Adopted for
Wind Power Management class
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GASTOPS

Oil Debris Condition Monitoring
For Wind Turbine Gearboxes

Presented by : Richard Dupuis

AWEA Wind Power Asset Management Workshop
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Making Machinery More Effective

Corporate Profile

AS9100 Rev B
ISO 9001:2000
FM 90574

- Advanced products and services for Machinery Condition Assessment and Control
- Supplier of MetalSCAN Oil Debris Monitoring technology since 1995
- Aviation, Defense, Energy and Marine sectors
- Founded in 1979
- Four locations:
  - Ottawa, Ontario (head office)
  - Halifax, Nova Scotia (field office)
  - Victoria, British Columbia (field office)
  - Pensacola, Florida (GasTOPS, Inc.)

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What's the Problem ?

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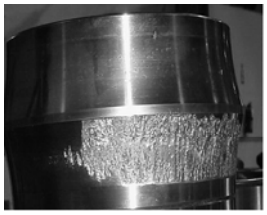
Gearbox Failures



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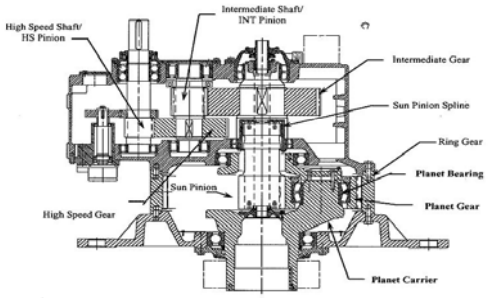
Typical Wind Turbine Gearbox Arrangement



Overview

- How can the problem be managed
- Condition Monitoring Theory & Feasibility
- Oil Debris Monitoring (ODM) method - principle of operation
- Why Bearings & Gears Fail
- Validation of ODM method for condition monitoring

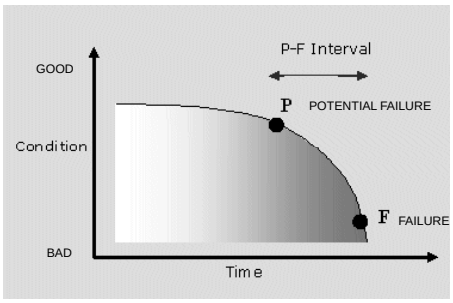
How to deal with the problem ?

- Conduct root cause investigations of gearbox problems
- Continue to make design modifications to gearboxes and their system interfaces
- Operators/owners must seek solutions to manage the problem

How can the problem be managed ?

- **Adopt Condition Monitoring (CM)**
- **Avoid "Failure" Event**
  - Contain the damage
  - Reduce repair time & costs significantly
- **Minimize Business Interruption**
  - Schedule repair support on-site before shutdown
  - Minimize lost revenue & penalties

Condition Monitoring Theory : P-F Curve

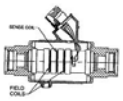


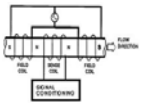
• Need to have a: 'Condition Indicator' (CI)

CM Technical Feasibility Criteria

- CI must detect the potential failure (P)
- CI must identify the degree of damage towards failure (F)
- P-F interval must provide adequate time for the organization to proactively plan
- P-F curve must be consistent for the failure mode

Oil Debris Monitoring (ODM) - Principle of Operation

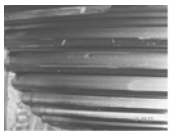




- Sensor includes 3-coil assembly
- Metallic debris from bearing or gearbox sump flows past the field coils creating a disturbance signal in the sense coil
- Signal characteristics define:
  - particle size based upon signal amplitude
  - type (Fe or NFe) based upon signal direction

How does ODM satisfy the CM criteria ?

Why Bearings/Gears Fail?



