Defending the Defenders with StressWave Monitoring

January 2012
Why is the military interested in prognostics or CBM+?

- **Condition-Based Maintenance Plus (CBM+) - What is it?**

  - **The CBM+ is a DoD proactive equipment maintenance capability**
    - Uses system health indications to identify and **predict functional failure in advance** of the event
    - Provides the ability to take appropriate action

- **Benefits**

  - Increase **operational availability and readiness** throughout the weapon system life cycle
  - Automation to improve maintenance productivity
  - **Reduce the deployed footprint** required to provide maintenance services to combat units
  - Provide visibility of equipment status needed to implement **anticipatory logistics concepts**
Why is the military interested in StressWave Technology?

- Technology initially demonstrated at U.S. Army Aviation Research and Technology Activity (AFSCOM) Fort Eustis, Virginia on a UH-60 helicopter transmission
- Has been used by the U.S. Navy on LCAC for over 10 years for pre-deployment availability
- Insensitive to operational vibration (e.g. helicopters, ground vehicles)
- Real time condition assessment
- New parameter which can be used to enhance current analysis techniques
# Current Markets Served

## Marine
- 40 Ocean Liners

## Wind Energy
- 4000 WTGs Serviced
- 100+ WTG 24/7
- Over 10 sites

## Process/Oil & Gas
- Steel Mill
- Chemical
- Oil & Gas

## Power
- Fossil Fuel
- Nuclear
Military Program Demonstrations

Military Maritime
- Hovercraft
- Surface Navy

Ground Military
- LAV
- Bradley/Abrams

Air
- Tankers
- Transport/Cargo

Rotorcraft
- Helicopter
- Tilt Rotor
Demonstration of a StressWave System in the U.S. Army

Helicopter Transmission Test Cell
Main Rotor Transmission Testing of StressWaves

Seeded Faults

- Spalled planet gear rolling element
- Spalled planet gear
- Main Module (MM) Timken bearing spall
- MM input pinion gear spall
- MM input pinion gear broken tooth
- MM input pinion bearing integral race spall
- Input module EDM’d roller bearing
- Input module EDM’d ball bearing
- Input pinion high vibration
Helicopter Standard Flight Profile

STANDARD FLIGHT PROFILE

- HOVER
- TRANSITION TO HOVER
- CRUISE
- DESCENT
- CLIMB
- TAXI

TIME: Minutes

TQMR: Lb.- Ft.
### StressWave System Test Results

<table>
<thead>
<tr>
<th>TEST CASE</th>
<th>ADN Actual</th>
<th>ADN Indicated</th>
<th>FDN Actual</th>
<th>FDN Indicated</th>
<th>FLN Actual</th>
<th>FLN Indicated</th>
<th>FIN Actual</th>
<th>FIN Indicated</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;Best-build &quot; Baseline</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td>OK</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shim survey Baseline</td>
<td>A</td>
<td>A</td>
<td>OK</td>
<td>OK</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spalled planet roller</td>
<td>A</td>
<td>A</td>
<td>F</td>
<td>F</td>
<td>MM</td>
<td>MM</td>
<td>BRG</td>
<td>BRG</td>
</tr>
<tr>
<td>Spalled tapered roller brg</td>
<td>A</td>
<td>A</td>
<td>F</td>
<td>F</td>
<td>MM</td>
<td>MM</td>
<td>BRG</td>
<td>BRG</td>
</tr>
<tr>
<td>Tooth spall + broken tooth</td>
<td>A</td>
<td>A</td>
<td>F</td>
<td>F</td>
<td>MM/SIM</td>
<td>MM/SIM</td>
<td>GR</td>
<td></td>
</tr>
<tr>
<td>Bearing race spall</td>
<td>A</td>
<td>A</td>
<td>F</td>
<td>F</td>
<td>MM</td>
<td>MM</td>
<td>BRG</td>
<td>BRG</td>
</tr>
<tr>
<td>Gear spall</td>
<td>A</td>
<td>A</td>
<td>F</td>
<td>F</td>
<td>MM</td>
<td>MM</td>
<td>GR</td>
<td>GR</td>
</tr>
<tr>
<td>&quot;EDM'd &quot; ball &amp; roller brgs</td>
<td>A</td>
<td>A</td>
<td>F</td>
<td>F</td>
<td>PIM/SIM</td>
<td></td>
<td>BRG</td>
<td>BRG/GR</td>
</tr>
<tr>
<td>&quot;EDM'd &quot; ball &amp; roller brgs plus planet gear tooth fault</td>
<td>A</td>
<td>A</td>
<td>F</td>
<td>F</td>
<td>PIM/SIM/MM</td>
<td>SIM/MM</td>
<td>BRG/GR</td>
<td>BRG</td>
</tr>
<tr>
<td>&quot;EDM'd &quot; ball &amp; roller brgs plus &quot;metal maker &quot; MM</td>
<td>A</td>
<td>A</td>
<td>F</td>
<td>F</td>
<td>PIM/SIM/MM</td>
<td>PIM/SIM/MM</td>
<td>BRG</td>
<td>BRG</td>
</tr>
</tbody>
</table>
Example of Deployed StressWave System in the U.S. Navy

