Wind turbine Gearbox Condition Based Maintenance Equipment and Challenges

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27th February 2014
Condition based maintenance - Striking a balance

**Reactive maintenance:**
- Run to failure ❌
- Too expensive!

**Preventive maintenance:**
- Fix/replace everything prematurely ❌
- 100s of routine maintenance operations
- Often expensive

**Predictive maintenance:**
- Optimised cost
- Enabled by key technologies and data analytics
Enabling technologies for predictive maintenance

- SCADA
- Predictive life models
- Full scale testing and failure data
- Component vibration
- Laboratory analysis
- Maintenance and inspections history
- Loads monitoring
- Statistical reliability analysis
Effectiveness of various CMS technologies

<table>
<thead>
<tr>
<th>Method</th>
<th>Main bearings</th>
<th>Planet tooth</th>
<th>Planet bearings</th>
<th>Parallel stage tooth</th>
<th>Parallel Stage bearings</th>
<th>Generator bearing</th>
<th>Generator stator wedge</th>
<th>Blade imbalance</th>
<th>Tower or foundation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vibration analysis</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Possible – analysis difficult</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Excellent – experience required to avoid false alarms</td>
<td>Possible - analysis difficult</td>
<td>Excellent</td>
<td>Possible - analysis difficult</td>
</tr>
<tr>
<td>Particle counter</td>
<td>NA (unless oil lubricated)</td>
<td>Moderate</td>
<td>Excellent</td>
<td>Moderate</td>
<td>Excellent</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Lubricant analysis</td>
<td>Excellent</td>
<td>Moderate / late warning</td>
<td>Moderate / late warning</td>
<td>Moderate / late warning</td>
<td>Moderate / late warning</td>
<td>Modermate / sampling difficult</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>SCADA analysis</td>
<td>Excellent</td>
<td>Poor</td>
<td>Poor</td>
<td>Poor</td>
<td>Moderate – few bearings measured</td>
<td>Excellent</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Multiple CMS technologies are required for fool proof wind turbine health diagnostics
Case study – Gearbox planet bearing failure

- Planet bearings are the life limiting component of the gearbox (if everything else is perfect)
- Planet bearing failure results in gearbox removal and replacement
- Premature planet bearing failure root cause
  - Surface initiated contact fatigue (debris)
  - Assembly errors
  - Load sharing
  - Non torque loading (wind, wakes, etc)
  - Material defects

Example planet bearing failure timeline:

- Normal operation
  - 7-9 years

- Planet bearing begins to pit due to subsurface contact fatigue
  - 9+ years

- Debris from failing bearing indents planet gearing

- Planet gear tooth breaks at full production
  - Seconds

- Planet stage locks up and fractures the gearbox housing
Cost of unexpected planet bearing failure

Reactive maintenance:
- Bearing fails with little or no warning
- Gearbox has significant secondary damage or fails catastrophically (core value = $0)
- Cost of new gearbox = $200-500k
- Cranes and service cost = $100k+
- Lost production = $20-50k and up (depending on season and availability)
- **TYPICAL COST** >$350k per failure
Pitting Planet Bearings

### Turbine Number | N##
--- | ---
Component | Planet Stage
Condition | Critical
Diagnosis | Planet Bearing Inner Race Fault
First Detected | 2/25/2014
Inspected On | 5/30/2014
Inspection Comments | Romax inspection found macropitting on PL2 A Inner Race. Magnet in Gearbox oil filter had build up of metal debris.
Recommendation | Inspect for damage
Notes | Schedule gearbox repair.

### Trend Parameter
- Aug-03-2013
- Aug-24-2013
- Sep-14-2013
- Oct-05-2013
- Oct-26-2013
- Nov-16-2013
- Dec-08-2013
- Dec-29-2013
- Jan-19-2014
- Feb-09-2014
- Mar-02-2014
- Mar-23-2014
- Apr-14-2014
- May-05-2014
- May-26-2014
- Jun-16-2014
- Jul-07-2014
- Jul-28-2014
- Aug-09-2014
- Sep-30-2014

### Gearbox Health Index
- Aug-03-2013
- Aug-24-2013
- Oct-05-2013
- Oct-26-2013
- Nov-16-2013
- Dec-08-2013
- Dec-29-2013
- Jan-19-2014
- Feb-09-2014
- Mar-02-2014
- Mar-23-2014
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- May-05-2014
- May-26-2014
- Jun-16-2014
- Jul-07-2014
- Jul-28-2014
- Aug-09-2014
- Sep-30-2014

**Romax inspection found macropitting on PL2 A IR. Consistent with Vibration analysis findings.**

**Large increase due to progressed damage. Peak growth and side band development.**

**Large increase since last report**

**Planet inner race frequencies have developed side bands**

**1st peak almost double**

**Inner race fault frequency peaks have increased**

**Large increase since last report**
Reduce costs with predictive maintenance

For a planet bearing failure requiring gearbox replacement:

**With predictive maintenance:**

- Bearing deterioration detected early by condition monitoring (>6 months warning)
- Turbine de-rated until replacement feasible
- Secondary damage minimized (core value now $25+K)
- Planned replacement minimizes lost production ($10K savings)
- Crane mobilization spread across two or more turbines ($50K savings)

- **COST SAVING >$80k per failure**
CMS Installation Cost Benefit Considerations

Hardware cost
Detection efficiency
Installation cost
Vibration analyst experience level
Data storage
NERC/FERC/CIPC
Annual monitoring fees
Reliability of communications
Cost of drivetrain components
Cost of cranes and labor

All turbines and sites are different. Component failure rates is the wild card. Understand detection efficiency carefully for each type of CMS equipment considered. Create ROI model for all competing solutions.
Case study – Main bearing

- Bearing inspected due to a steady increase in band limited RMS acceleration
- Wear bands of micro pitting accompanied by Macropitting found on bearing outer ring and rollers
- Recommendation: increase lubrication interval and monitor bearing temperature and vibration until repair can be scheduled

Monitoring main bearing vibration provided ample warning to plan for replacement

Bearing inner race and rollers at 6 O’clock position
Summary and Conclusions

1. Predictive maintenance is a cost-optimal strategy for O&M
2. A hardware retrofit is required for effective predictive maintenance – this has historically been a barrier
3. Vibration is the most effective CMS technology however it is not a silver bullet and should be augmented with lubricant analysis (particle and lab) as well as SCADA data analysis for complete health monitoring
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- Supply drivetrain design software to most of the world’s automotive and heavy equipment majors
- Solve drivetrain issues for the largest industrial players
- Develop next generation design technology
Thank you for listening!

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