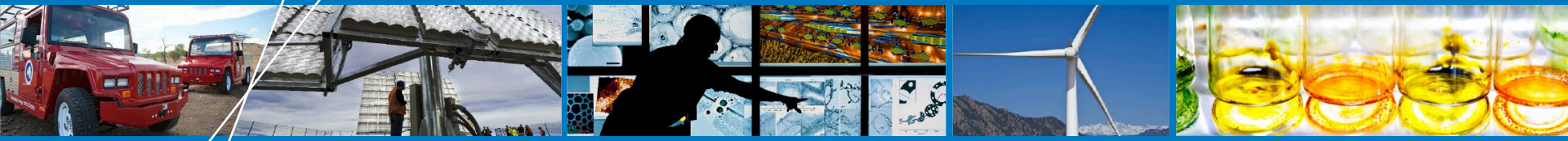
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

The "GRC1.5": Uptower Gearbox Testing to Investigate Bearing Axial Cracking



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Drivetrain Reliability Workshop

Golden, Colorado
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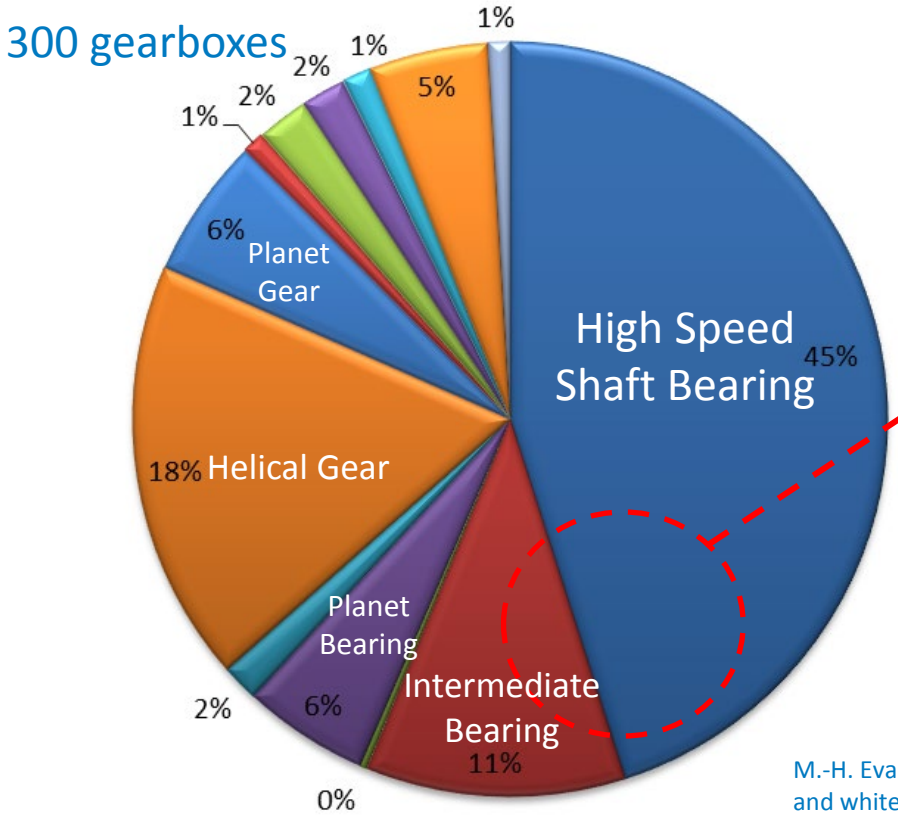
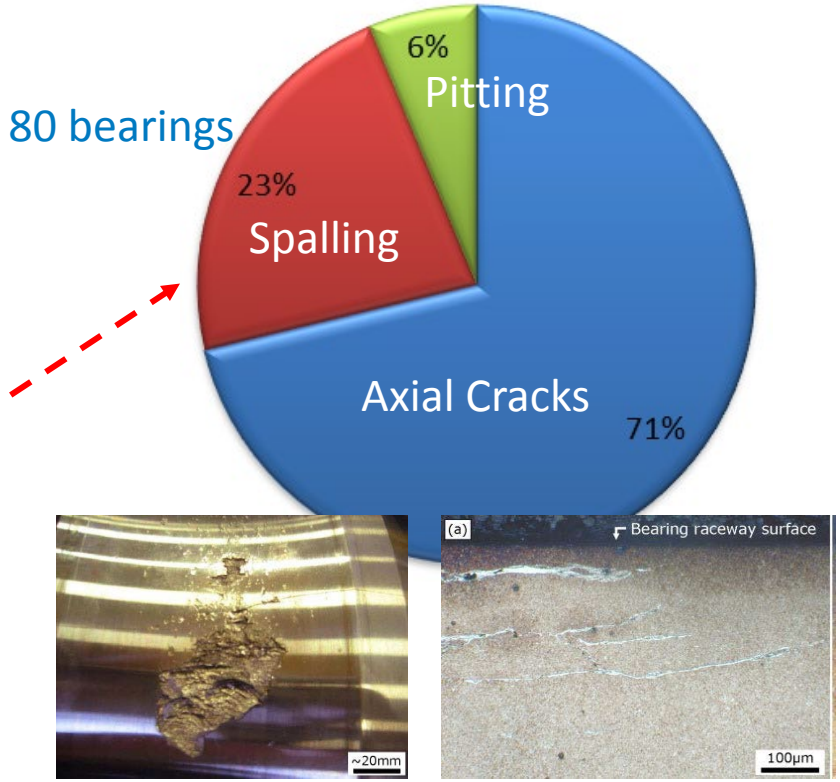
NREL/PR-5000-65738

