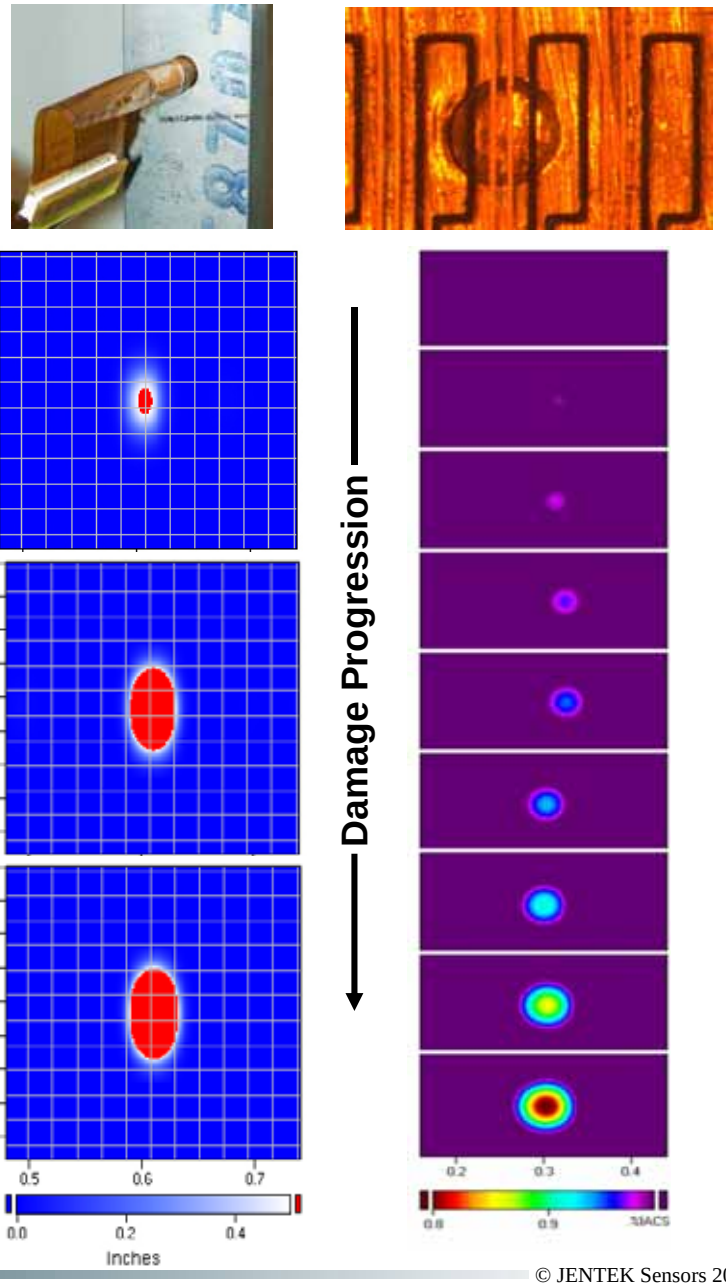
10th Joint NASA/DoD/FAA Conference on Aging Aircraft
April 16-19, 2007; Palm Springs, CA

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

Neil Goldfine, Mark Windoloski, Vladimir Zilberstein
JENTEK Sensors, Inc.
Waltham, MA USA

