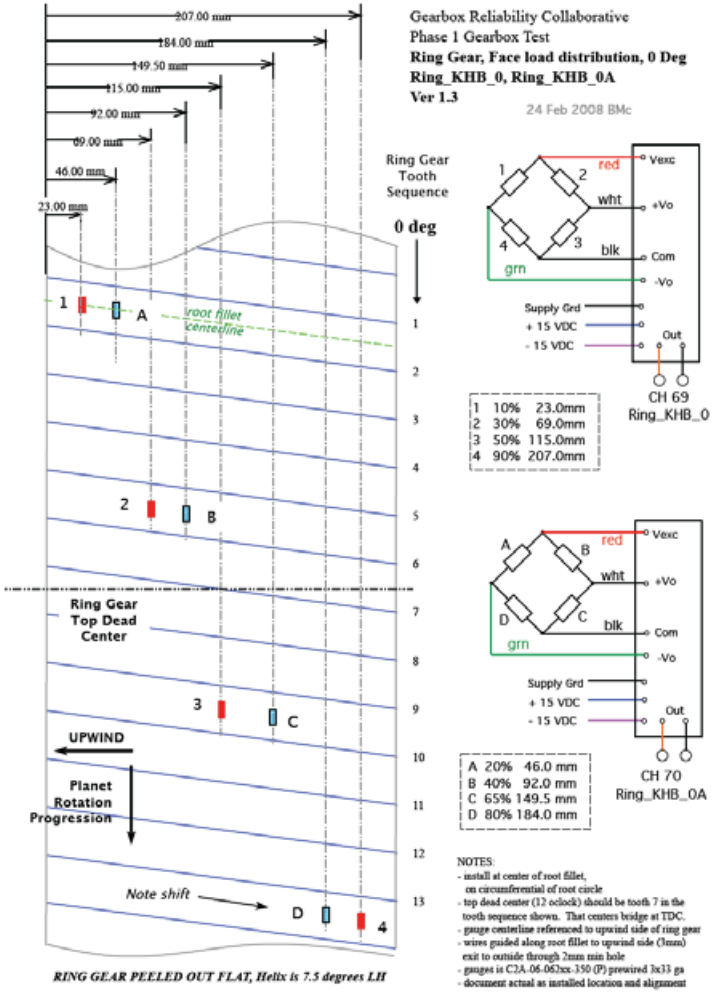


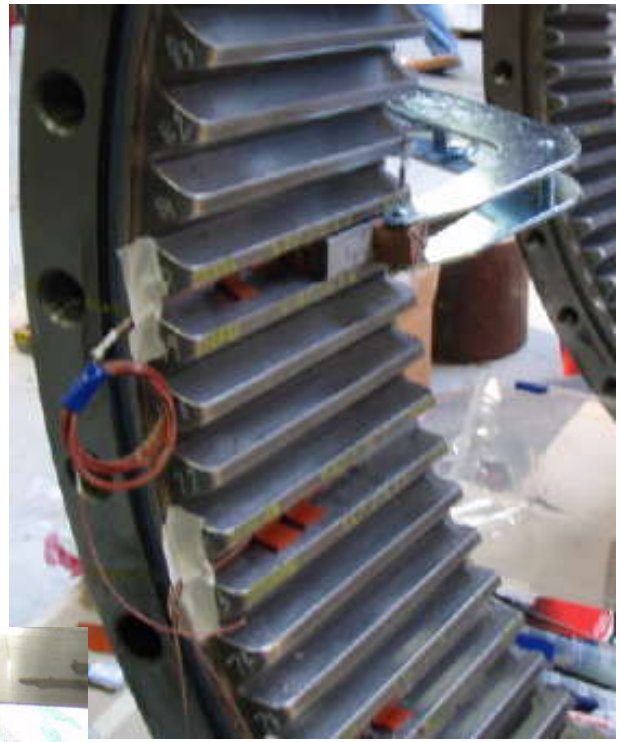


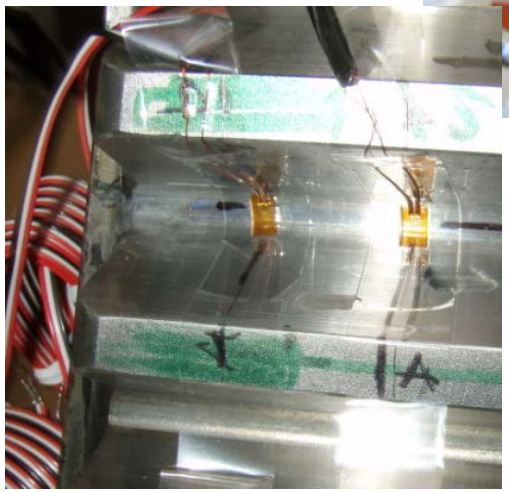
# Instrumentation (and lots of it)