Project Motivation

- **Bearing axial cracking is most common damage in gearboxes**
  - Intermediate and high-speed section bearings most prone to axial cracking
  - Many factors suspected; *but wind-specific are grid influences and transients*
- **Planetary failures more costly, but GRC 750 examined in depth**
  - What research remains?





M.-H. Evans, White structure flaking (WSF) in wind turbine gearbox bearings: effects of 'butterflies' and white etching cracks (WECs). Materials Science and Technology 2012, Vol. 28 No. 1.

Testing Options Considered

Operational Wind Plant

- Investigate gearbox loads, bearing axial cracking, and other plant experiments
- Pros: “real” wind regime and grid connection, no gearbox or crane cost
- Cons: partner cooperation (gearbox overhaul, plant operations), data transmission, waiting for events (stop, curtailment, grid event), and warranty.

National Wind Technology Center

- Investigate bearing axial cracking only
- Pros: site technicians, instrumentation without warranty concern, induce transients and grid events
- **Dynamometer**
  - Con: Pay for whole drivetrain
- **Uptower in U.S. Department of Energy (DOE)-owned GE1.5 SLE**
  - Con: Pay for crane services.

Photo by Dennis Schroeder, NREL 21864

NREL completed an IEC 61400-13 mechanical loads test
http://www.nrel.gov/docs/fy15osti/63679.pdf