Georg Contag, Nam Phan, Randy Davis
NAVAIR
Patuxent River, MD USA



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

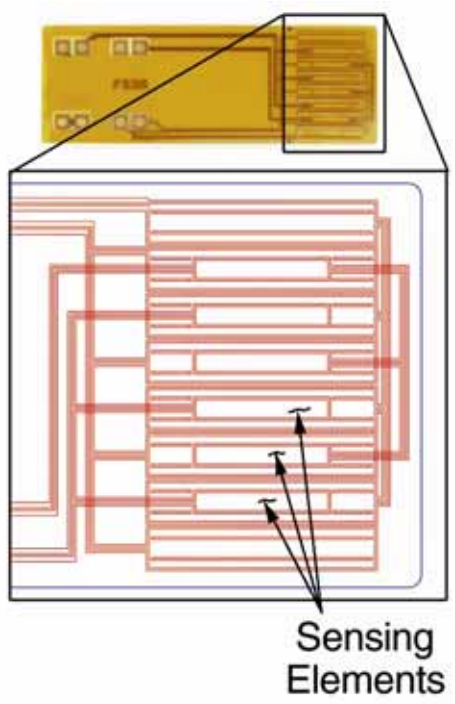
Outline

- **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

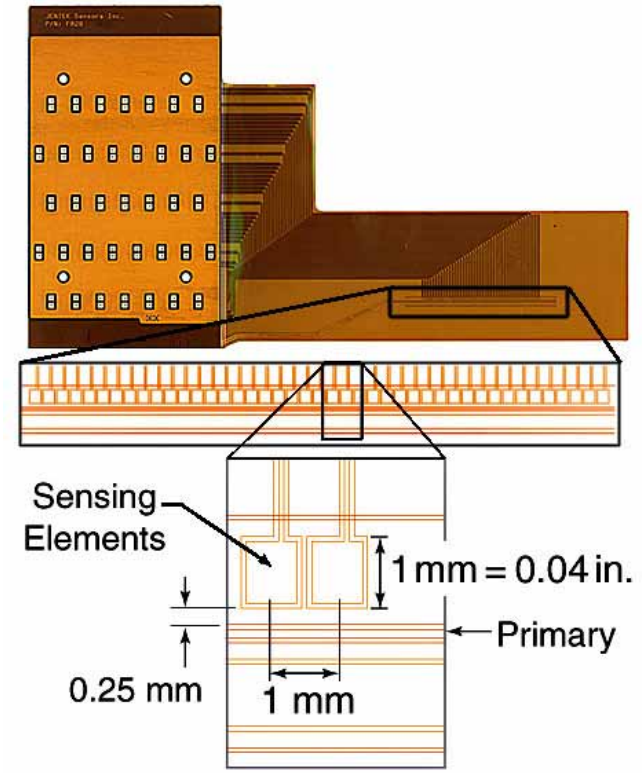
MWM® and MWM-Array Eddy Current Sensors

Paradigm Shift: Sensors are Designed to Match Models

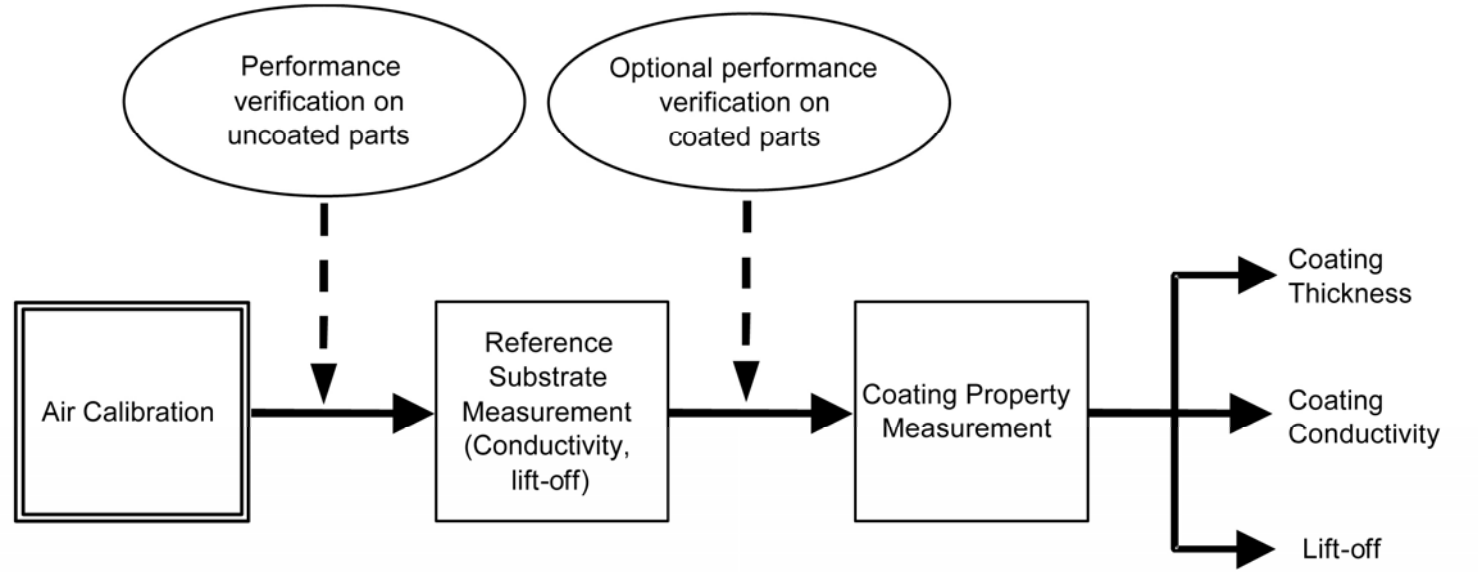
Single-channel
FS35 MWM sensor



Multiple channel
FA28 MWM-Array sensor



ASTM Standard – "Air Calibration"



