Content of Report

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October, 2013

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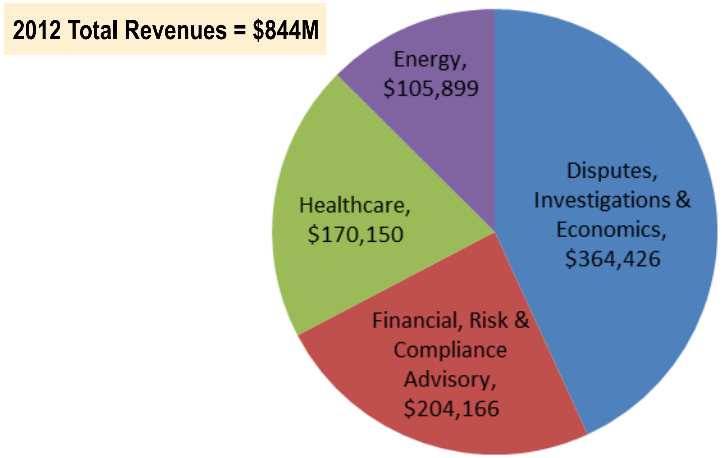
Navigant is a major international management consultancy with more than 2,000 professionals serving clients in more than 70 countries.

Operating Segments



Core Locations in Primary Markets

Energy Practice Offerings

- ✓ Strategy Development & Strategic Services
- ✓ Operations Consulting
- ✓ Regulatory Services
- ✓ Performance Management & Organizational Effectiveness
- ✓ Market Modeling
- ✓ Portfolio/Asset Optimization
- ✓ Project Management & Planning
- ✓ Project & Infrastructure Development
- ✓ Due Diligence Support
- ✓ Mergers & Acquisitions
- ✓ Transaction Advisory
- ✓ Valuation Services
- ✓ Litigation Support
- ✓ Innovation & Energy Technology Management

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AWEA's O&M Working Group issued the first draft of a Recommended Procedures manual in January 2013.

AWEA O&M Sub-Groups

- Gearbox
- Generator
- Blades/Rotor/Hub
- Balance of Plant
- End of Warranty
- Towers
- Data Reporting
- Condition Monitoring

July 2011	Sub-groups created
January 2013	1st draft of RP Manual
January 2014	2nd Draft of RP Manual

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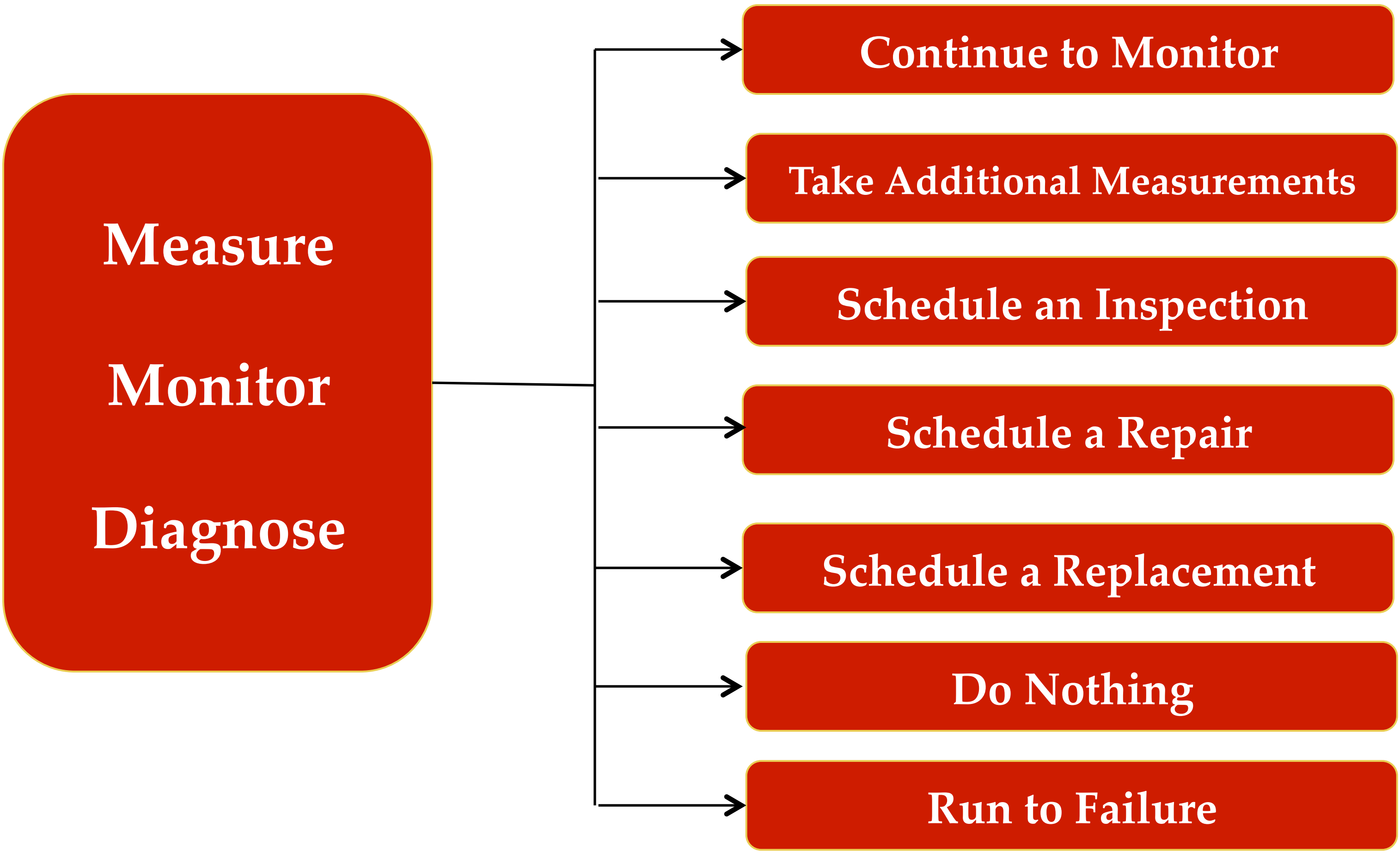
13 Recommended Practices have been developed by the Condition Based Maintenance team.