Bearing Axial Cracking Project

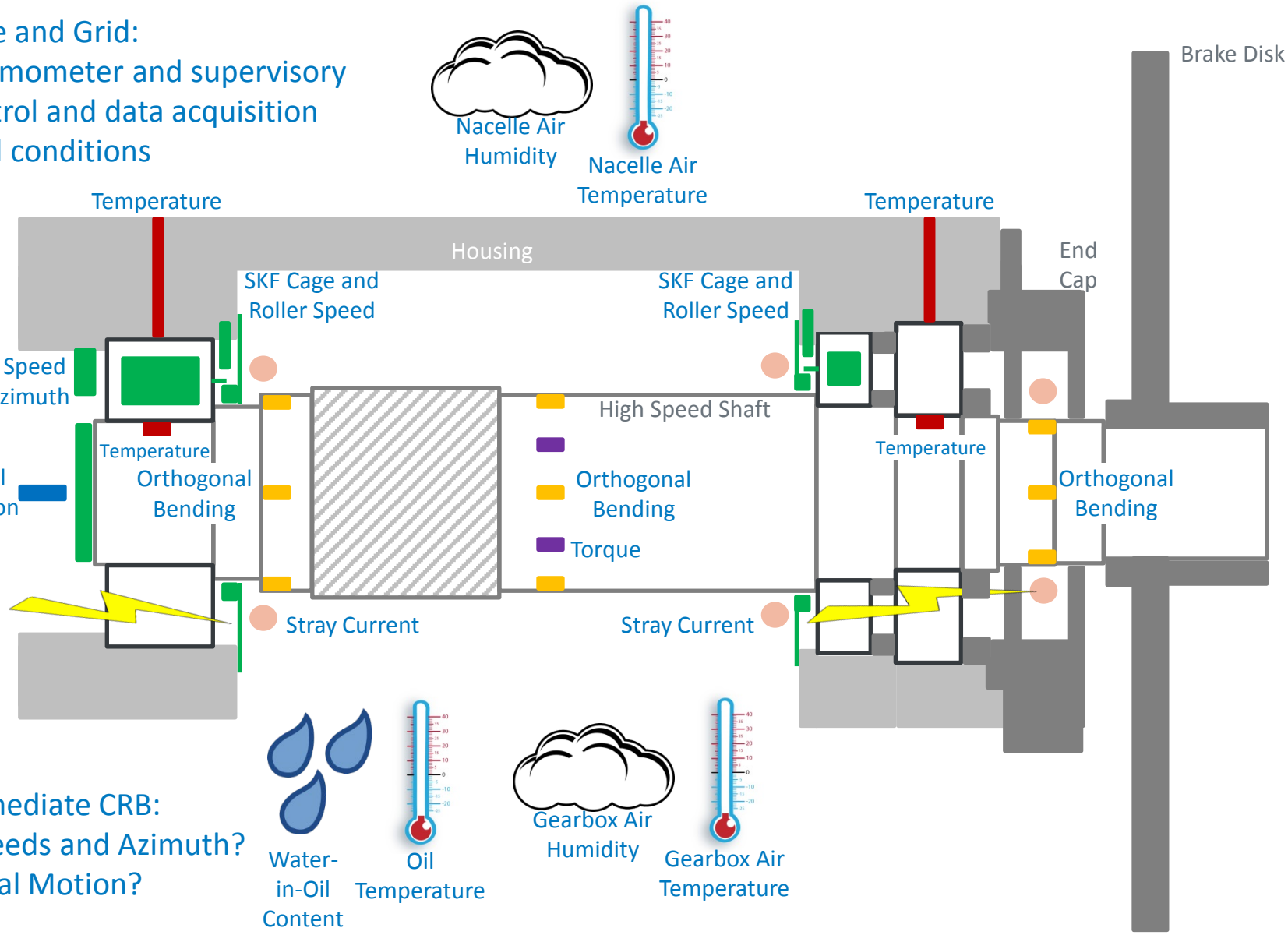
- **Goal: Understand cause(s) of white etch crack (WEC) formation**
  - Argonne National Laboratory and Partners: bench-level tests and modeling
    - *What critical contact conditions result in WEC formation?*
      - Stress, speed, slide-to-roll ratio, lubricant temperature, and film thickness
      - Absolutely intended to induce WECs (and even count them!)
    - Inform decisions for tribological mitigation such as coatings and steels.
  - NREL and Partners: uptower tests and modeling
    - *What turbine and grid conditions result in the critical contact conditions?*
      - Measure bearing speeds, loads, temperatures; but model stresses
      - Investigate environmental factors: humidity, oil-in-water, and stray current
      - Not intended to induce WECs or result in axial cracking (but could!)
    - Inform bearing/gearbox hardware or turbine software mitigation solutions.

Challenges for Bearings

- **Steady-State Operation**
  - Sliding during acceleration into and deceleration out of load zone
  - Operation for noise reduction and curtailment
- **Transients and Events**
  - Torque and thrust reversals
  - Generator transients, power electronics faults, and grid events
  - Acceleration and deceleration of rotor and drivetrain
    - Mechanical braking with asymmetric brake loads and e-stops
  - Wind speeds below cut-in
    - Idling, pendulum, and braked with significant axial motions at low load