Designation: E 2338 – 04

Standard Practice for Characterization of Coatings Using Conformable Eddy-Current Sensors without Coating Reference Standards[1]

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.

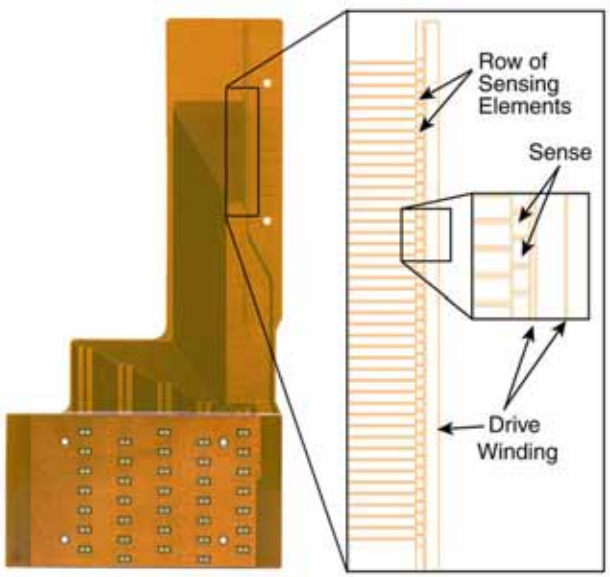
Air, Shunt Calibration (No Crack Standards)

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**

Sensor in "air"