RP	Title	Primary Author
801	Condition Based Maintenance	Jim Turnbull, SKF
811	Drive Train Vibration Analysis	Jim Turnbull and Greg Ziegler, SKF
812	Grease Sampling - Main Bearing	Rich Wurzbach, MRG
813	Grease Sampling - Generator Bearing	Rich Wurzbach, MRG
814	Grease Sampling - Pitch Bearing	Rich Wurzbach, MRG
815	Grease Analysis	Rich Wurzbach, MRG
816	Temperature Measurement	Eric Bechhoefer, NRG Systems
817	Nacelle Process Parameters	Don Doan, GE
818	Oil Debris Monitoring	Andrew German, Gastops
819	On-line Oil Condition Monitoring	Ryan Brewer, Poseidon Systems
821	Blade Condition Monitoring	David Clark, Bachmann
831	Electrical and Electronic Components	Wenxian Yang, Newcastle University
832	Lightning Protection System	Kim Bertelsen, Global Lightning Protection Services

The fundamental concept behind CBM is a practice that enables the measurement, monitoring and diagnosis of the equipment's health.



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A multiple measurement / multiple parameter approach is critical to detecting problems using vibration analysis.

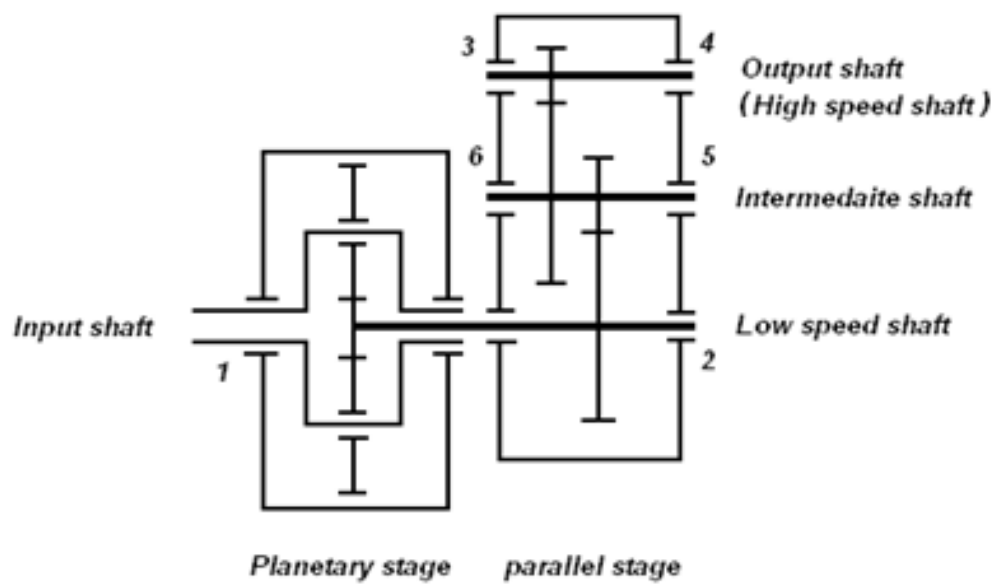
Primary Components Monitored

Main Shaft Bearing(s)
- Axial Movement
- Radial Vibration

Generator Bearings
- Drive End Radial
- Non-Drive End Radial

Gear Box Bearings
- Low Speed Shaft Radial
- Intermediate Speed Shaft Radial
- High Speed Shaft Radial

Typical Wind Turbine Gearbox Configuration with Transducer Locations



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Grease sampling methods must provide an effective means to obtain grease close to the moving parts of the bearings.

Main Bearings

- With Access Plugs
- Without Access Plugs

Generator Bearings

- Sampling from bearing drain w/chute or deflector
- Sampling from bearing drain w/ spatula or straw

Pitch Bearings

- Recovery from Purge Container w/ Removable Lid
- Recovery from Purge Container without a Lid

"T-Handle" Tool

Straw Sampling of Main Bearing Grease

A comprehensive, disciplined approach to grease sample collection and specific analysis can help identify grease, bearing and gear issues.

Grease Analyses	Procedures Used
Ferrous Debris Quantification	Measure the change in voltage as it is dropped through an electromagnetic field
Consistency Testing	Rheometry or Die Extrusion. Consistency reductions of as much as 40-50% may be considered typical
