Challenges Associated with Qualifying a New Measurement Technique for Gas Turbine Health Monitoring

National Research Council and Industrial Applications of Gas Turbines Committee Collaborative Forum

Ottawa, October 2008

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Outline of Presentation

1) Failure Mode of Interest (Rolling Element Bearings)
2) Measurement Technique (On-line Oil Debris Sensor)
3) Technical Challenges
4) Qualification Process
   - Component Testing
   - In-Service Validation
5) Commercial Challenges
6) Summary
7) Questions for Audience

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Why Bearings Fail

- Most bearings 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

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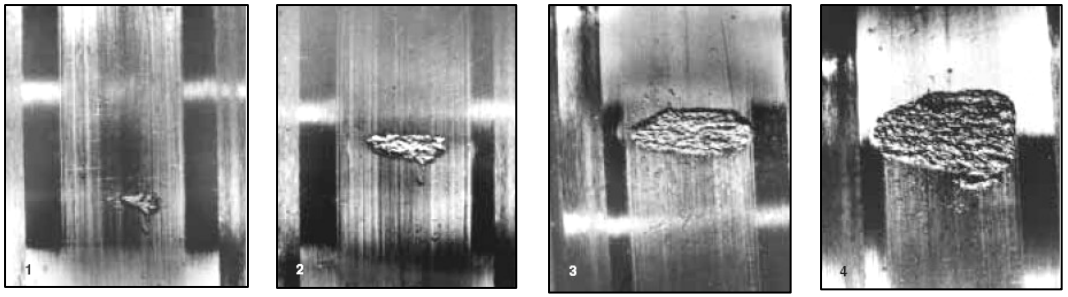
Bearing Surface Distress

- Fatigue starts at surface defects
- Spall propagates at sub-surface cracks
- Rate of damage progression depends on:
  - Bearing material properties
  - Bearing geometry
  - Load (contact stress)
  - Rotational speed
  - Lubricant viscosity
  - Chemical interactions at crack root (e.g additives)



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Oil Debris Sensor

- On-line, full-flow sensor fitted into lube oil lines
- Based on inductive sensing technology
- Detects 100% of particles above minimum particle size threshold
- Detects both ferrous and non-ferrous metallic particles
- Counts and classifies (size and type) particles passing through the sensor

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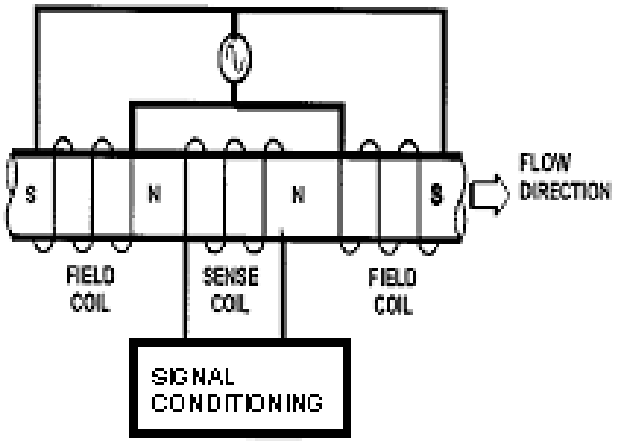
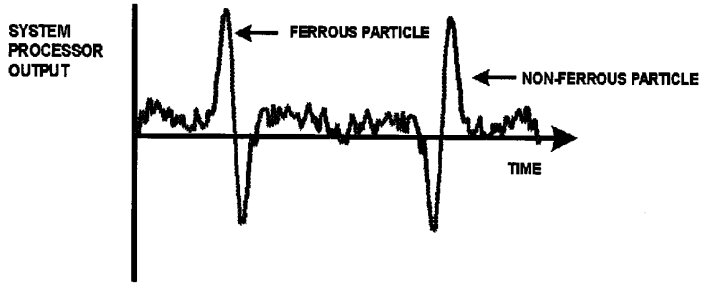
Principle of Operation





- 3-coil, balanced field principle
- Metallic debris particles from bearing sump flow past the field coils creating a disturbance signal in the sense coil
- Signal characteristics define:
  - particle size (amplitude)
  - particle type (phase)