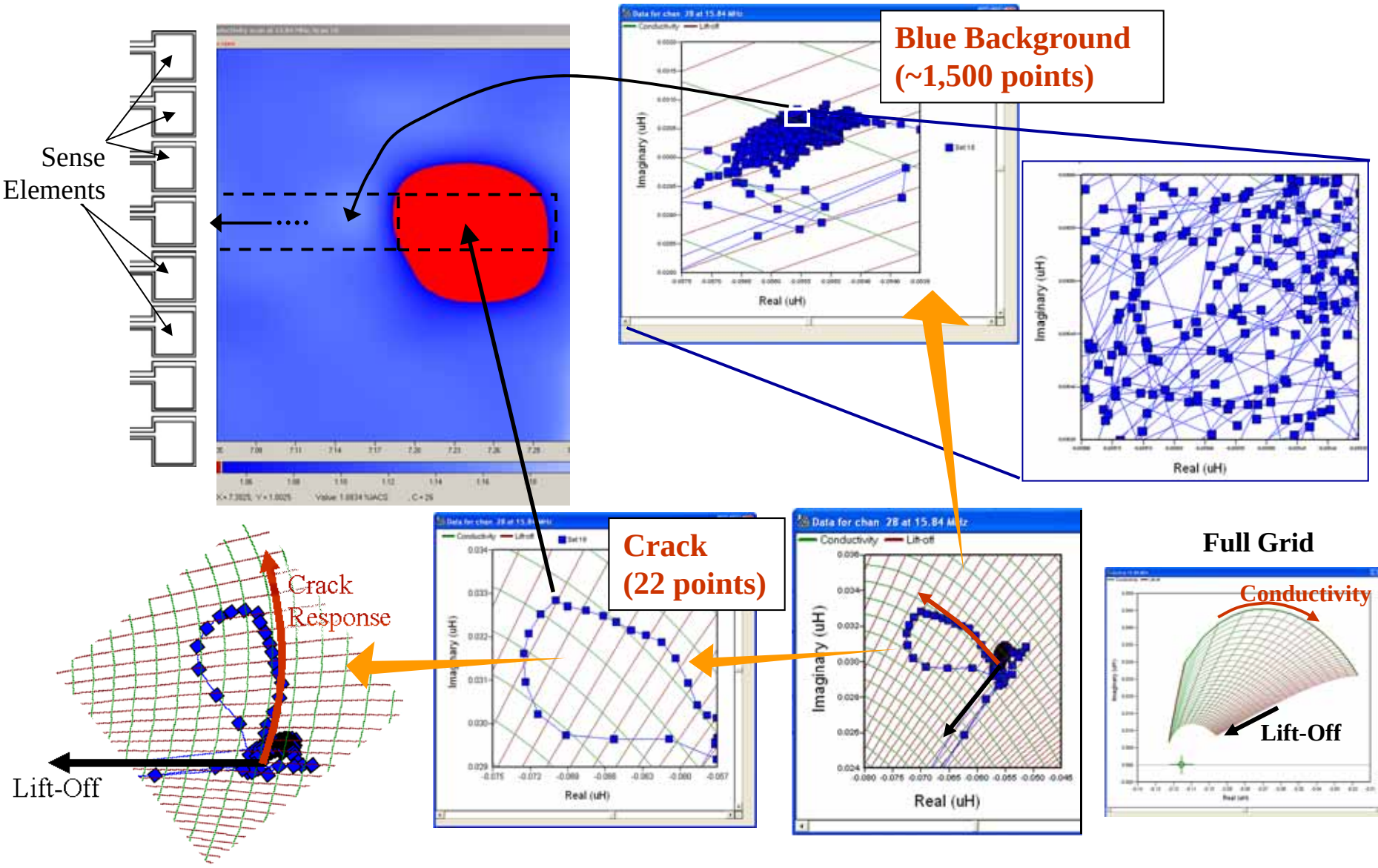
MWM-Array Sensor FA102



MWM-Array Replacement Cartridges

Shunt

Rapid Data Processing with Grid Methods and "Air" Calibration



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- Case