Failure modes and testing methods

Advances in White-Etch Crack Research

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Reliability - Trends in Turbine Downtime

- Gearbox failures remain leading cause of downtime
- Main shaft bearings have increased and surpassed other subsystems

NREL- Gearbox Reliability Collaborative
Failure Database- Dr. Shawn Sheng

The chart are based on about 750 damage records.
- Bearings: increased to 76%, still dominated by HSS and IMS bearings
- Gears: reduced to 17%, dominated by Helical gears
- Others: reduced to 7%, dominated by housing and lubrication & filtration system
- Both bearing and gear faults are concentrated in the parallel section.

Database participants represent 34% of US wind capacity
Contact Failure Modes in Drivetrains

- ‘Classical’ contact fatigue
  - 20-year design life models for bearings and gears are based on ‘classical’ fatigue calculations
    - Considers steady operating conditions
    - No influence due to bearing sliding
    - Not descriptive of how gears and bearings are failing in WT drivetrains

- Other failure modes
  - Wear
  - Micropitting
  - Scuffing
  - False brinelling/ fretting
  - White-Etching Cracks/Axial Cracks
Macropitting Fatigue

- AKA: Spalling

- Occurs in rolling/sliding or pure rolling contact:
  - Gear teeth
  - Bearings

- A result of material fatigue initiated either at the surface (debris dent other feature) or subsurface (inclusions or case/core interface)

- **Prevention measures include:** reducing surface stress (alignment or load control), improved steel cleanliness, oil filtration (remove debris), dry & cool lubricants
Wear

- AKA: abrasion, polishing

- Occurs in rough surfaces with inadequate lubricant separation in rolling/sliding contact or debris:
  - Gear teeth
  - Skidding bearings

- A result of mild material removal caused by a hard asperities or hard particles, leads to misalignment and vibration issues

- **Prevention measures include:** reducing surface roughness, protective coatings, lubricant formulation (anti-wear), oil filtration (remove debris)
Micropitting

- AKA: Peeling, Frosting, Microspalling

- Occurs in rough surfaces with inadequate lubricant separation in rolling/sliding contact:
  - Gear teeth
  - Skidding bearings

- A result of surface initiated cracks at asperities in sliding contact causing shallow pitting and progressive wear

- **Prevention measures include:** reducing surface roughness, protective coatings, reduced bearing skidding, lubricant formulation for reduction in surface shear stress
Scuffing

- AKA: Smearing, Galling, Scoring

- Occurs in high sliding loaded contact
  - Skidding bearings
  - Gear contact (inadequate lubricant/high temps)

- A result of large-scale plastic deformation of the surface due to frictional heating during sliding

- Prevention measures include: minimizing bearing skidding (preloaded bearings), use of protective/sacrificial coatings, lubricant formulation (EP and friction modifiers)
Fretting

- AKA: False Brinelling, Fretting Corrosion

- Occurs in low amplitude vibration Sliding contact
  - GB bearings and gears during break condition
  - Pitch and yaw drives during normal operation

- A result of loss of lubricant in contact leading to removal of protective oxide layer and subsequent adhesive wear

- Prevention measures include: replenishing lubricant between contact (moving the contact), lubricants with anti-wear additives, or protective surface coatings

R. Evans, Timken
White Etching Cracks

- AKA: Axial cracks, IrWEA, WSF, brittle flaking

- Cracking and pitting associated with localized irregular microstructural alteration
  - High speed and intermediate stage bearings

- The root cause is still a matter of debate and topic of ongoing research

- Prevention measures include: ? Still a matter of debate and topic of ongoing research
What are WECs?

White-Etching Cracks cause premature bearing failure through spalls or cracks and are characterized by irregular microstructural alteration in the subsurface material

- Reported to cause up to ~80% of wind turbine high speed bearing failure at ~1-10% of design life
- Reported to broadly affect bearings of all types and manufacturer
- Several theories to the root cause of WECs have been proposed but still highly debated
Bearing Inner Race Surface Failure - WEC

Cross sectional analysis of WECs

Bearing inner ring

Cross section

Optical micrograph

Pitted contact surface

Etched cross section

SEM micrograph

APS X-ray Tomography
Verifying Microstructural Alteration

Raceway

Crack Section 1

Crack Section 2

540μm

600μm
Bench-top Testing for WEC Failures

Gould and Greco, “The Influence of Sliding and Contact Severity on the Generation of White Etching Cracks.” Tribology Letters

Images from PCS MPR Brochure

MPR
Test Parameters

- 1.9 Gpa
- $\lambda \sim 0.1$
- +/-30% SRR, +/-5% SRR
- 100°C
- VG 68

$$SRR = \left( \frac{U_{Roller} - U_{Ring}}{U_{Ave}} \right) \cdot 100$$

Gould and Greco, “The Influence of Sliding and Contact Severity on the Generation of White Etching Cracks.” Tribology Letters
Influence of sliding magnitude and direction of WEC

Both magnitude of sliding, and direction of sliding were found to be dominant drivers in WEC generation within the MPR.

Gould and Greco, “The Influence of Sliding and Contact Severity on the Generation of White Etching Cracks.” Tribology Letters
Influence of lambda condition on WEC

WECs were formed at all tested lambda conditions with -30% SRR, but the number of WECs decreased with increase in lambda.
WEC Failure Comparison with Field Bearings

- Field bearing often exhibit vertical jumps in WEC
  - This is normally attributed to hoop stress
  - We observe the same thing, however there is no hoop stress.

Gould and Greco, “The Influence of Sliding and Contact Severity on the Generation of White Etching Cracks.” Tribology Letters
Summary

- Several leading causes of wind turbine reliability issues are related to tribological failures.
- Wind turbine operation presents challenging conditions for lubricants and lubricated contacts.
- Many of the failure mechanisms of contact failure are commonly understood.
- The leading cause of gearbox failures is white-etching cracks, related to irregular microstructural alteration to subsurface steel.
- WECs have been confirmed to form subsurface of bearing race using X-ray tomography.
- Bench-top testing using the MPR has successfully produced WEC in a lab environment.
- Testing shows that the contact severity influences the formations of WECs, suggesting that a local energy criteria is necessary to form WECs.
References

Presentation:
- Session 4D – **Tuesday, 10:40 am - 11:00 am** Gray's Peak A
  Energy/Environment/Manufacturing I “Recreation of Surface Initiated White-Etching Cracks, on a Benchtop Test Rig, by Varying Contact Severity” B. Gould, A. Greco

Poster:
- Mt. Evans Room on the 2nd floor- **Student Poster** “A Study of the Dominant Drivers of White-Etching Crack Formation in a Three Ring on Roller Contact” B. Gould, A. Greco

Publications:
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