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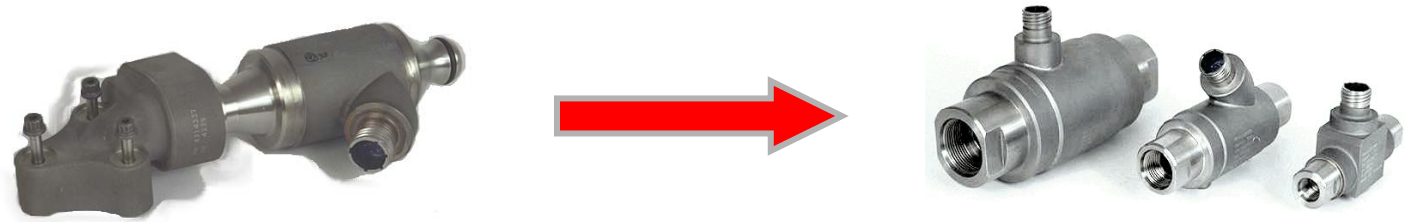
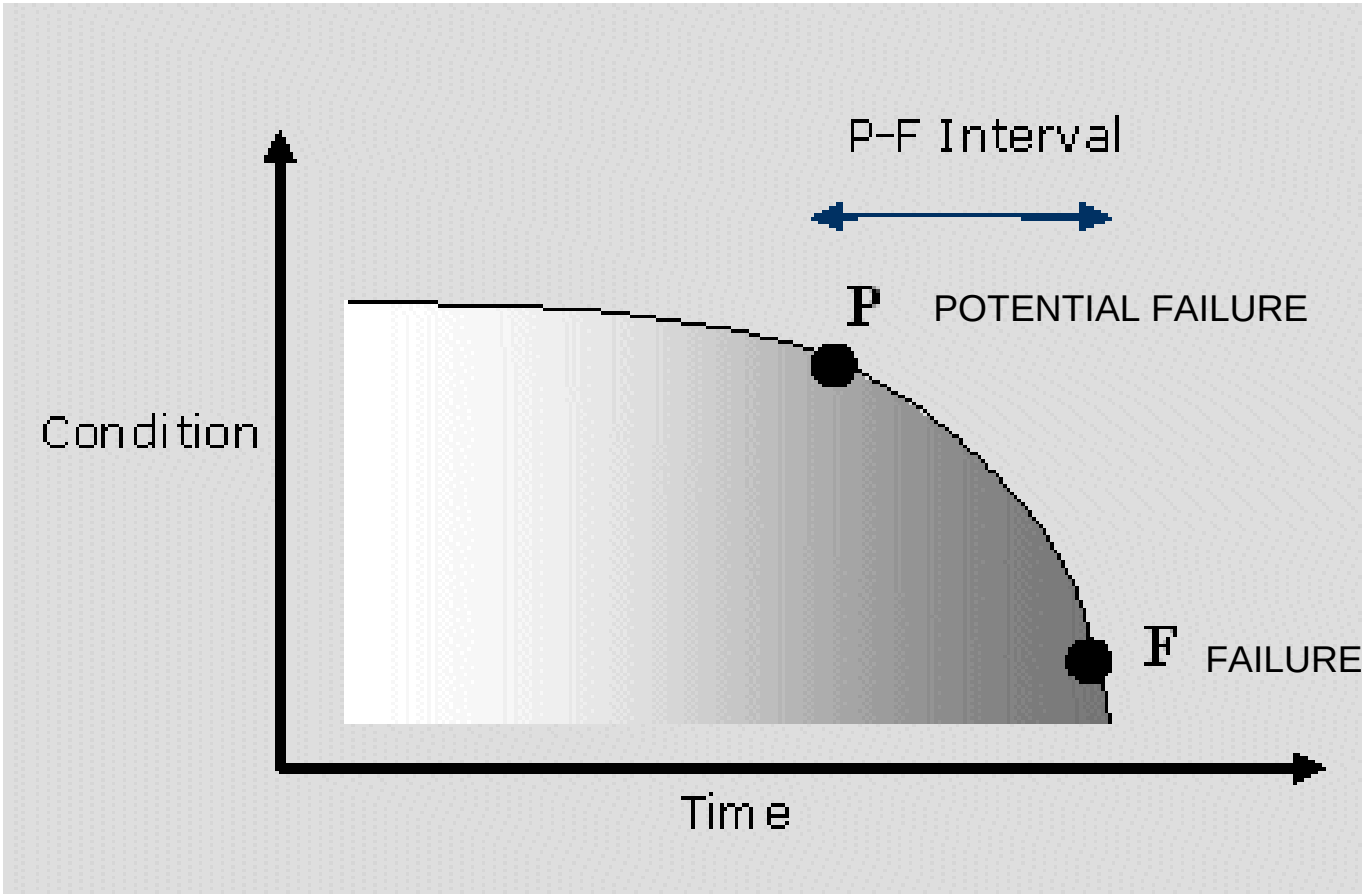
Development History

- Technology acquired from Canadian Government in 1991
- Selected for F22 fighter engine development program in 1992
- Introduced to aero-derivative engine market in mid to late 1990s
- Operational on more than 300 aero-derivative engines

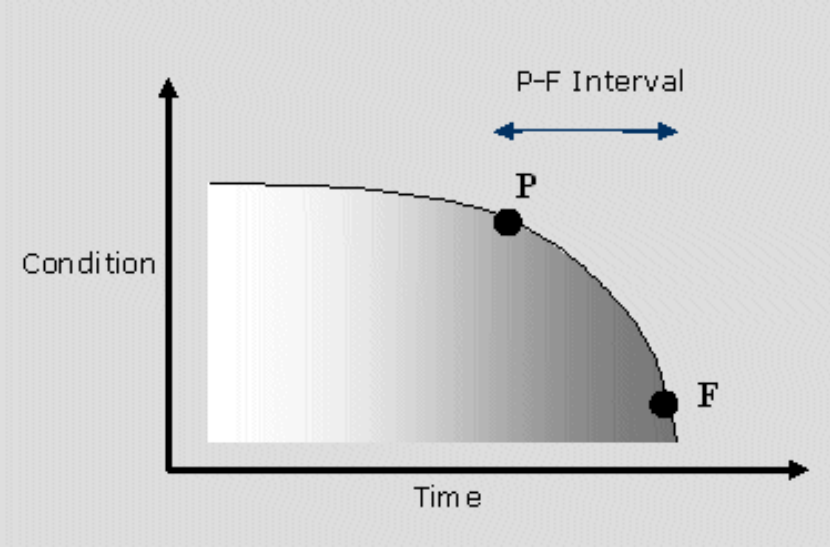


Health Monitoring Requirements



Technical Challenges

- Measurement must be sensitive enough to detect the potential failure (P) so as to provide adequate time for the operator to take remedial action
- Measurement must unambiguously identify the failure mode of interest
- Measurement must yield a P-F curve that is a recognizable and repeatable so that criterion for decision making can be established with confidence