GRC1.5 High-Speed Shaft Instrumentation

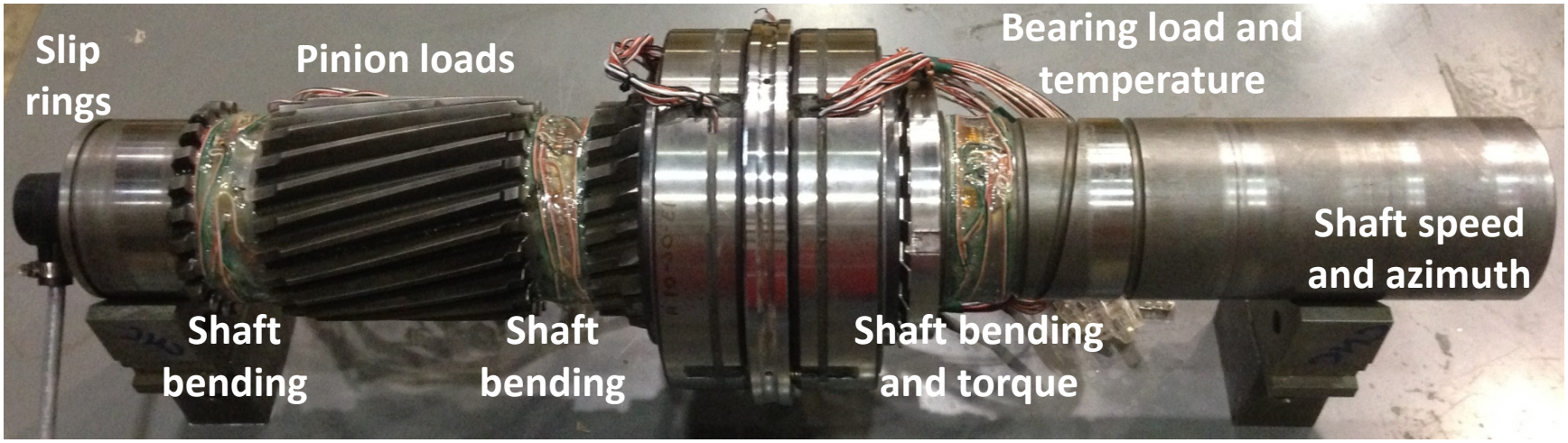
Turbine and Grid:
- Anemometer and supervisory control and data acquisition
- Grid conditions



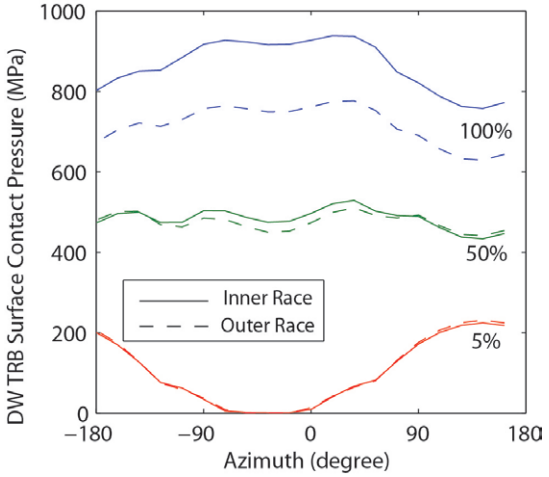
Intermediate CRB:
- Speeds and Azimuth?
- Axial Motion?

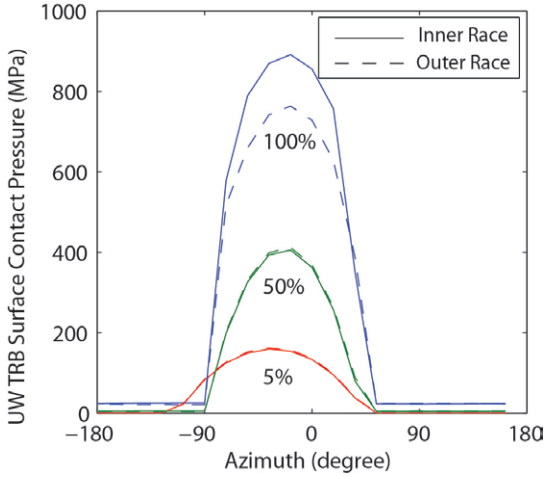
GRC750 High-Speed Shaft Instrumentation

- **We've done this before…**



GRC high speed shaft instrumentation. *Jonathan Keller, NREL 27895*



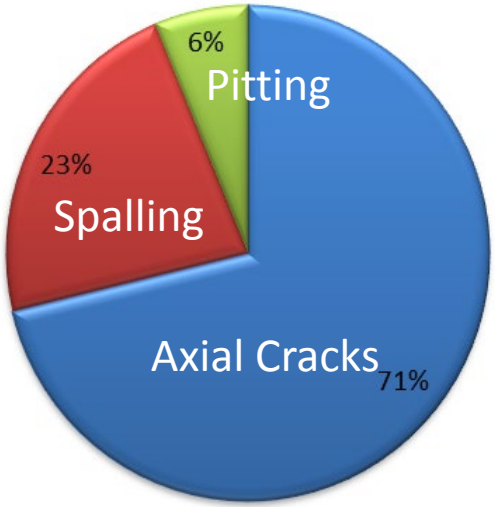


Measured bearing load zones correlate to model

Predicted bearing stresses, measured temperatures and sliding relate to failures

Critical Conditions for Bearings

More than loads and speed!