Infrared Spectroscopy	Infrared (IR) Spectroscopy or Fourier Transform Infrared Spectroscopy (FT-IR)
Anti-Oxidant Additive Quantification	Linear Sweep Voltammetry measures the Remaining Useful Life of the anti-oxidant additive package
Elemental Spectroscopy	Rotating Disc Electrode (RDE), Inductively Coupled Plasma (ICP) or Xray Fluorescence (XRF) quantify the metallic elements in grease
Visible Appearance	Grease Colorimetry measures light absorbance in the visible light range (400-700 nm)
Water PPM	Karl Fischer titration by oven method

The key to using temperature is to remove the environmental factors so that differences in temperature reflect actual bearing faults.

Areas where Temperature can be used for Condition Monitoring

- Main Bearing
- Generator Bearings
- Generator Windings
- Gearbox Oil Sump
- Gearbox Bearings
- Yaw Motors
- Pitch Motors
- Slip Ring
- Hydraulic Pumps

Use of SCADA for Temperature Condition Monitoring

- Define a component temperature rise (CTR) which is the difference of the sensor and ambient temperatures
- Use a minimum of 6 machines, with a minimum of 21 acquisitions per machine, to generate test statistics
- Set CTR thresholds for each power bin as Mean + 3*Standard Deviation
- Set Alarm Alerts for Hot Bearings at 82°C
- Set Generator/Motor Alerts based on NEMA MG 1-1998 as appropriate

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Process parameters available from SCADA data can provide an early warning indicator for degraded operation of assets.

Areas Where Statistical Models Are Used for Condition Monitoring		
1	Hub System	
	a.	Main Bearing
	b.	Blades
2	Gearbox	
	a.	Bearings
	b.	Oil Sump
	c.	Gears
	d.	Oil System • Online Oil Particulates • Oil Cooler
3	Generator	
	a. b. c. d. e.	Bearings Windings Slip Rings Controls Cooling Systems
4	Transformers	
5	Converters	
6	Yaw	
	a. b.	Controls Position

Physical Measurements and Calculations Associated With These Assets
Pressures
Temperatures
Vibrations; including deterministic characteristic: Kurtosis, Crest Factor, Spike Energy, Stress Wave
Voltage
Current
Torque
Strain
Moment
Particle Count
Wind Direction
Wind Speed
Wind Deviation
Blade Tip Speed Ratio
Ambient Temperatures
Ambient Pressures
Power
Position
Set Points
Control Demand Signals