- 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

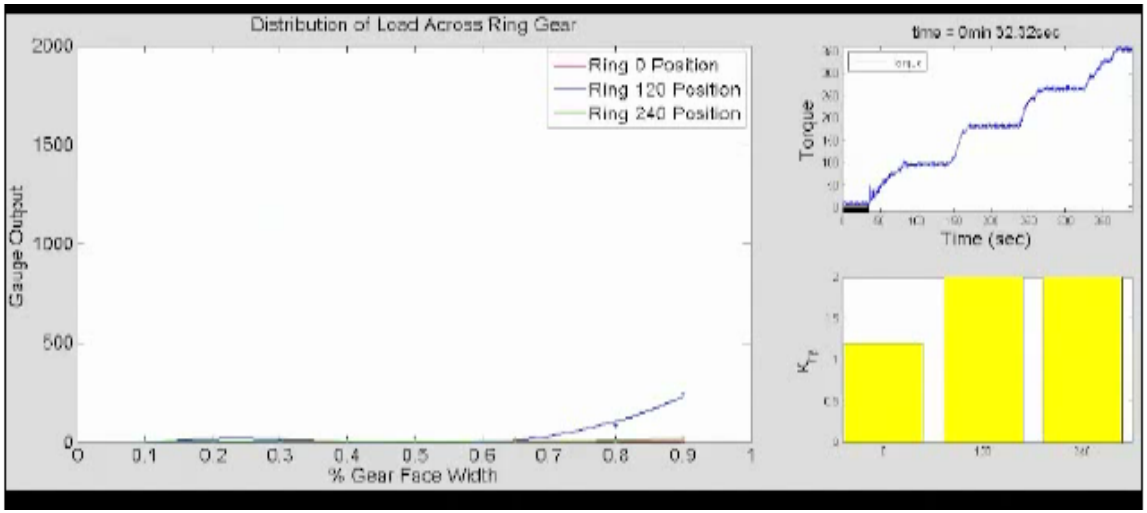
- Dyno Gearbox 1: run-in and instrumentation checkout
- Field Gearbox 1: loads, responses, events
- Dyno Gearbox 2: run-in, limited non-torque loading

Phase 2

- Dyno Gearbox 2: extensive Non-Torque Loads (NTL), dynamics, HSS misalignment
- Dyno Gearbox 1: NTL, condition monitoring

# Data Analysis

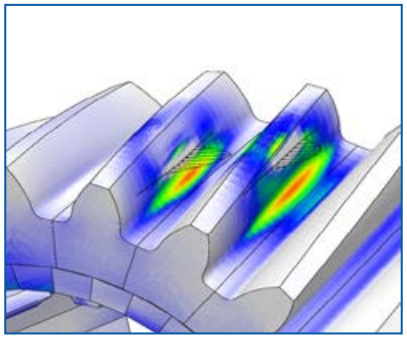
- Did we measure what we wanted accurately?
- Did we achieve the test conditions we wanted?
- What data are available and where?
- Can the data be released for model validation?
- Were unexpected loads observed?



# Gearbox Modeling

## Gearing Analysis

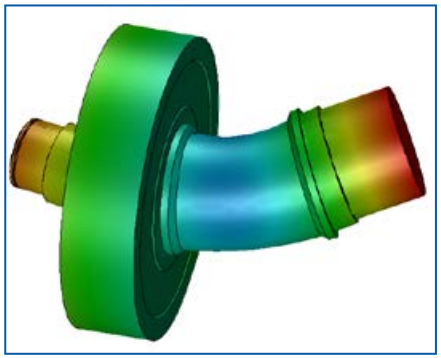
- Gear tooth loading
- Gear mesh stiffness
- Gear tooth contact stress



Source: Ansol (Calyx)