Drivers for premature failures/axial cracks and WEC:

- **Stress-related weakening**
  - Short duration high loads → Bending and torque measurements
  - Structural stresses.
- **Environmental-related weakening:**
  - (Standstill) corrosion → Water-in-oil/air humidity
  - Stray current → Rogowski coils
  - Tribochemistry/mixed friction.

Speed
Roller slip
Axial vibration
Temperature
Load

→

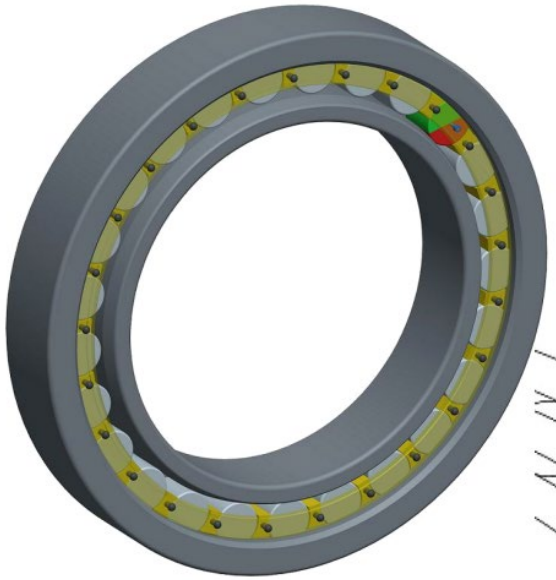
Advanced simulation

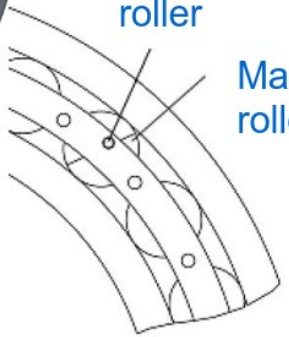
→

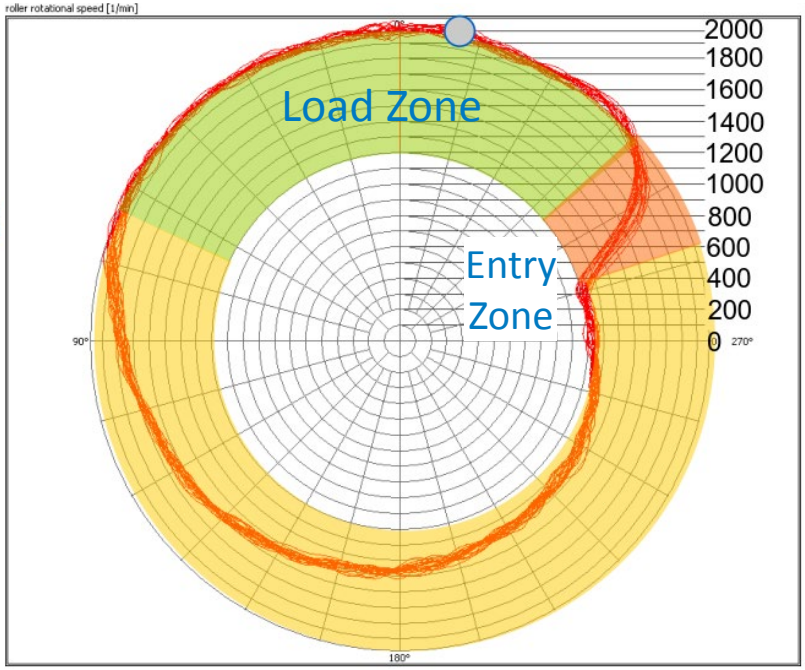
Roller motion
Roller slip losses
→ evaluate risk for mixed friction and/or smearing