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Qualification Process

1) Component Testing
   - Failure progression testing of sample bearings under controlled conditions
   - Assessment of measurement sensitivity, ambiguity and repeatability criterion
   - Characterization of representative failure events
   - Definition of in-service data processing and interpretation requirements
2) In-Service Validation
   - Validation of measurement criterion under actual operating conditions
   - Validation and refinement of data processing and interpretation methods

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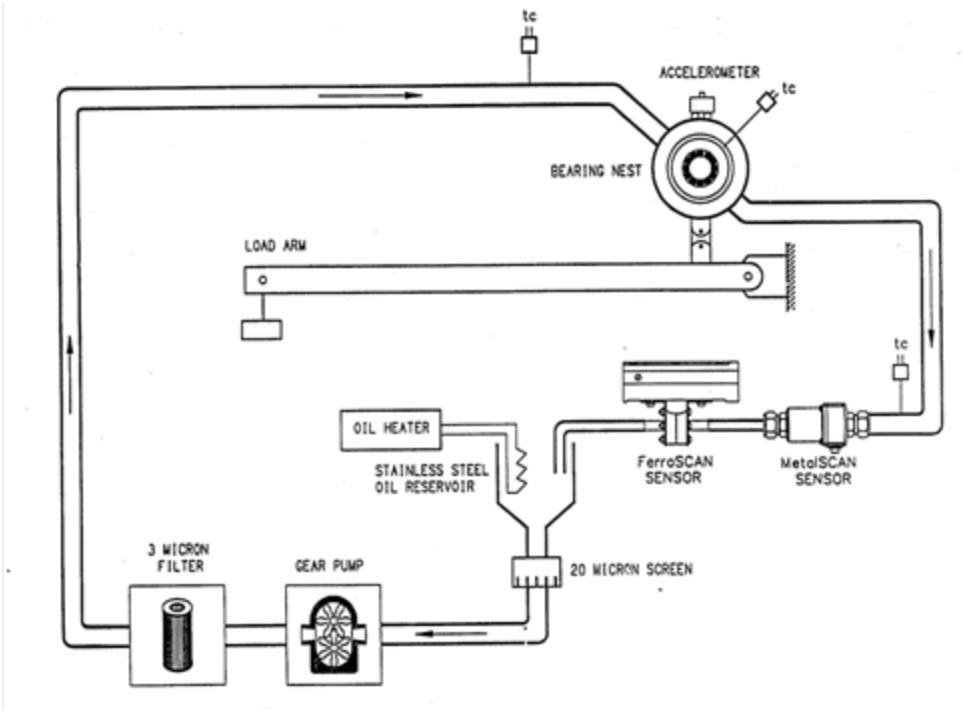
NRCC Test Program



- 2 inch ball (single and double row) and roller bearings
- Over 40 bearings of tested to failure under different load/speed conditions
- Debris captured for post-test analysis

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AFRL Test Program

- 40 mm bearing test facility (8 heads)
- Bearing life and spall propagation testing – materials, lubricants and load/stress levels
- Oil debris sensor used to quantify effects of contact stress on bearing life and rate of damage progression