Study 4: Hydraulic Tubing Inspection
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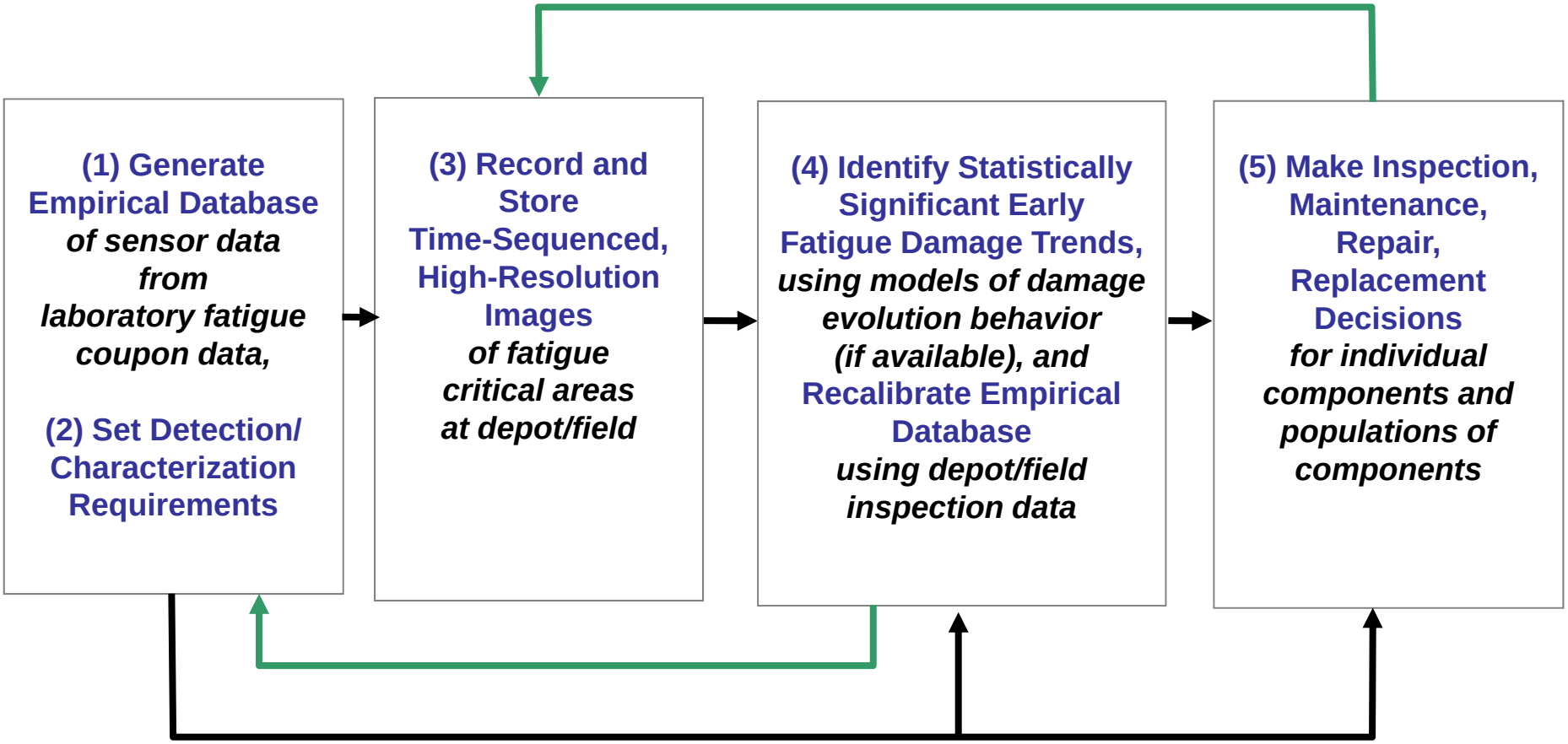
Proposed Adaptive Life Management Approach