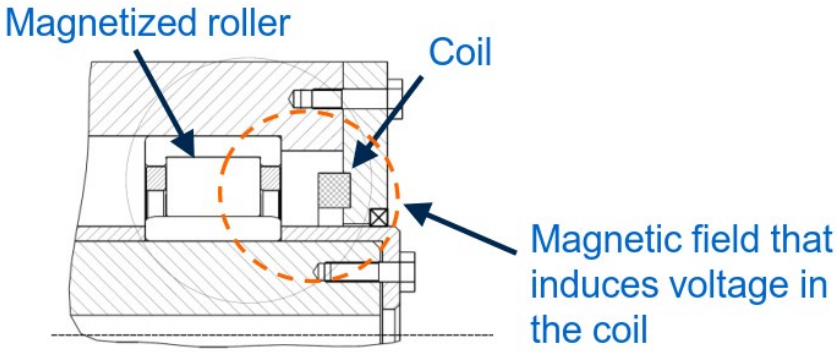
SKF®

SKF Roller Speed Measurement





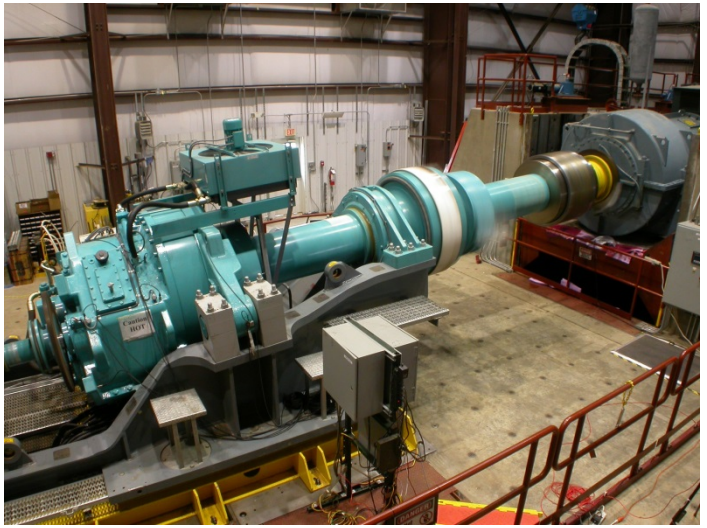




Source: M. Volkmuth, K. Stadler, R. Heemskerk, Slippage measurements in roller bearings, Antriebstechnisches Kolloquium ATK, Aachen, Germany, 2009.

“Baby Steps” to Uptower Testing

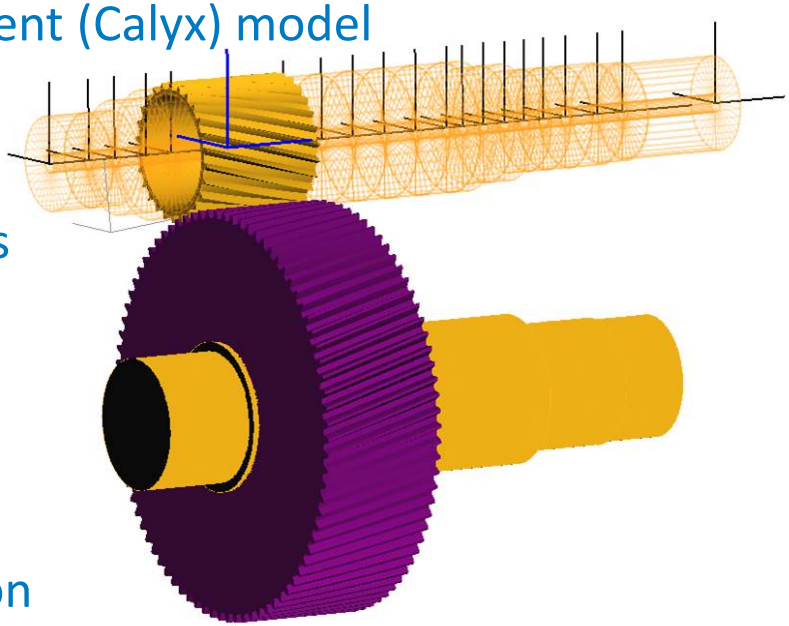
- **Bench-top rig (Summer 2016)**
  - Design of housing-like mounting structure underway
  - Spin instrumented high-speed shaft at full speed, but no load
    - Want roller acceleration; considering radial load, torque, or shaft acceleration
  - Understand cable mounting, routing, and signal checkout.
- **Dynamometer (Fall 2016)**
  - Install instrumented shaft into full gearbox
  - Spin gearbox at speed and/or load
  - Ensure instrumentation working as expected.
- **Uptower in DOE1.5 (Spring 2017)**