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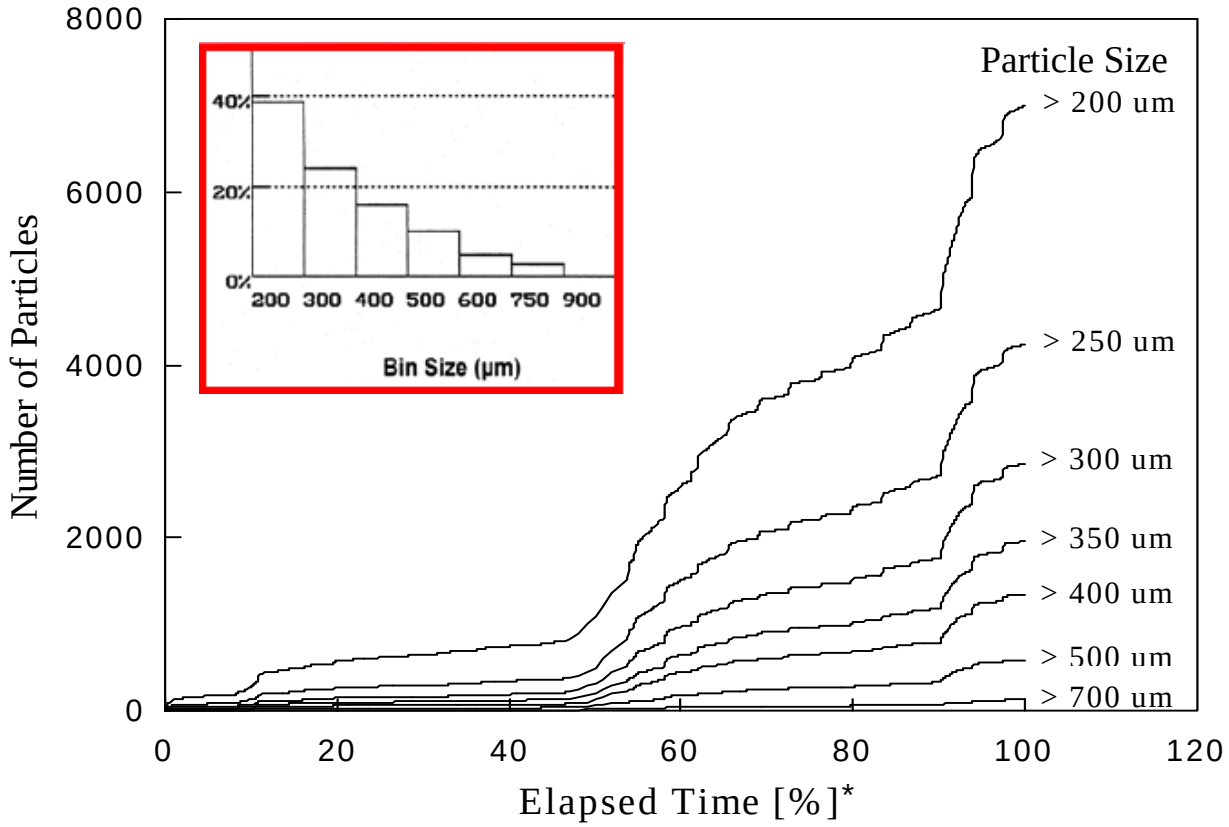
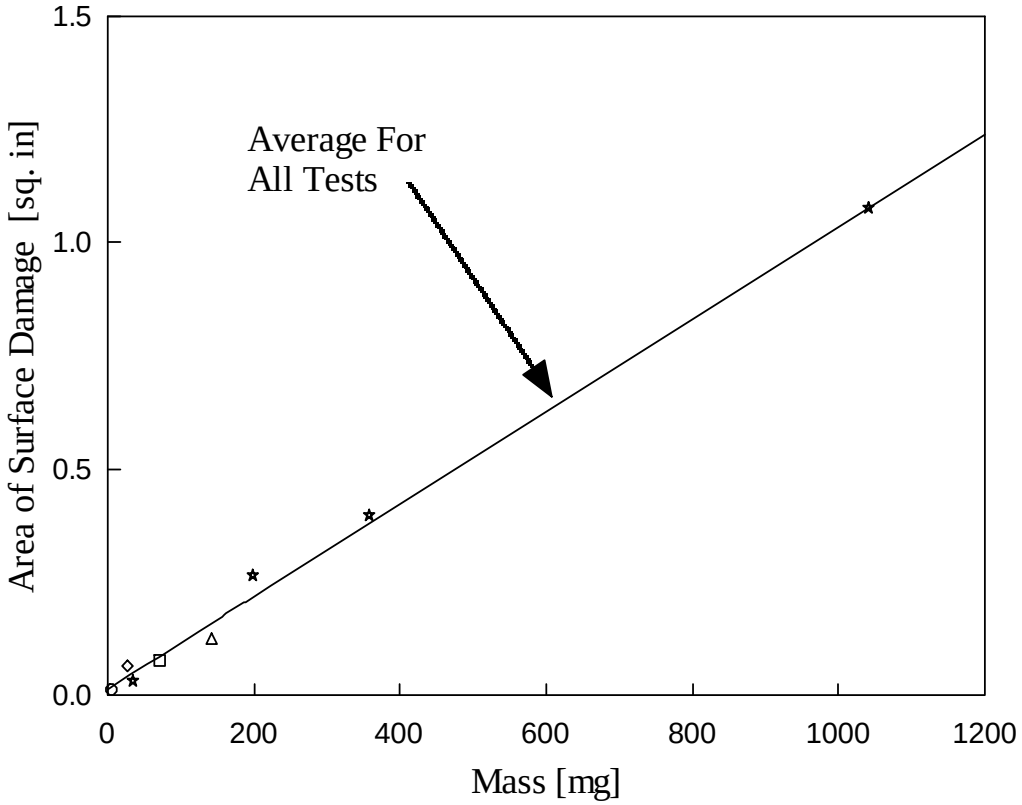
Characteristics of Bearing Distress