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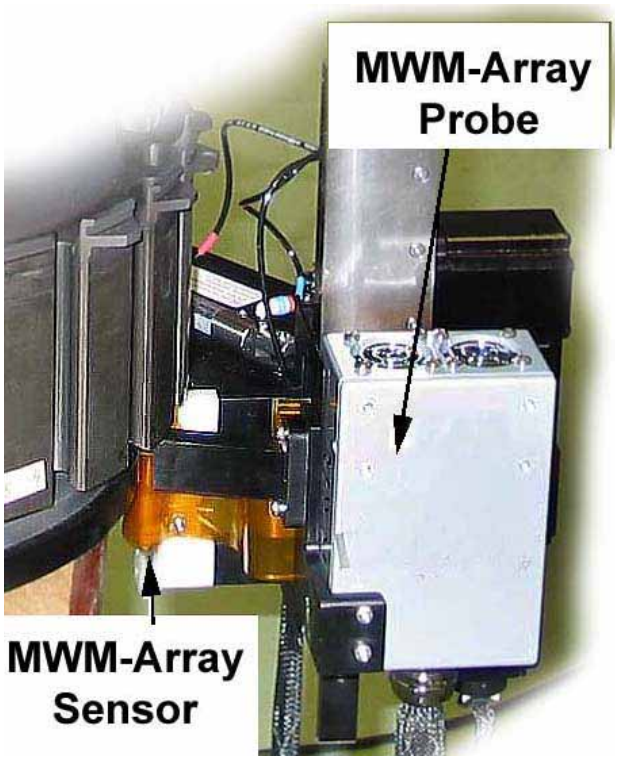
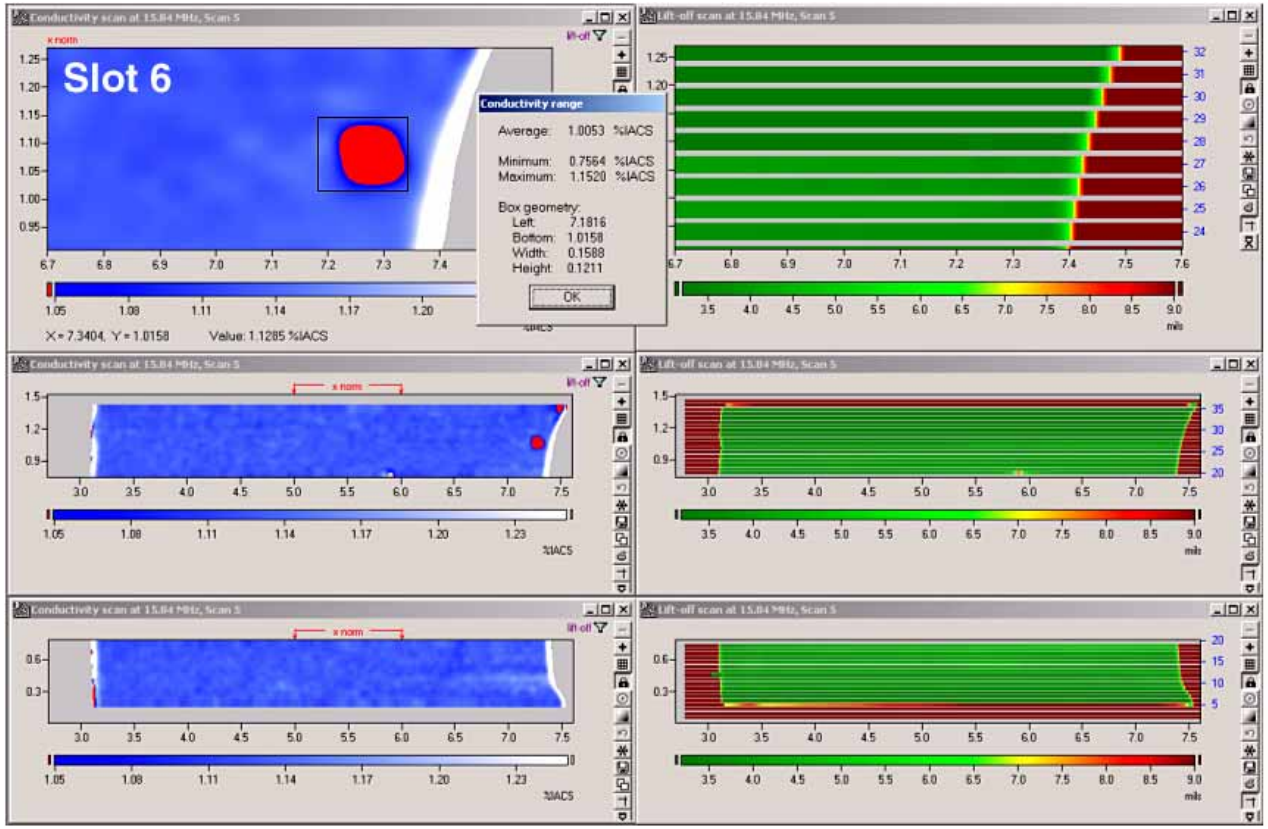
Automated Engine Disk Inspection System

