Machinery Prognostics and Condition Monitoring Technical Group

Dr. Karl Reichard

Applied Research Laboratory

Phone: (814) 863-7681

Email: kmr5@psu.edu

Steve Conlon  Cliff Lissendon  Steve Hambric
Jeff Banks  Marty Trethewey  Joe Cusumano
Jason Hines  Mitch Lebold  Jeff Mayer
Joe Rose  Jason Hines  Bernie Tittman
Wind Turbine Health Monitoring

Karl Reichard\textsuperscript{1}, Eli Hughes\textsuperscript{1}, Mark Turner\textsuperscript{1}, Brenton Forshey\textsuperscript{2}

\textsuperscript{1}Applied Research Lab
\textsuperscript{2}Department of Aerospace Engineering
Goals and Objectives

- Monitor health and status of individual wind turbines
- Facilitate CBM by predicting equipment failures and maintenance requirements
- Characterize wind-induced unsteady loads
- Monitor health of generator, blades, batteries, and power conversion and control electronics
- Optimize capacity of wind farm by aligning CBM with forecasted weather conditions
Experimental Wind Turbine

- Instrumented Penn State Center for Sustainability’s Southwest Windpower Whisper 500, 3 kW, turbine
- Sensors:
  - 3 phase AC voltage and current
  - Converted DC power
  - Tower vibration
  - Local Meteorology
  - Blade vibration (planned)
Wind Turbine Instrumentation

- Blades
- Generator
- Tower
- Slip Ring
- Electronics
- Batteries
- Met. Sensors

- 3-axis blade accel.
- 3-axis tower accel.
- 3-phase (AC) V&I
- 3-axis gen vibe
- Battery (DC) V&I
Blade Health Monitoring

- Student team designed and is fabricating new blades for wind turbine
- New blades will contain embedded accelerometers to monitor blade vibration and unsteady loads
- Wireless monitoring system in hub will transmit vibration information to monitoring station at base of turbine.
- Future project – energy harvesting for wireless monitoring system
Accelerometer Installation

- Triaxial accelerometer was installed 8 inches from the blade tip
- Cable will run to the hub where we will connect to a wireless transmitter
System Design

Planning / Logistics

Operations

Knowledge

Subsystem Health

Subsystem Health

Subsystem Health

Intelligent Sensor Node

Intelligent Sensor Node

Intelligent Sensor Node

Intelligent Sensor Node

Intelligent Sensor Node

Intelligent Sensor Node

Sensors

Blades

Electrical Generator

Gearbox

Data
Wind Turbine Laboratory Testbed Suite

- **Blades**
- **Motor/Generator**
- **Gearbox**
- **Electronics**
- **Energy Storage**

**Static & Dynamic Testing**

- Generator electrical and mechanical
- Gear, Bearing and Shaft Testing
- Power conversion and switching

**Monitoring System**

- Embedded Systems, Processing, Data Fusion
- System Integration Lab

**Batteries**

- Enterprise Systems
Wind Energy Enterprise
Health Management

- Monitor health and status of individual wind turbines
- Facilitate CBM by predicting equipment failures and maintenance requirements
- Optimize capacity of wind farm by aligning CBM with forecasted weather conditions
Embedded Diagnostic and Predictive Technology Development for Platform Power Generating Devices

Jeff Banks, Mark Brought, Jason Estep, Jason Hines, Nathaniel Hobbs
Objectives

- Demonstrate condition monitoring technologies on representative US Army tactical wheeled vehicle
- Vehicle Under Test: Freightliner 915 Truck
- Condition monitoring applied to detect alternator electrical (windings) and mechanical (bearing) faults
Alternator

- Housing
- Stator
- Regulator

- Fan Blades
- Rotor Assembly
- Rectifier Diodes in Housing
Alternator Faults

- Stator
- Regulator

- Fan Blades
- Rotor Assembly
- Rectifier Diodes in Housing
# Alternator Instrumentation