PEAS 4390 Testing. *Lee Jay Fingersh, NREL 14688*

Current and Near-Term Activities

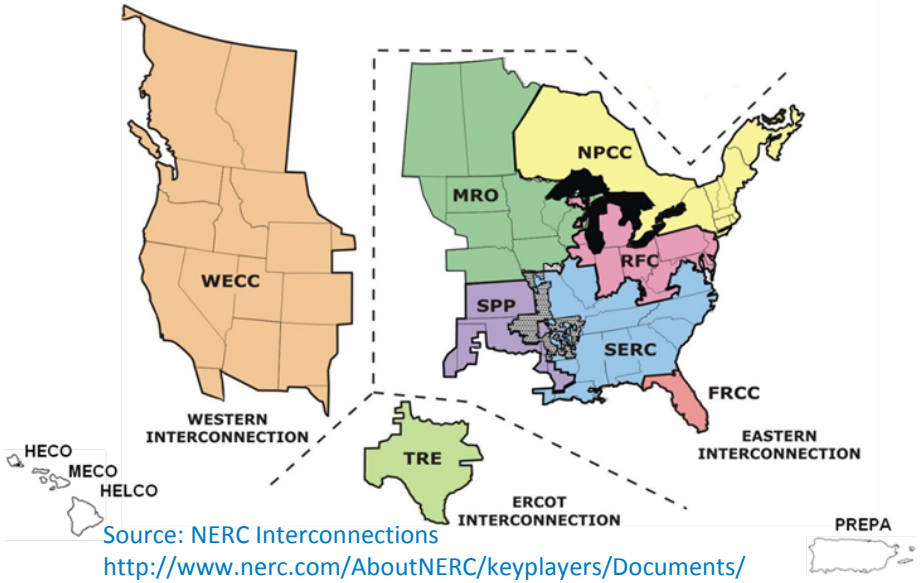
- **NREL and McNiff**
  - Multibody (SIMPACK) and full finite-element (Calyx) model
    - Simulated steady-state operation and loads
  - Instrumentation design and modifications
  - Bench-top rig design and fabrication.
- **SKF**
  - Bearing modifications and instrumentation
  - Stray current, humidity, and water-in-oil sensors.
- **Gearbox partner**
  - Provide high-speed shaft, drawings, and engineering support



Initial high speed pinion and gear SIMPACK model

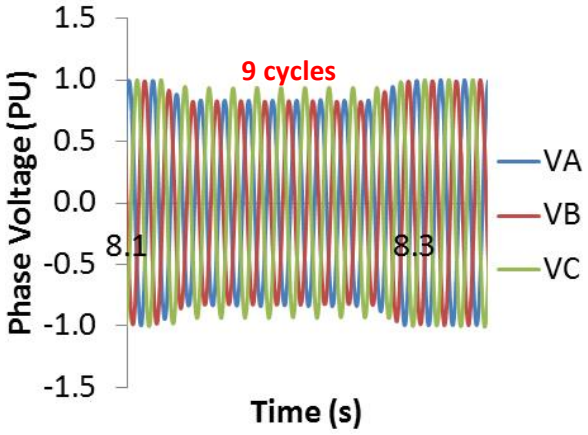
What Could We Use from the Field?

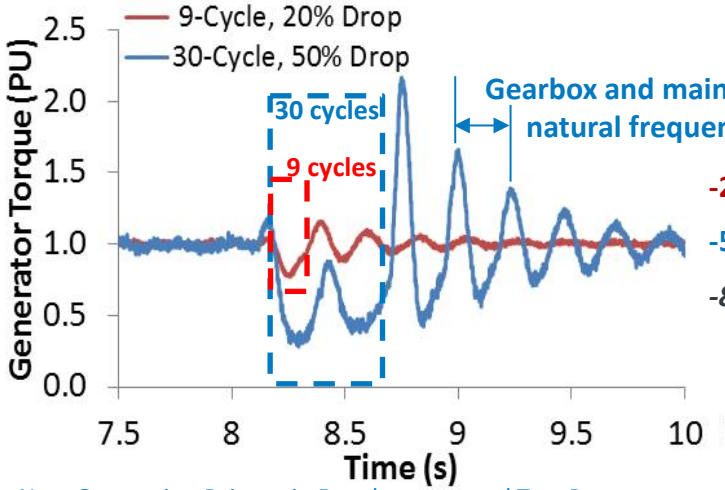
- **Grid event measurements**
  - How often?
  - What type?
  - What magnitude?
  - Regional and site differences?