Correlation of Measurements to Damage Severity



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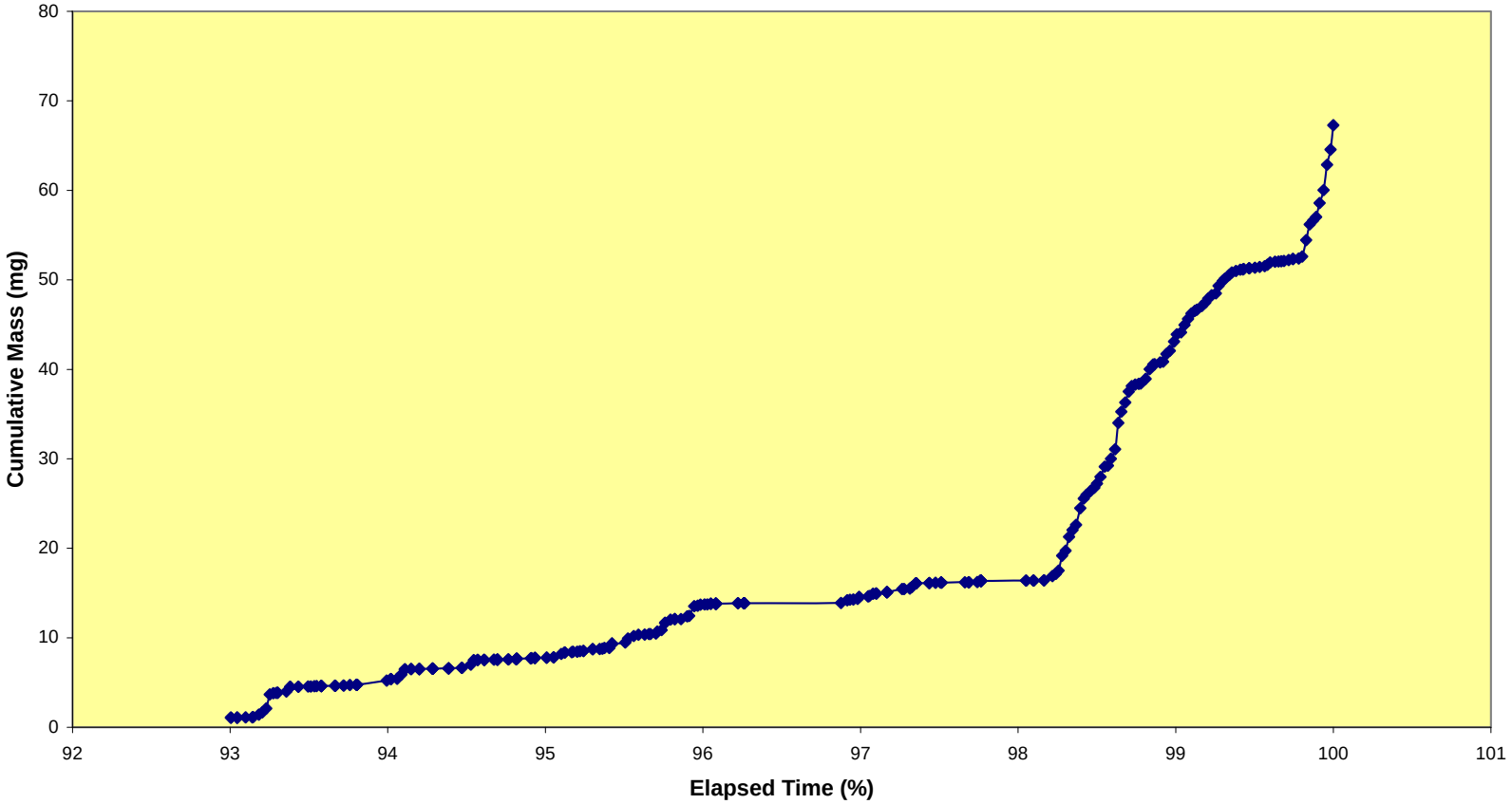
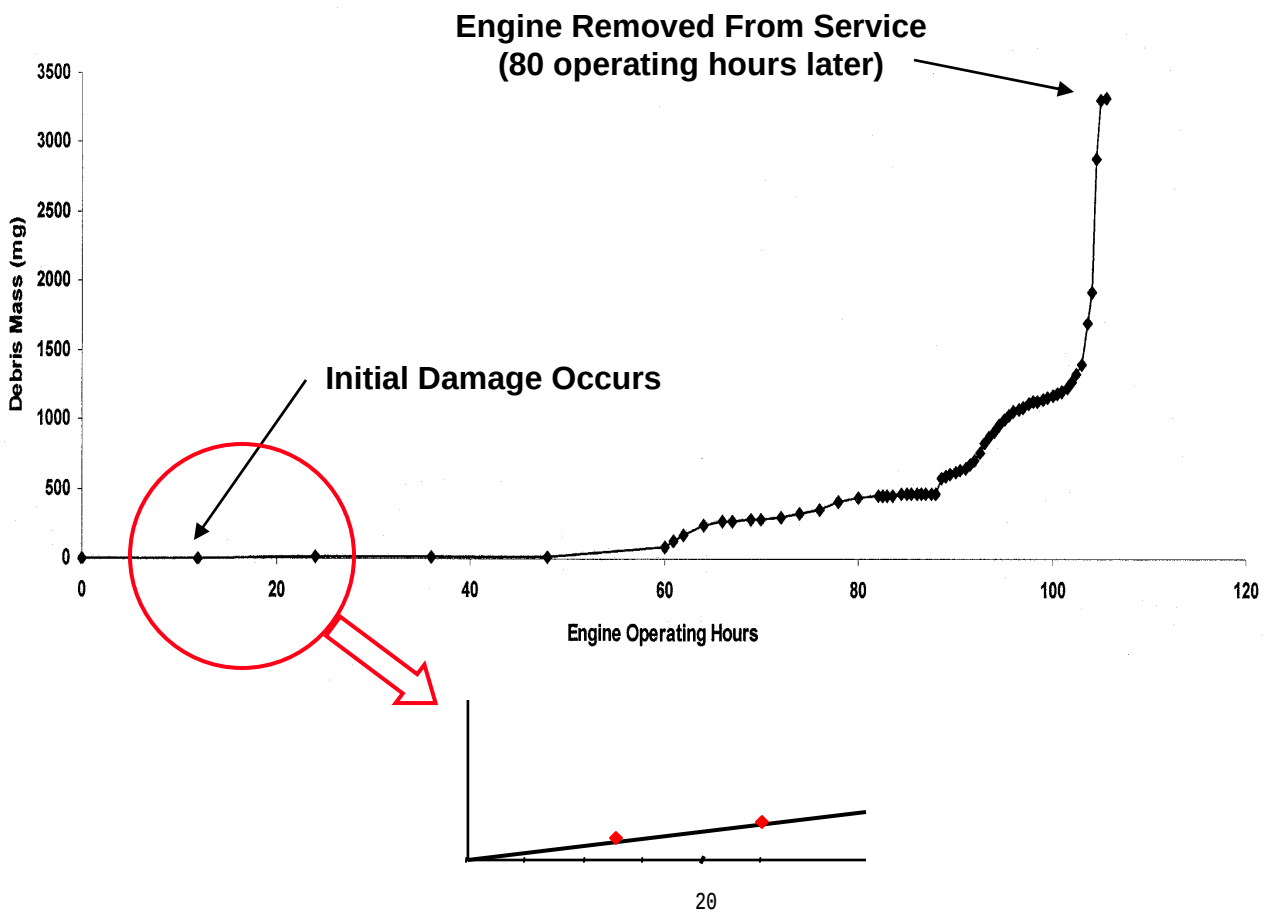
In-Service Implementation?