<table>
<thead>
<tr>
<th>Measurement Description</th>
<th>Sensor Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternator Voltage</td>
<td>LEM Model LV 20-P</td>
</tr>
<tr>
<td>Alternator Phase AB</td>
<td>LEM Model LV 20-P</td>
</tr>
<tr>
<td>Alternator Phase BC</td>
<td>LEM Model LV 20-P</td>
</tr>
<tr>
<td>Alternator Phase CA</td>
<td>LEM Model LV 20-P</td>
</tr>
<tr>
<td>Alternator Field Voltage</td>
<td>LEM Model LV 20-P</td>
</tr>
<tr>
<td>Alternator Current</td>
<td>LEM Model HAL 200-S</td>
</tr>
<tr>
<td>Alternator Field Current</td>
<td>LEM Model HAL 50-S</td>
</tr>
<tr>
<td>Alternator Temperature</td>
<td>Standard K type Thermocouple</td>
</tr>
<tr>
<td>Alternator Vibration</td>
<td>PCB Piezotronics Model 356M154</td>
</tr>
</tbody>
</table>
Alternator Output Current

Time Domain Alternator Current Signature - 75 Amps - 100Hz Shaft Speed

- Stator Short
- No Fault

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Alternator Output Current

Power Spectral Density of Alternator Output Current

- Stator Short

- No Fault
Alternator Stator Short Fault Condition Indicator

Power Spectral Density of Alternator Current

- Comb filter used for fault detection

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Alternator Stator Short Fault Condition Indicator

Power Spectral Density of Alternator Current

Alternator Condition Indicator Response to Stator Winding Short

Comb filter used for fault detection
Alternator Vibration Spectrum

Periodogram Power Spectral Density Estimate of Acceleration (Vertical)

- Inner Race Defect
- No Fault

Frequency (kHz) vs. Power Spectrum Magnitude (dB)

- 1x Shaft Sideband 238Hz
- 1x Shaft Sideband 338Hz
- 2x Shaft Sideband 638Hz
- 2x Shaft Sideband 538Hz
- Inner Race Defect Frequency: 438Hz
Conclusions

• Tested a variety of different faults on 140 Ampere Prestolite vehicle alternators for the Freightliner 915 truck.
• Alternators were then run under various electrical load and engine speed conditions to assess the detectability of faults utilizing different sensors and data collection systems.
• Electrical fault of a single-phase stator winding short, and the induced mechanical fault of a defect on the bearing inner race were easily detected.
Conclusions

• The condition indicator algorithm developed for the single-phase stator winding short looked at the variance in the time waveform of the sampled alternator current output
  – Simple and effective at indicating the presence of a seeded single phase stator winding short at varying engine speeds and varying electrical loads.
  – Can be implemented on existing fielded data analysis hardware that is currently being used on other vehicle systems in theater.

• A more robust algorithm based on the frequency analysis of the amplitude of harmonic components of the alternator signal was also developed.
  – Requires more computing horsepower, but is more sensitive to earlier detection
  – Capable of giving a fault indication prior to failure that would allow for condition based maintenance.
Torsional Vibration Monitoring for Nuclear Power Plant Reactor Cooling Pump Shaft Crack Monitoring

Mitch Lebold, Marty Trethewey, Nathan Lasut, Jonathan Bednar
Overview

- Multi-year project sponsored by EPRI
- Uses torsional instead of lateral vibration to monitor for cracks in RCP shaft
- Prototype system developed and tested on ARL test bed and on scale reactor test bed
Experimental Test Bed

- Bearing Block Accelerometer
- Load Bearing Block
- Proximity Probes
- 1PPR Laser Tachometers
- Hydraulic Ram Assembly
Sensor Installation

180° Orientation

Shaft rotation

Increasing orientation angle

Encoder hub

Slew angle

Offset distance

Orientation angle

Time history of Orientation Snapshot 1
Cutoff frequency: 100000 Hz

Amplitude [V]

0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0

x 10^3

Collected data
Filtered data
Torsional Vibration Spectrum

![Torsional Vibration Spectrum Graph]

Frequency (Hz) vs. Degrees peak
Change in Torsional Vibration Frequency

Results from Test #6 - Sensor #CN2

1st Mode - Model Frequency (Hz)

Torsional Freq: Full health
Torsional Freq: Possible failure detected
Torsional Freq: Failure detected