Presented at ASNT Fall, Oct 2006

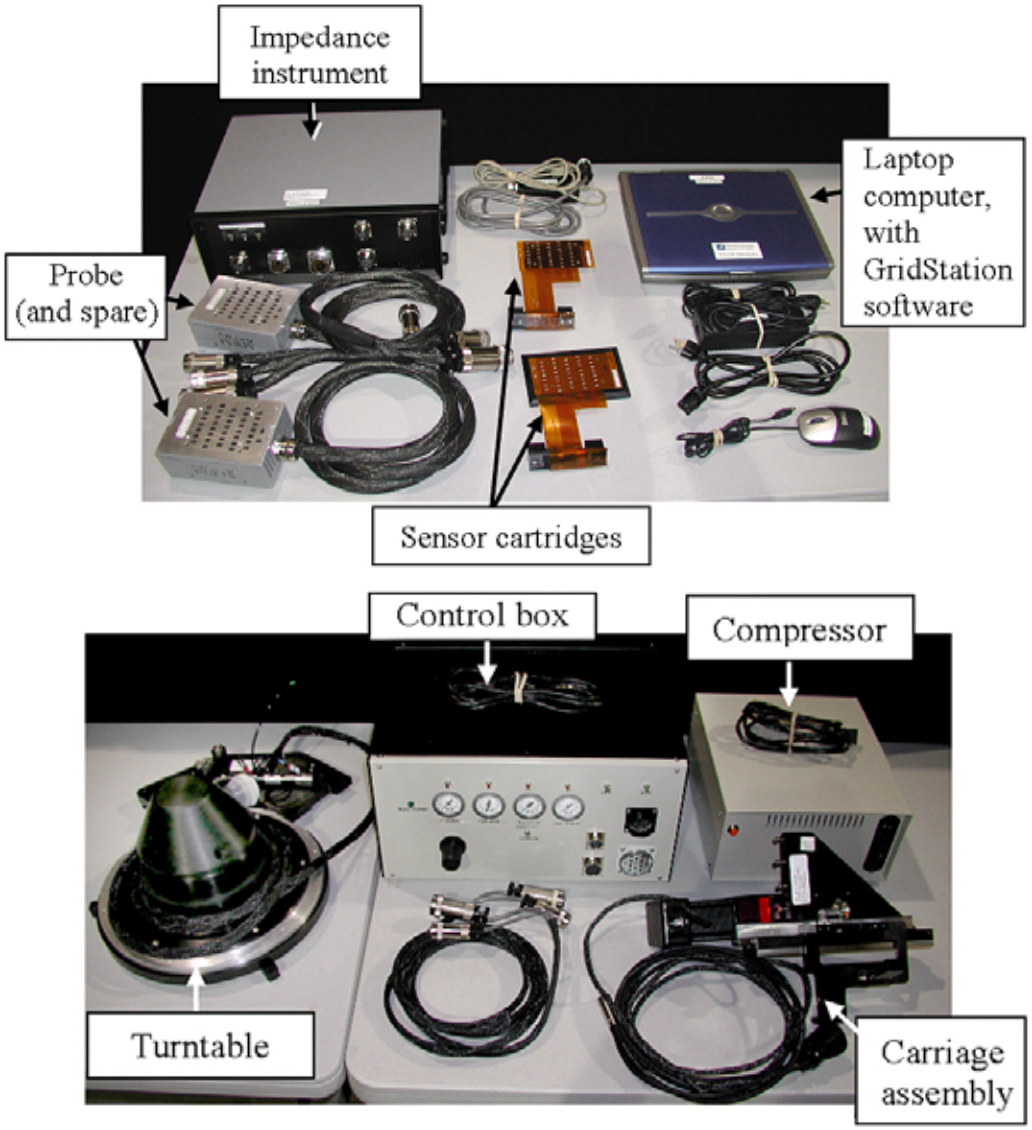
- In use at NAVAIR Depot since April 2005
- Nine disks with verified cracks detected, several of these large and small cracks not detected by conventional ET and LPT
- No false indications (over 3000 slots inspected), false indication rate <0.04