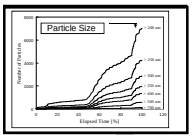
- Most bearings/gears are damaged in-service due to stress concentrations that arise from:
  - **Physical / dimensional discrepancies** - ***….Misapplication, Mishandling, Defects***
  - **Overrolling of debris -** ***….Contaminants in lube oil***
  - **Corrosion pitting** - ***….Chemical interactions***

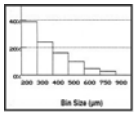
Validation of ODM method

- Bearing and Gear component damage - research data
- Engine and Gearbox damage - rig test data
- Fielded Applications damage – field data

Bearing and Gear Component Damage Research

Bearing Damage Research (NRC)



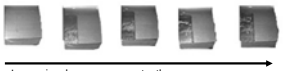


- Rig data from over 40 bearings (2” to 18” in diameter; ball and roller)
- **Observations:**
  - Early damage is series of ‘particle bursts’
  - Later damage is more progressive
    - …Rate is dependent on load and speed
    - …Quantity is dependent on size of bearing
  - Particle size distribution is independent of bearing size
- **Conclusions:**
  - ***Quantity*** correlates to ‘**degree of damage’**
  - ***Quantity + Rate*** correlates to ‘**remaining life’**

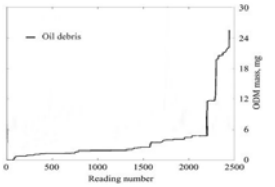
Reference document: *“Rolling Element Bearing Failure Detection with ODM (Oil Debris Monitor) On-line Oil Debris Sensor”, NRCC doc. – IMR-MCM-CTR-020*

Gear Damage Research (NASA)

- Seeded fault test data from gear rig monitored by ODM



Increasing damage on gear tooth



Reference document: *"Integrating Oil Debris and Vibration Gear Damage Detection Technologies Using Fuzzy Logic", NASA/TM – 2002-211126*

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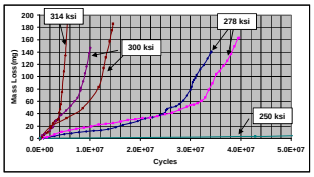
Bearing Prognostics Research (AFRL)

- Seeded fault test on bearing test rig
- 52100 and M50NiL bearing steels
- ODM used to monitor debris quantity



AFRL Observations-

1. Higher stress = quicker damage progression
2. Mass loss is repeatable for constant stress

Reference document: *"ISHM presentation by Dr. Nelson Forester, Aug 11/05"*

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Engine and Gearbox Damage Rig Tests

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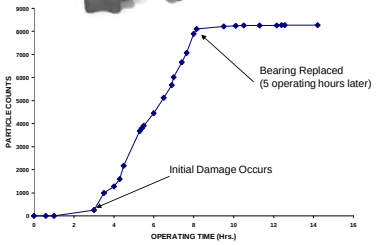
Gas Turbine F119 (F22 Aircraft) Bearing Damage – Test Data (P&W)



- New engine run on test stand
- Damage due to mis-assembly
- Bearing highly overstressed
- *NO SECONDARY DAMAGE occurred*

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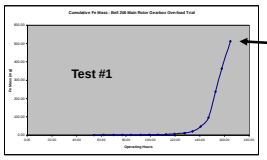
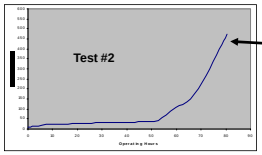
Bell 206 Helicopter Gearbox
Bearing Damage – Test Data (DSTO)



- Rig test of two B206 main rotor gearboxes at DSTO test facility
- 150% overload stress test
- Test #1 & 2 teardowns showed damage limited to planet bearing



Data is presented by permission from the Australian Defense Science & Technology Organization

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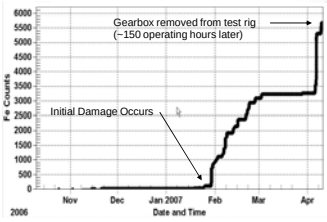
Apache Helicopter Gearbox
Bearing Damage – Test Data (NAVAIR)



- Rig test of AH-64 drive-train at USNavy Patuxent River transmission test facility
- 200 hour high stress component qualification test
- Gearbox ran for ~50 hrs with only small quantity of build debris detected
- No chip detector alarm
- Teardown confirmed damage limited to input shaft bearing

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Fielded Applications
Damage
Experience

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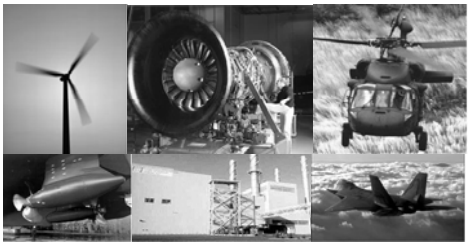
Proven *Oil Debris Monitoring* (ODM)
Applications for Rotating Equipment