Landing Craft Air Cushion (LCAC)
Importance of LCAC Worldwide Operations

Navy ACV Operational Relevance

Jan’05 Tsunami Relief
Mar’03 Iraqi Freedom
Jan’10 Haiti Relief
Jul’06 Beirut Evacuation
How does the Navy use StressWaves?

- The U.S. Navy uses a portable StressWave System with deployments in Little Creek, VA and Camp Pendleton, CA
- The system monitors each of the four (4) main engine gearboxes, the (2) forward offset gearboxes and the two (2) aft offset gearboxes
- Testing is performed at the following intervals
  - Initial gearbox baseline condition assessment
  - Seventy-five (75) hour intervals of operation
  - Sixty (60) days prior to deployment
  - Sixty (60) days prior to induction into the Service Life Extension Program (SLEP) or the Fleet Modernization Program (FMP)
Data Analysis is then performed on the StressWave Energy (SWE) data, Voltage Distribution (Histogram) data and Frequency Spectra (Fast Fourier Transform - FFT) data.

Results of the analysis determine if gearbox removal and replacement is warranted.

CONCLUSION

The Navy has found a number of issues using the StressWave System which would have resulted in critical failures during deployment and operations putting personnel and equipment at risk.
SWAN sensors were attached to the machine surface via epoxy on type mounts at various locations providing a structural path between the sensor and the machine component being monitored. SWANview system configuration was achieved on a known good SPS-49 unit for both the Elevation and Azimuth Drives, and then two units of questionable condition were subsequently tested. A determination was easily made that the EL drive and AZ drive of one of the questionable units was failing as compared to the known good unit without disassembly of the units.

SPS – 49 Elevation and Azimuth Drive Systems
– Case Study

EL & AZ Gear Box Sensors
Safety Demonstration of StressWave System in new Helicopter Transmission
Example Sensor Placement
Increasing and/or erratic SWE trends are signs of increasing contact stresses and imminent or existing damage.
SWE increases significantly and consistently over three days prior to critical operational failure.
Significant increases in the amplitude and number of both synchronous and asynchronous periodic friction/shock events throughout test. Significant growth of pinion 1/rev & harmonics are a particular concern.
Decreasing kurtosis, and skewness changes from positive, through 0, to negative, are signs of increasing dynamic contact stresses.
Electro-Mechanical Actuators (EMAs)

- **Seeded Fault Testing**
  - Good
  - Bad Bearing
  - Bad Ballscrew
V-22 Prop Rotor Gear Box (PRGB)

- Gearbox Oil Debris & Component Defect
- Green Run Testing – Reduce Production Costs
- Test Stand Monitoring
- Future On-board application for safety/availability
USMC LAV Differentials

- Lubrication and Failure Prediction
- Water and Sand Debris in Differentials cause early failures
- Constant Oil Analysis not cost effective
Bradley Transmissions

- Life Tests - Transmission Failures
- Data collection on transmissions during HALT Testing
Funding to support business case and testing at Aberdeen
Tanker Fuel Bladder

- Fuel Bladder separates in flight and leaks fuel
- Need non-intrusive technology outside fuel vapor
Fleet Management for Condition Based Maintenance

Brigade Level Status

Brigade Overview:
Multiple user-defined regions
Unlimited sites per region
Unlimited assets per site
Huge asset density on one page

Vehicle Level Status

Vehicle Overview:
User defined asset categories
Multiple user-defined sub-areas
Unlimited assets per site
All assets on one page if desired

Engine/Transmission Level Status

Greater Detail

Greater Density
Projects in Progress
Questions?

Curtis J. Reichenfeld, P.E.
Chief Technical Officer

Curtiss-Wright Controls
Defense Solutions
28965 Avenue Penn
Santa Clarita, CA 91355
(661) 705-1207
(661) 705-1216 fax