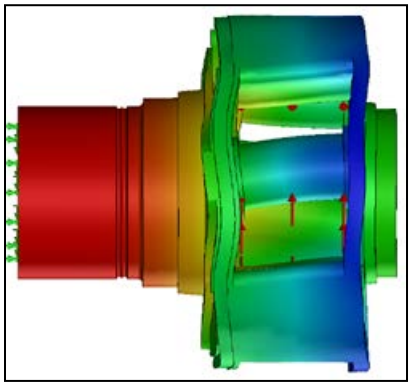
## Shaft Analysis

- Torsional deflections
- Bending defection and misalignment



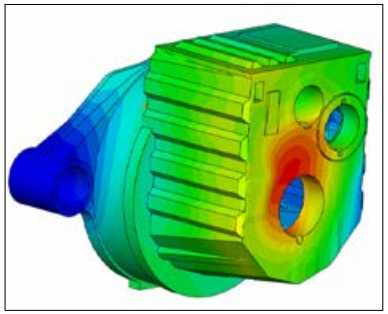
## Planet Carrier Analysis

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



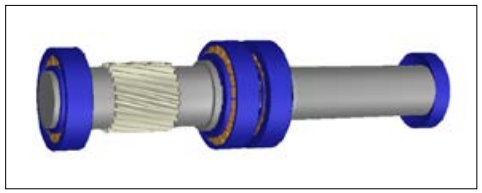
## Housing Analysis

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

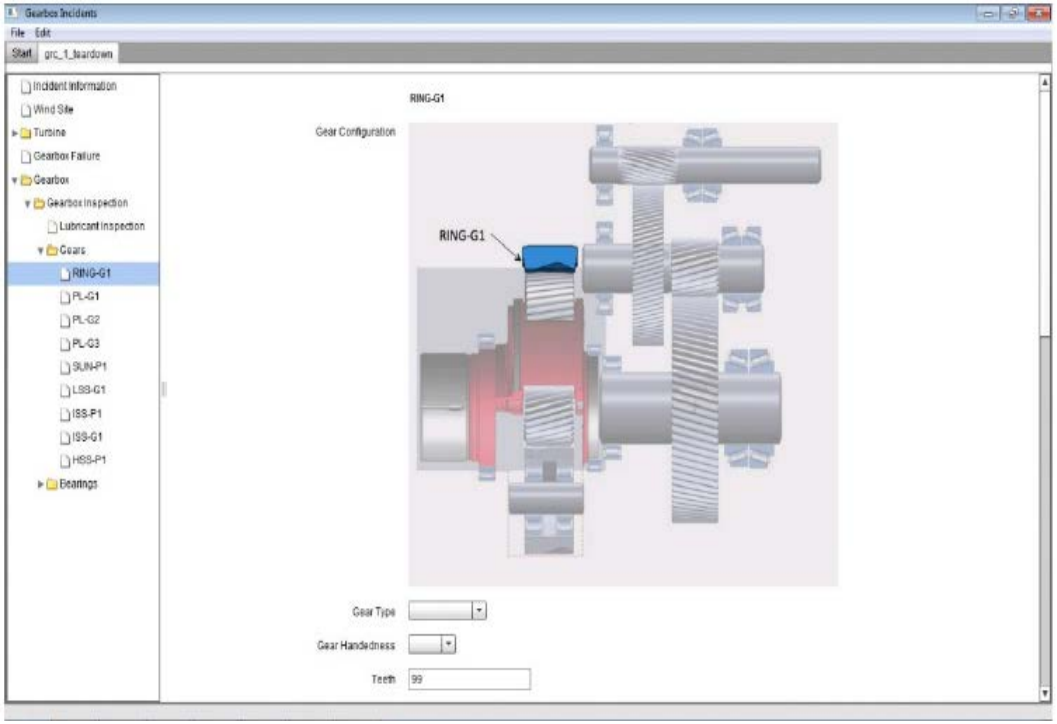


## Bearing Analysis

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



# Gearbox Failure Database




## Why?

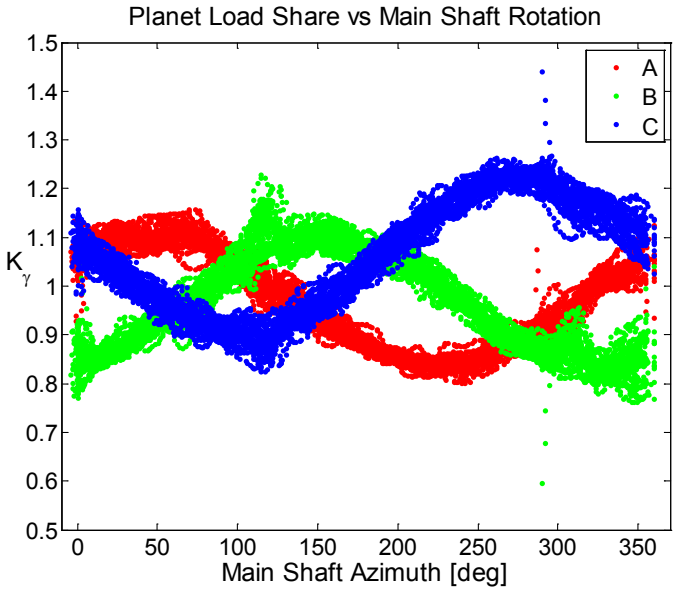
- Connects testing and simulations to actual failures
- Helps to identify root causes of failures
- Sanitized data can be shared among GRC members