In-Service Damage Event -FT8



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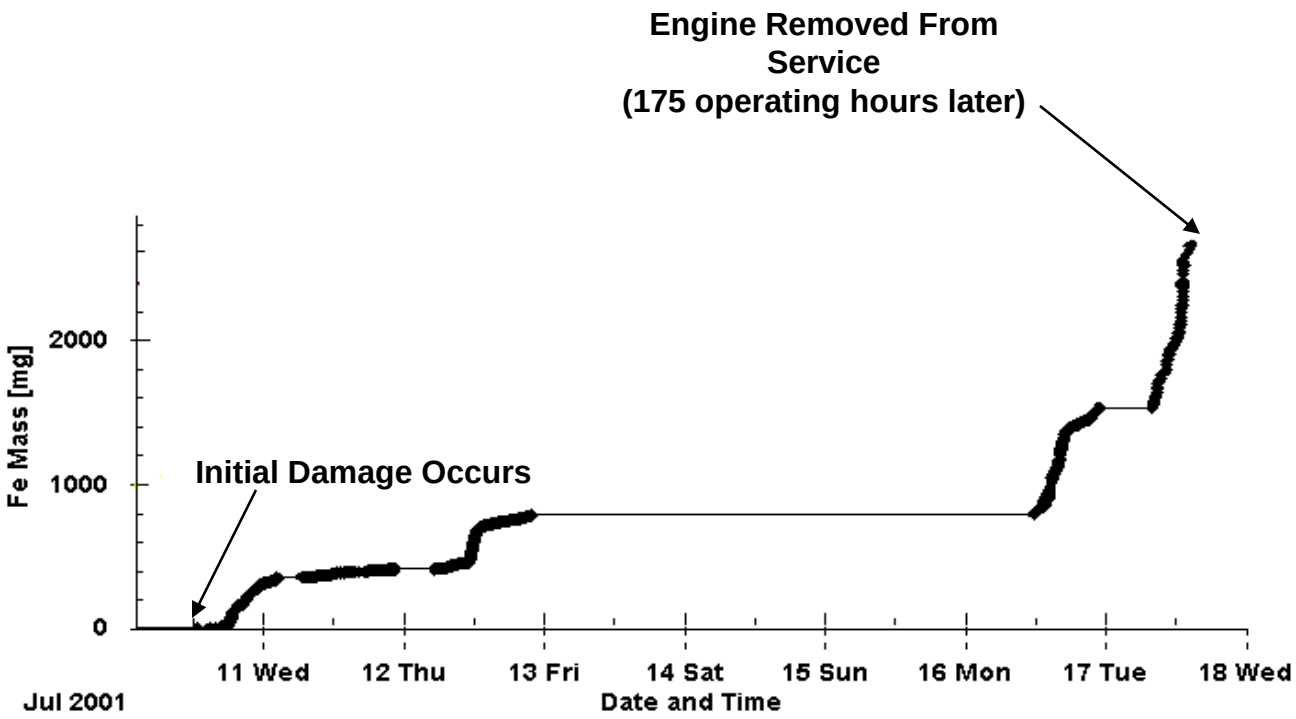
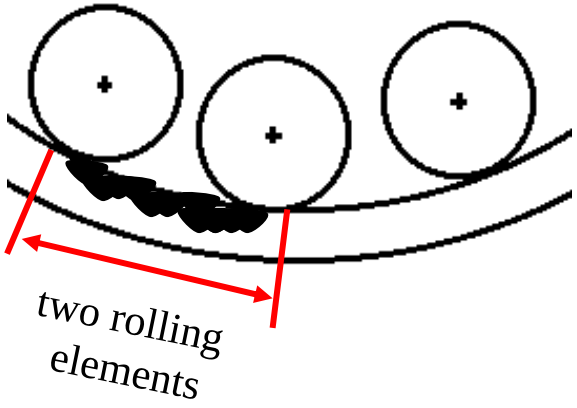
In-Service Damage Event -FT8 [#2]



In-Service Alarm and Warning Limits



Experience, thus far, has shown that the critical damage progression point for race distress is the circumferential area affecting two adjacent rolling elements