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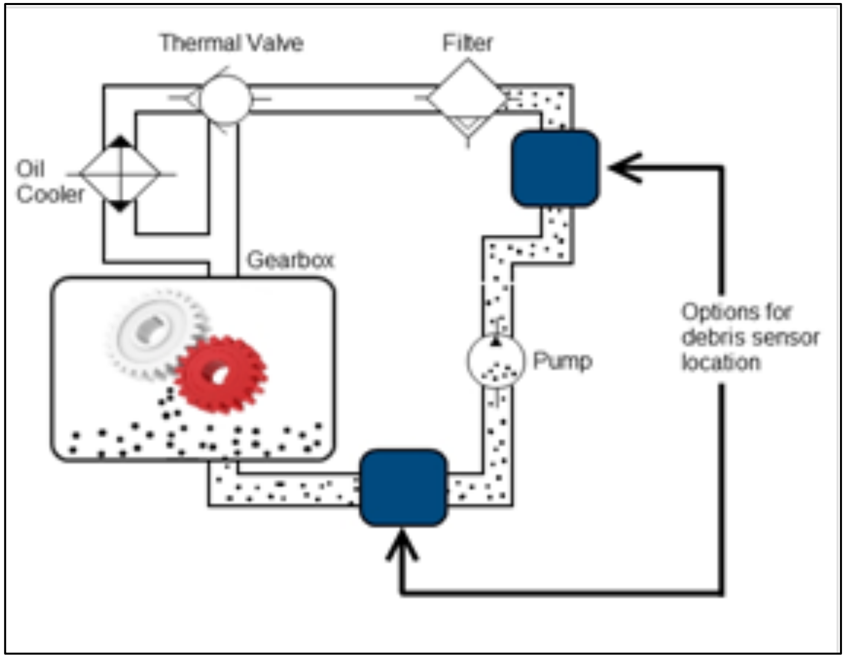
Oil debris monitoring is well suited to provide an early indication and quantification of surface damage to bearings and gears of a gearbox.



Lube Oil System

- Oil debris monitoring used in conjunction with PHM techniques offers the potential of:
  - Detecting early gearbox damage
  - Tracking damage severity
  - Estimating the time to reach pre-defined damage limits
  - Providing key information for proactive maintenance decisions
- The sensor must be located down-stream of the gearbox oil return port and prior to the filtration system, either before or after the pump.
- Recommended parameters for indicating severity of bearing damage:
  - Total accumulated particle counts
  - An increasing rate of particle generation

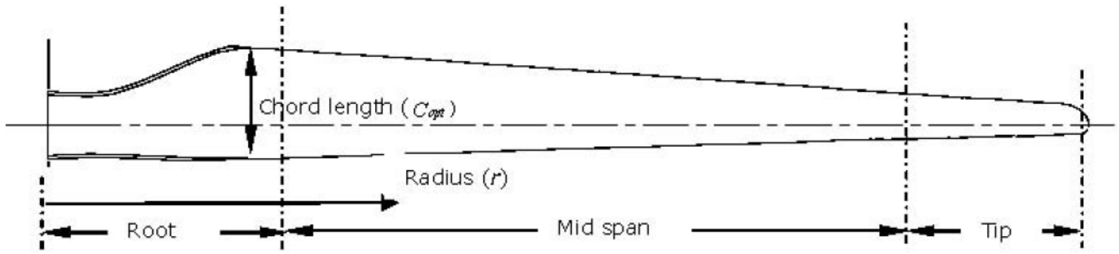
Many online oil condition sensing devices are available which offer insight into a variety of oil condition parameters.

Sensing Technologies	Procedures Used
Impedance Spectroscopy	Set of electrodes immersed in the lubricant to measure the fluid's impedance over a range of frequencies
Conductivity Sensing	Set of electrodes immersed in the lubricant to measure the electrical properties of the fluid
Infrared Spectroscopy	Infrared (IR) Spectroscopy or Fourier Transform Infrared Spectroscopy (FT-IR)
Moisture Sensing	Capacitive sensing element with a hydrophilic dielectric
Viscosity	Viscosity sensing techniques including rotational, vibrational, and displacement based sensors

Blade condition monitoring systems may be capable of detecting and predicting failures and conditions in megawatt class wind turbines.