Source: NERC Interconnections
http://www.nerc.com/AboutNERC/keyplayers/Documents/NERC_Interconnections_Color_072512.jpg

- **Portable electrical system measurements?**





-20% voltage = ±20% torque

-50% voltage = +117% torque

-80% voltage = ?? torque

IEC 61400-21, Table 1

Source: Keller, Erdman, Blodgett, Halse, and Grider. Next Generation Drivetrain Development and Test Program, 6th Drivetrain Concepts for Wind Turbines Conference, Bremen, Germany, December 2015. http://www.nrel.gov/docs/fy16osti/65497.pdf

Acknowledgments

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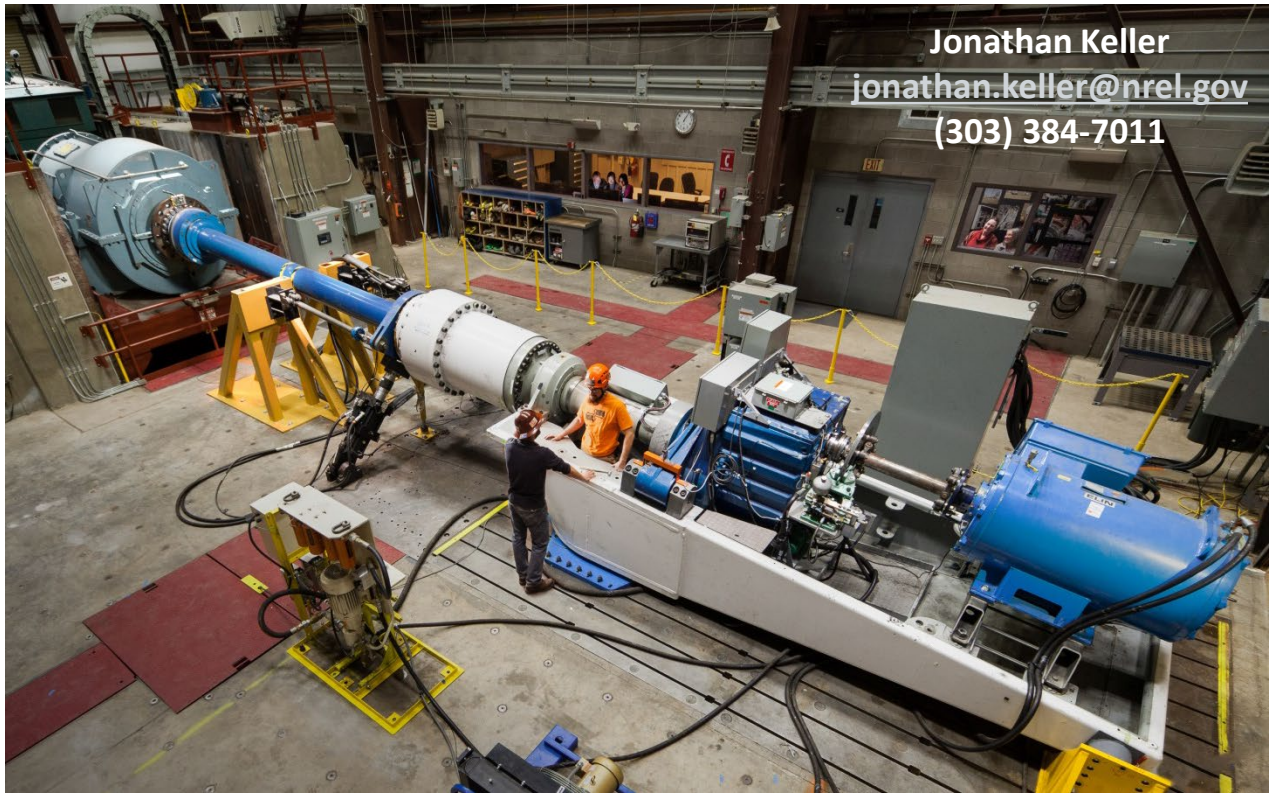

GRC dynamometer testing. *Mark McDade, NREL 32734*

GRC field testing. *Jeroen van Dam, NREL 19257*

Recent GRC References

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3. Keller, J., Wallen, R. 2015. Gearbox Reliability Collaborative Phase 3 Gearbox 2 Test Report. (Technical Report). NREL/TP-5000-63693. National Renewable Energy Laboratory (NREL), Golden, CO (US). http://www.nrel.gov/docs/fy15osti/63693.pdf.
4. Keller, J., Guo, Y., Sethuraman, L. 2016. Gearbox Reliability Collaborative Investigation of Generator Misalignment on High Speed Shaft Loads. (Technical Report). NREL/TP-5000-65321. National Renewable Energy Laboratory (NREL), Golden, CO (US). http://www.nrel.gov/docs/fy16osti/65321.pdf.
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6. Helsen, J. Guo, Y., Keller, J., Guillaume, P. 2016. Experimental Investigation of Bearing Slip in a Wind Turbine Gearbox During a Transient Grid Loss Event. *To be published in Wind Energy in mid-2016*.