“Alarm” level set at mass removal associated with critical surface area

“Warning” level set at 10% of Alarm level

Rate of debris generation used to substantiate Alarm condition

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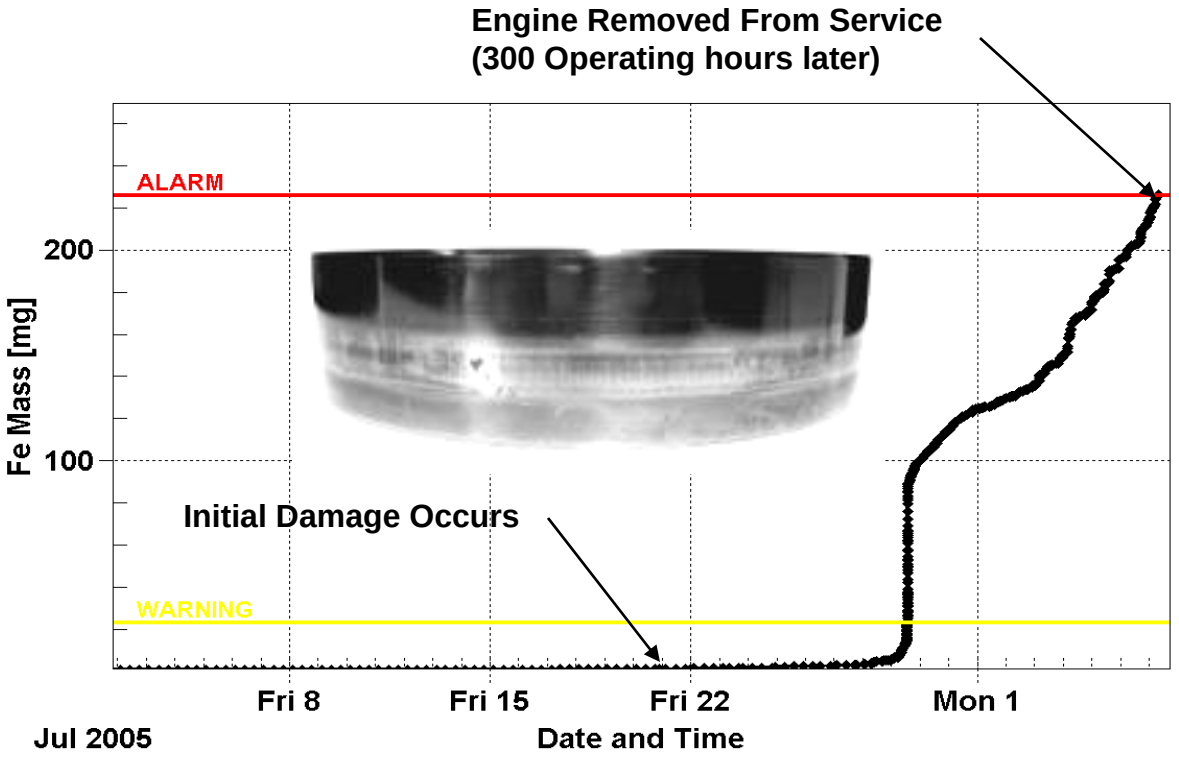
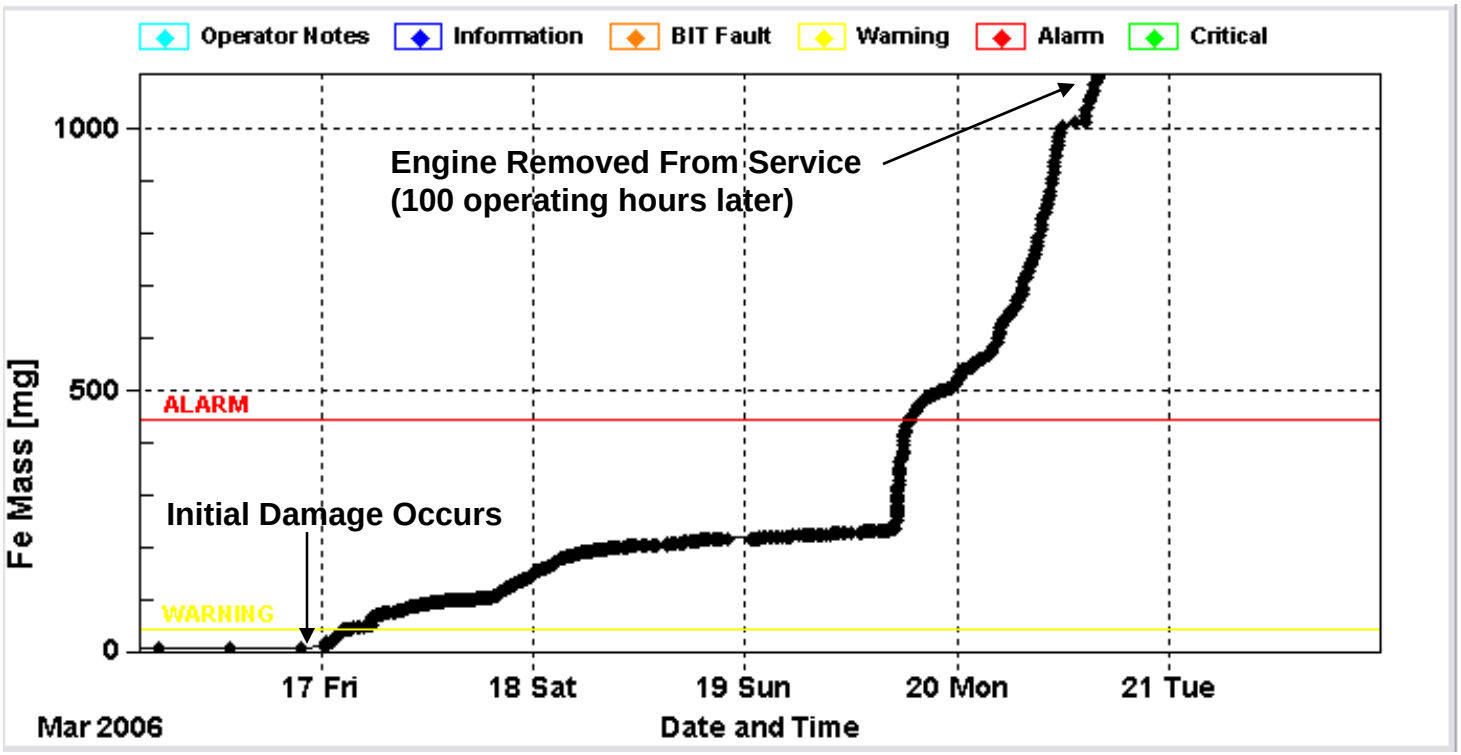
In-Service Damage Event - LM2500 Bearing