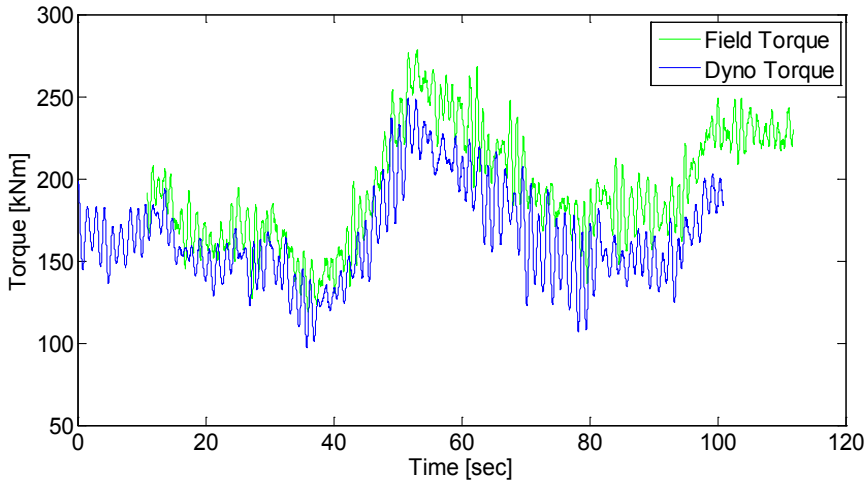
## Status

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

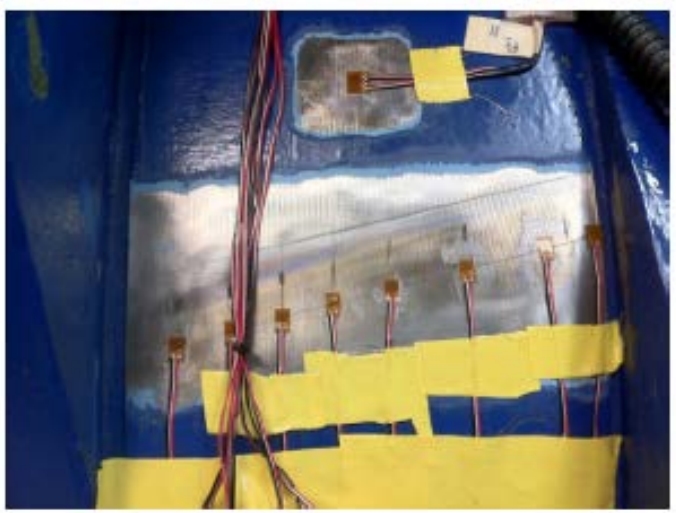
# Findings

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

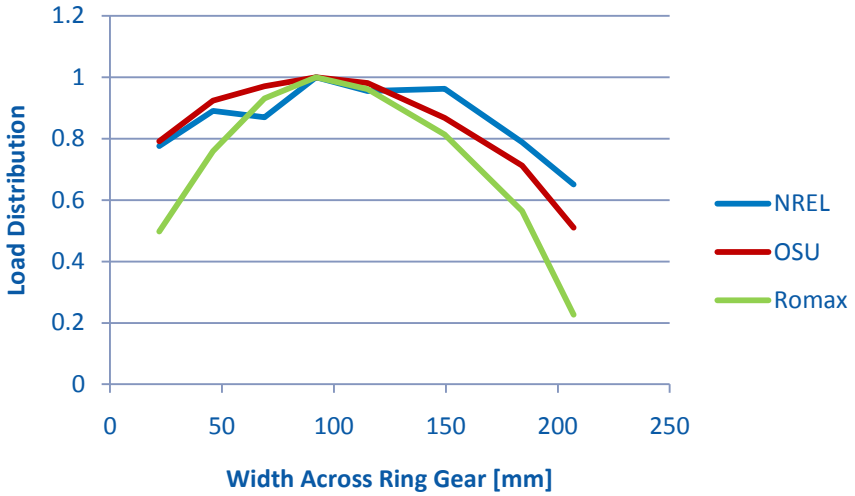