Failure Modes
Cracks
Delamination
Icing
Imbalance
Lightning Strikes

Technology Approaches
Fiber Optic
Strain Gauges
Acoustic
Vibration Sensors
Laser Reference



Typical Blade Plan and Region Classification

Electrical current, flux, and power monitoring techniques have been well developed and are now successfully applied to WTGs.

Component	Procedures Used
Generator bearing	Onboard vibration monitoring and analysis, often in combination with temperature measurement
Generator ground fault	Rotor earth/ground fault detector applies a DC bias voltage to the rotor winding and monitors the current flowing to the rotor body via an alarm relay
Generator electrical discharge	On-line discharge monitoring systems
Generator Turn-to-Turn Faults	Stator and rotor temperature
Generator Brush Gear	Measuring brush or brush-holder temperature

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Power electronics includes components that are most prone to fail, but condition monitoring techniques have not been fully developed.

Component	Procedures Used
Semiconductors (e.g. IGBT)	Temperature Measurement
Electrolytic Capacitors	Capacitance, Equivalent Series Resistance, Dissipation Factor, and Temperature
Film Capacitors	Capacitance and Temperature
Transformer Bushings	Bushing Capacitance, Dielectric Dissipation Factor, and Transient Overvoltage Conditions
Other Transformer Practices	Dissolved Gas Analysis, Partial Discharge Monitoring, Temperature, Vibration Analysis , Leakage Flux, Analysis Of Current Signals , Bushing Oil Pressure
Low Voltage Electric Cables	Infrared Assessment
Medium and High Voltage Cables	Off-line 50/60Hz PD Test, Thermocouples to Spot Check , IR Camera in Junction Boxes

The lightning protection system can prevent or reduce damage that results in outages and long-term degradation of components.

Direct Effects to be Monitored
Peak Current
Energy
Charge
Current Rate-of-Change
Wave Shape
Location

Indirect Effects to be Monitored
Surge Protective Device Faults, including upstream fuses
Surge Protective Device Operation

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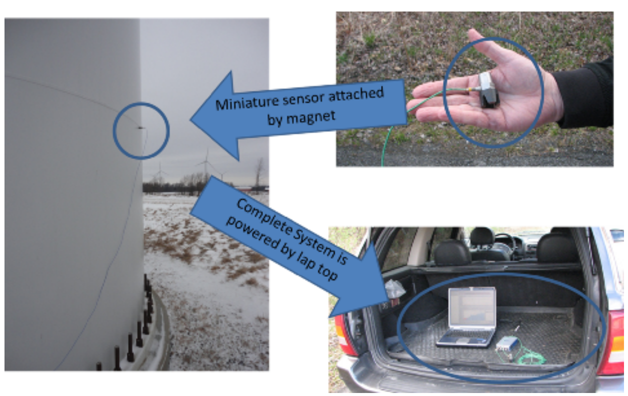
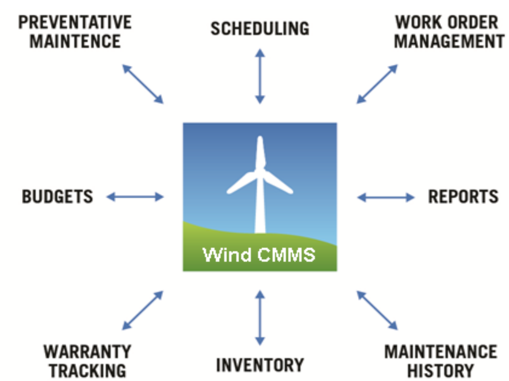
Emerging technologies will be added to the AWEA RP manual as they become commercially proven.

Title	Primary Author
WTG Vibration Assessment Using Down-Tower Sensors	Tom Walter, Mechanical Solutions, Inc.
Mobile Computerized Maintenance Management System	James Parle, Muir Data Systems
Acoustic Emission for Monitoring the Structural Integrity of WTG blades	Denja Lekou, Centre for Renewable Energy Sources & Saving, Greece



Down-Tower Vibration Sensor



Mobile CMMS Overview

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Key Takeaways
» The fundamental concept behind CBM is a practice that enables the measurement, monitoring and diagnosis of the equipment's health.
» CBM practices are becoming increasingly common in the wind industry as the cost:benefit ratio tilts in their favor - although there is a long way to go compared to other industries.
» CBM practices are best used in combination with each other along with a proactive maintenance program.
» As emerging technologies are introduced to the wind industry, they are being vetted and disseminated by the AWEA O&M Working Group.

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