In-Service Damage Event – LM6000 Bearing



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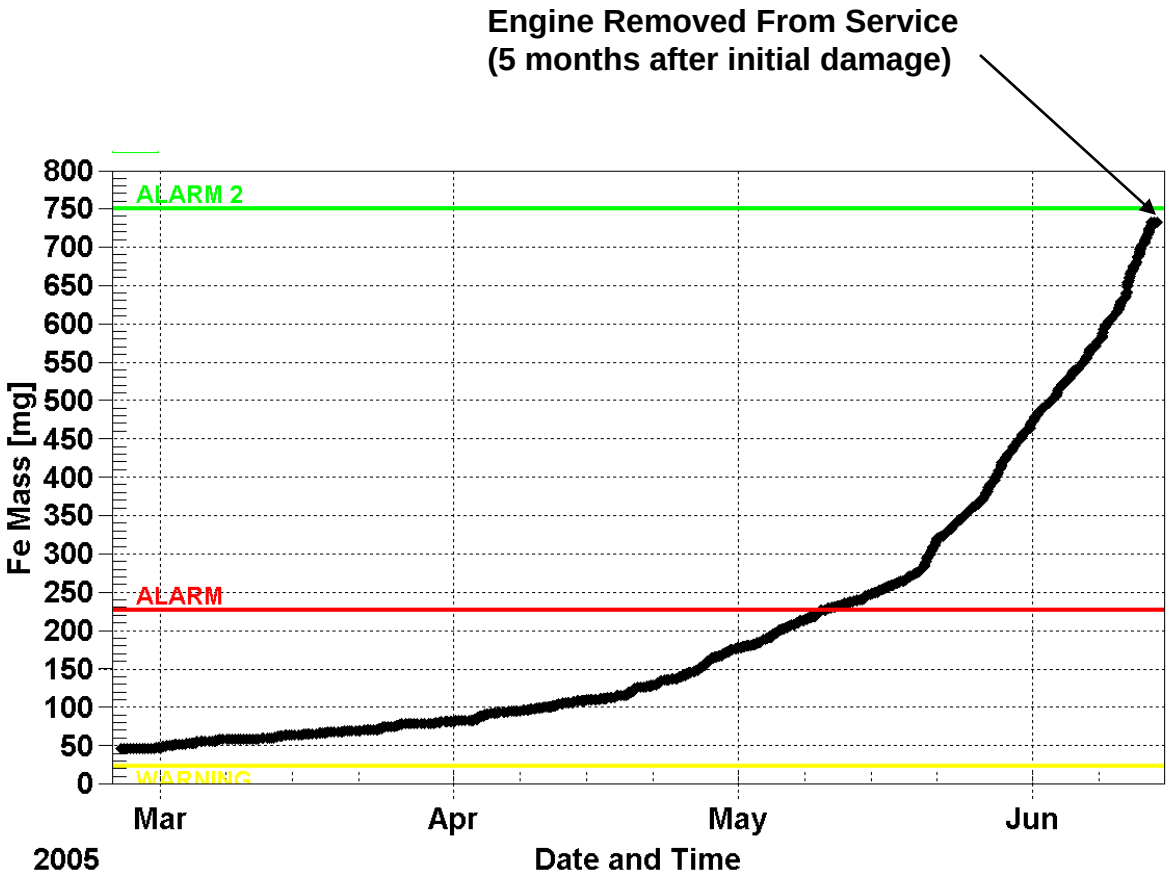
In-Service Damage Event - LM2500 Seal



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Commercial Challenges

1) The qualification process requires a sustained and purposeful effort over many years
   - pay back periods can be long
2) The nature of the qualification process requires collaboration
   - Technology provider
   - End users
   - OEM
   - Government research organizations
3) OEM support is important - to facilitate and expedite the qualification process
4) The financial investment required is substantial

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Summary

1) On-line oil debris measurement has been successfully commercialized for aero-derivative gas turbine bearing damage detection and monitoring

2) Qualification process was a significant and time consuming component of the overall commercialization effort

3) Key technical challenges were in the areas measurement sensitivity, ambiguity and repeatability – all of which needed to be substantiated by component testing and in-service data before decision making criterion could be validated

4) Key commercial challenges included collaboration agreements, OEM support and financial investment

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Questions for Audience

1) Is there a better way to foster the collaboration that is required to bring new health monitoring technologies into service?

2) Is there a problem or need facing this industry that could be used as a focal point for future health monitoring developments?

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