# External Gauges Facilitate Tooth Load Measurements

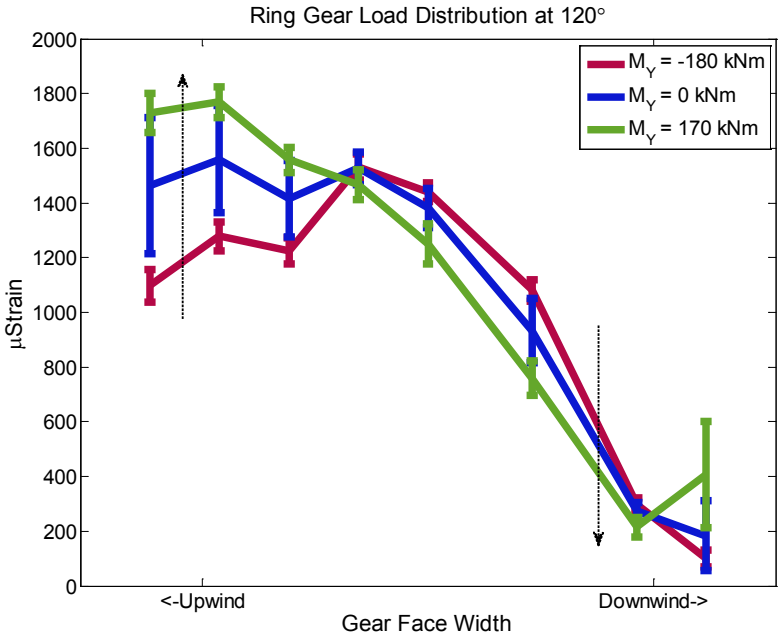


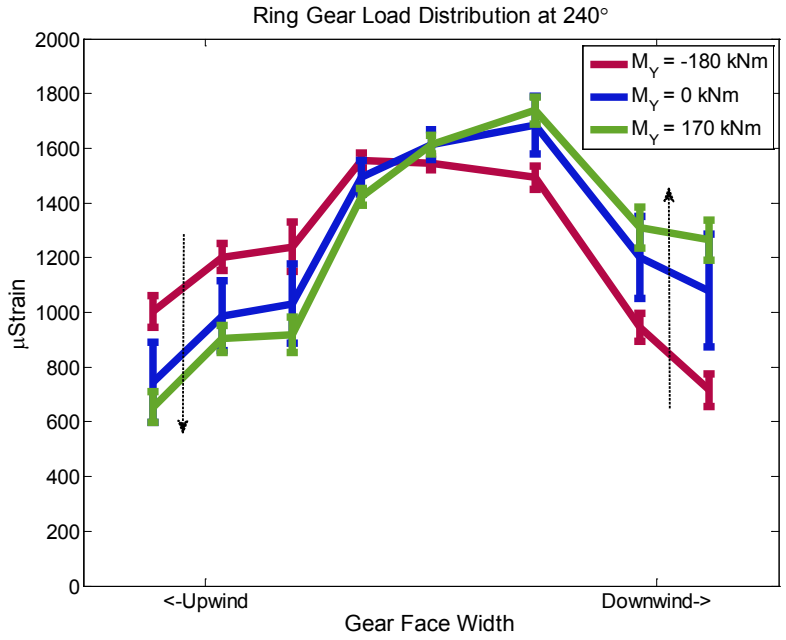
NREL PIX # 19221




- 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, Khß

# 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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