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Facts about the Equipment Bearing and Gear Damage

- Rotating Equipment suffer bearing or gear events periodically, often without warning.
- Depending upon the equipment application the cost of each undetected event can be in the hundreds of $000.
- Experience shows that damage develops progressively over time…. days, weeks or months from initiation to failure, depending upon the equipment type.
- Operators/owners require early detection solutions to ***Proactively Manage*** the event and ***Avoid the Failure.***

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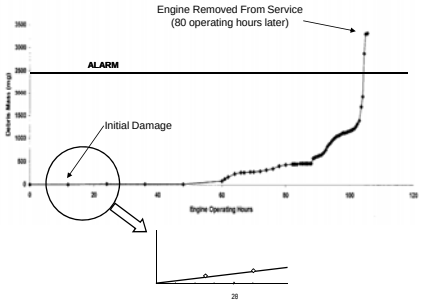
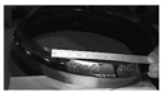
Gas Turbine FT8 (JT8D derivative) Bearing Damage – Field Data





- Only last 100 hrs shown
- Engine ran for ~5000 hrs with virtually no debris detected.
- Operator ran past Alarm Limit to convenient shutdown period (weekend)
- *NO SECONDARY DAMAGE occurred*

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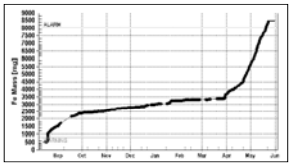
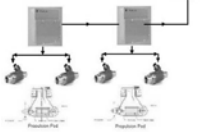
Marine Propulsion Pod Bearing Damage - Field Data



2 sensors per pod, one per bearing



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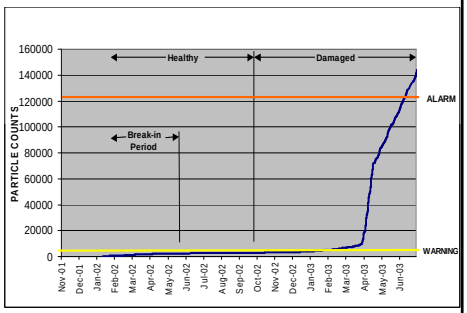
Wind Turbine Gearbox Damage – Field Data



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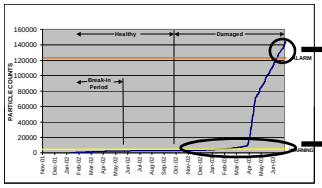
History of a Failure - At Removal



140,000 total particles counted
1,500 particles/day in later stages

8 months operation from detection of initial damage to removal

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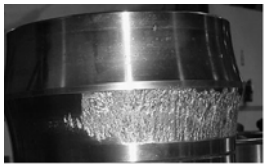
History of a Failure - Planetary Stage Bearing Damage



Inner Race

Roller

Damage limited to:
- *<u>one</u> planetary stage bearing &*
- *<u>one</u> planetary stage gear*

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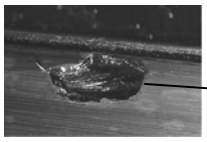
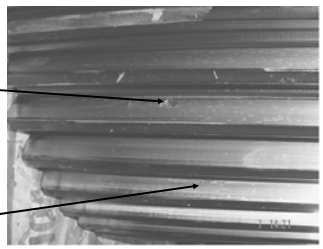
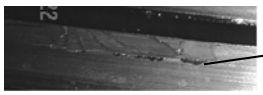
History of a Failure –
Planetary Stage Gear Tooth Damage







Damage limited to:
- *<u>one</u> planetary stage bearing &*
- *<u>one</u> planetary stage gear*

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Summary

- ODM has been proven to be a technically feasible condition indicator of damage for bearings and gears
- ODM provides an EARLY indication of damage and quantifies the SEVERITY and RATE of damage progression towards failure
- ODM is interpreted easily as a condition indicator to answer 2 essential questions:
  - *Can the machine be operated ?*
  - *If so, for how long ?*

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