The Gearbox Reliability Collaborative

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Gearbox Problems

- Actual life is below expected design life.
- Most failures manifested in bearings.
- Failures not accounted for in standard fatigue analysis.
- Problems are generic in nature.
  - Independent of size, design or mfg.
- Poor quality is not the primary cause.
Gearbox Failure Lessons

- taught us that **gearboxes are not forever**, operator can still survive by repairing or replacing gearboxes as they fail in service.
- also learned that **without clean oil no gearbox can survive**
- **gear tooth failures practically disappeared**
- **bearing failures continued to be serious problems in many units**
Bearings are a still a problem
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- still don’t understand why some wind turbine gearbox bearings fail and others survive
Bearing are a still a problem

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• still don’t understand why some wind turbine gearbox bearings fail and others survive
• bearing arrangement and selection?
  • What’s with Spherical roller bearings?
  • Workhouse/ golden boy of other industries
Bearings are a still a problem

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- bearing arrangement and selection?
  - What’s with Spherical roller bearings?
  - Workhouse/ golden boy of other industries
- Can we learn anything from where failures are and are not?
Trouble Spots

1. Planet bearings
2. Intermediate shaft-locating bearings
3. High-speed locating bearings
Good bearing survival locations

- Planet carrier bearings
- Hollow shaft bearings
- Non-locating bearings
What is the difference?

- Lower stress?
- Less cycles?
  - Doesn’t compute, since planet bearings are low speed
- Cooler operation?
- Mystery factors?
  - Locating bearings? Torque reversals?
  - Case deflection and misalignment?
- Something being left out in design process
Possible Design Process Weaknesses

- Missing Load Cases
- Not describing the loading properly
- Irregular or unanticipated bearing responses
- Excessive flexibility of gearbox mount.
- Non-uniform safety applied to gearbox subcomponents.
Bearing capacity calculation

- Based on very empirical “fudging” of physics
  - Empirical approaches require learning from history
- Methods based on statistical analysis of lab tests
  - of small bearings (50 mm)
  - at constant speed and constant load
- Uses equivalent torque and speed
  - How to convert measurements of wind turbine torque to equivalent constant torque?
  - Is equivalent torque a valid criterion? What speed?
- Does this hide something
Light Loading?

- No defined cases in IEC 61400-1
- bearings with small load zones lose traction between raceways and rollers
- rollers skid, overheats and locally dissipates lube,
- creating adhesion wear on race = macro-pitting
Bearing Failure Observations

- General adherence to design standards
- Proprietary rating codes prevent design transparency.
- Bearing manufacturers are not equipped to solve the problem alone
- Collaborative approach is needed.
- No single, simple solution is expected.
- Weakness in design process is suspected.
Reliability Collaborative Tasks

1. Bearing **Root Cause** Failure **Analysis**
2. Exercise complete turbine/ gearbox **design process**
3. Acquire, redesign & **rebuild 2 gearbox**s to best practice
4. **Field Test** - Characterize bearing and structural response during loading events and situations
5. **Reproduce events in dynamometer** and test fixes
6. **Simulation** to improve design tools & understanding
Bearing Failures Analysis

- Develop/ adapt methods to characterize bearing damage
- Develop database of existing (past) data from owner/ operator partners
- Train gearbox rebuilders and field personnel to add future failures to database (disguise data source)
- Use database of failures to evaluate root cause
- Modify bearing selection criteria and life rating to avoid such failures
Target Test Article - Phase 1

- Test turbine - 600 kW to 900 kW range
- 2 gearboxes with identical instrumentation
- 3 point mount, 1 stage planet, 2 stage parallel
- Upgrade both units to state-of-the art
  - Active lubrication, cooling, filtration, gear finish, lubrication, and bearing types.
- Measure external and internal loads, defelections and displacements
- Evaluate rebuild for retrofit effectiveness
Three Point Approach

Drivetrain Analysis and Modeling

Full Scale Dynamometer Testing

Field Testing

McNiff Light Industry
Wind Turbine Testing and Analysis
Field Testing

- Ponnequin Windfarm in Northern Colorado USA
- Extensive measurements on a single turbine.
- Characterize load events
- Correlate loads with internal gear/ bearing responses.
- Document site-wide failures and statistics.
Dynamometer Testing

- Measure bearing responses to controlled load cases.
- Increase load complexity and build confidence.
- Develop non-torque load capability and simulate actual operating conditions.
- Establish transfer functions between shaft loading and bearing responses.
Drivetrain Analysis

- Multi-body dynamic analysis of test article.
- Codes: FAST, Simpack, LVR
- Model gear/ bearing response under various load conditions measured in Dyno and Field.
- Model drivetrain solutions with tuned model.
- Round robin validation of public rating software to proprietary bearing codes
Collaborative Status

- Acquired 2 gearboxes -> Geartech proctology
- Redesign is in an advanced stage
- Rebuild contract in place, bearings identified
- Draft WTG aero model and multibody model
- Internal instrumentation and test plans soon
- Still working out an observer status for interested industry partners.
WTG Vendor/ Supplier “Secret” Opinion

The wind turbine is a dark and nasty beast, the design of which is left to a lying, inbred, secretive priesthood of miscreants and decidedly unstable personalities.
What to Modify in Future Designs

- Increased concern with lubricant
  - Cleanliness thru lifetime, property monitoring
- Bearing rating assumptions
  - L10 to L1 may not solve problem
  - Predictable gear/ shaft alignment
- Predictable surface life (pitting)
- Loads – internal dynamics, low loads