Mapping & Tracking of Damage in Titanium Components for Adaptive Life Management

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Overview

- Wide use of titanium in dynamic components and increasing use in structural components
- Need to improve life management tools and understanding of early damage evolution behavior

**MWM-Array Technology Advances:**

1. Improved nondestructive testing (NDT) of engine disk slots and blade dovetails
2. Mapping & tracking of early stage fatigue damage
3. More reliable and reproducible imaging enables new adaptive life management approaches to extend life and reduce life cycle costs
Requirements for Mapping & Tracking of Damage Initiation and Growth

- Reliable and reproducible images
- High resolution
- Position registration
- Fast
- Low cost
- Easy to use in field and depot
Outline

- MWM-Arrays
- Air Calibration and Grid Methods
  - Adaptive Life Management Approach
  - Case Study 1: Engine Disk Slot Inspection
  - Case Study 2: Engine Blade Dovetail Inspection
  - Case Study 3: Bolt Holes
  - Case Study 4: Hydraulic Tubing Inspection
- Summary
MWM® and MWM-Array Eddy Current Sensors

Paradigm Shift: Sensors are Designed to Match Models

Single-channel
FS35 MWM sensor

Multiple channel
FA28 MWM-Array sensor

Sensing Elements

1 mm = 0.04 in.
0.25 mm
1 mm

Primary
ASTM Standard – “Air Calibration”

Air Calibration → Reference Substrate Measurement (Conductivity, lift-off) → Coating Property Measurement → Coating Thickness, Coating Conductivity, Lift-off

Designation: E 2338 – 04


This standard is issued under the fixed designation E 2338; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.
Air, Shunt Calibration (No Crack Standards)
This is now an accepted practice in use at the NAVAIR Depot

- Perform “Air Calibration” each day
- Perform Calibration Check on disk with known cracks once per week
- Perform Self-Diagnostic in each inspected slot at over 30,000 data points

MWM-Array Sensor FA102

MWM-Array Replacement Cartridges

Sensor in “air”

Shunt
Rapid Data Processing with Grid Methods and “Air” Calibration

Blue Background (~1,500 points)

Crack (22 points)

Lift-Off

Conductivity

Full Grid
Outline

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• **Adaptive Life Management Approach**
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• Summary
Proposed Adaptive Life Management Approach

1. Generate Empirical Database of sensor data from laboratory fatigue coupon data,
2. Set Detection/Characterization Requirements
3. Record and Store Time-Sequenced, High-Resolution Images of fatigue critical areas at depot/field
4. Identify Statistically Significant Early Fatigue Damage Trends, using models of damage evolution behavior (if available), and Recalibrate Empirical Database using depot/field inspection data
5. Make Inspection, Maintenance, Repair, Replacement Decisions for individual components and populations of components
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• Summary
Automated Engine Disk Inspection System

- In use at NAVAIR Depot since April 2005
- Nine disks with verified cracks detected, several of these large and small cracks not detected by conventional ET and LPT
- No false indications (over 3000 slots inspected), false indication rate <0.04

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Conductivity

Lift-Off

Presented at ASNT Fall, Oct 2006
Production/Depot GridStation System

- Impedance instrument
- Probe (and spare)
- Sensor cartridges
- Control box
- Compressor
- Turntable
- Carriage assembly
- Laptop computer, with GridStation software

GridStation System 1
- MWM-Array 1

GridStation System 2
- MWM-Array 2
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Automated Disk Slot & Blade Dovetail Inspection
At FRC-SE, Jacksonville (delivered in October 2006)

Photos of Delivered System
Filtered MWM-Array Results

Note:
Training Set Blade “with Known Cracks”

**Convex Side**

**Corner 2**

**Corner 3**

**Concave Side**

**Corner 1**

**Corner 4**

*Lower threshold designed to detect smaller cracks by increasing sensitivity, but this may also increase false indication rate

**42-mil Crack**

**75-mil Crack Cluster**

(Maximum Crack Length 50 mils)

Also Presented at ASNT Fall, Oct 2006
Filtered MWM-Array Results

Note:
Training Set Blade Identified as Having “No Cracks”
Filtered MWM-Array Results

Note:
Training Set Blade Identified as Having “No Cracks”

Convex Side

Concave Side

Crack Cluster

25-mil Crack

Also Presented at ASNT Fall, Oct 2006
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Generation of “Real Crack” Specimens

MWM-Array FA75

Channels 19-24
Channels 13-18

Channels 7-12
Channels 1-6

Normalized Conductivity

Fatigue Cycles

0.0175 in.
0.0205 in.
0.0259 in.
MWM-Array Scans for Bolt Hole Inspection

MWM-Array FA43

Conductivity

Lift-Off
Time Sequenced Images of Crack Growth

24,840 cycles
0.017 in.

25,348 cycles
0.0205 in.

25,907 cycles
0.0259 in.
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- **Case Study 4: Hydraulic Tubing Inspection**
- Summary
Tubing Inspection for Mechanical Damage

MWM-Array

MWM-Array Response vs. Scratch Depth (mils)

MWM-Array Sensor
Ti-6Al-4V Fatigue Coupon Tests
for Permanently Mounted & Scanning MWM-Arrays
MWM-Array Scanner for Fatigue Tests

Fatigue Coupon

MWM-Array FA43

0.344 in.

0.326 in.
Surface Mounted MWM-Array Sensors

MWM-Array FA75
Photograph Showing MWM-Array Placement on Mechanical Damage (Ding) Specimen

Drive windings (six pair shown in image)

Sensing elements

0.050 in.
Scanning MWM-Array Results

Before Fatigue Cycling

Conductivity scan at 3.981 MHz

After Fatigue Cycling

Conductivity scan at 3.981 MHz

Damage Progression
Mapping and Tracking of Crack Initiation and Growth at “Dings” in Ti-6Al-4V

Scanning & Permanently Mounted MWM-Array Data
Summary

- Mapping & tracking of early damage with MWM-Arrays demonstrated
- Capability continues to improve
- Adaptive life management is the goal
  - Generate empirical databases with coupons
  - Calibrate/recalibrate using field inspection data
  - Map & track early damage
  - Learn/recalibrate from fleet experience