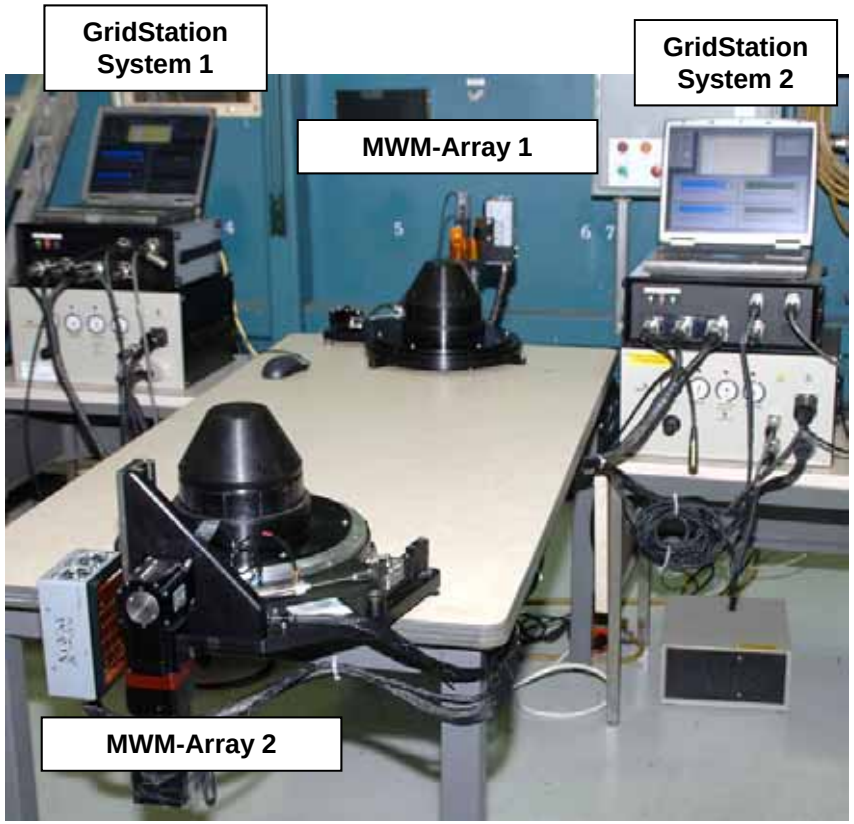


Conductivity **Lift-Off**



Production/Depot GridStation System





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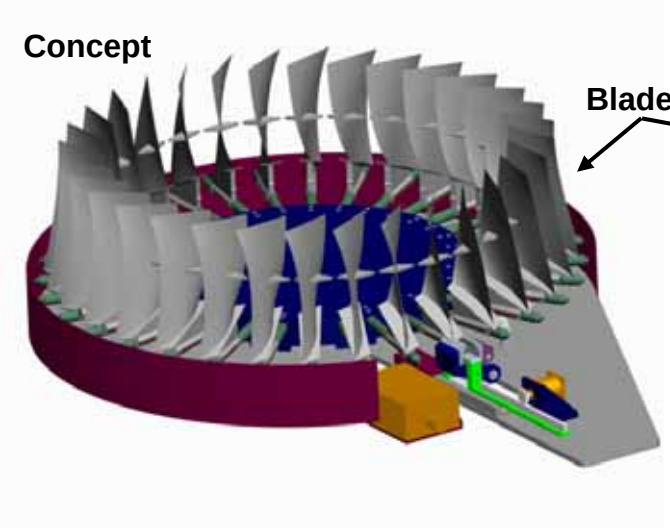
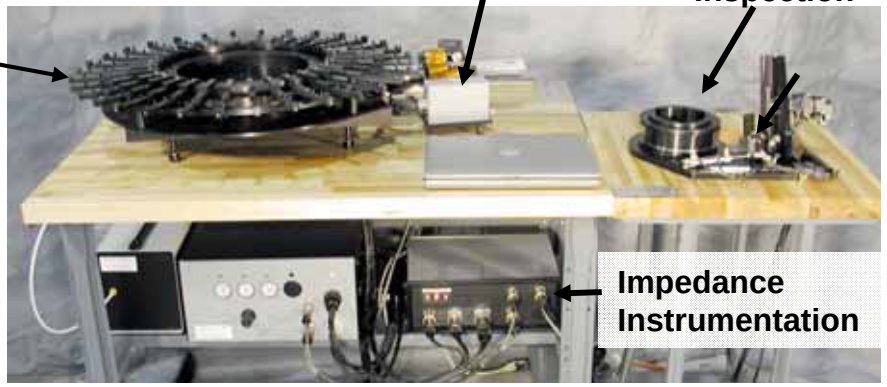
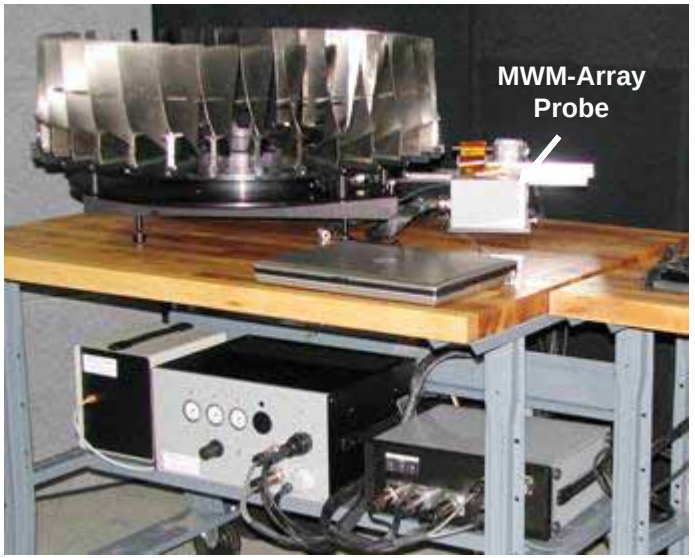
Automated Disk Slot & Blade Dovetail Inspection

At FRC-SE, Jacksonville (delivered in October 2006)





Photos of Delivered System



Filtered MWM-Array Results

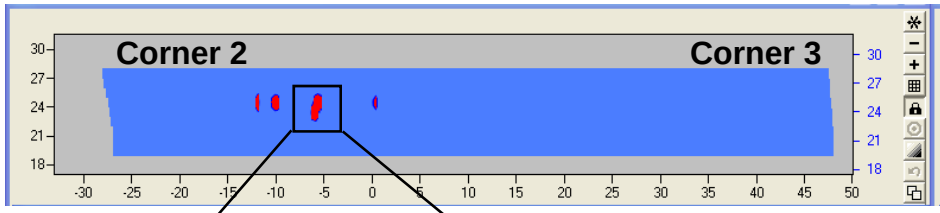
Also Presented at ASNT Fall, Oct 2006

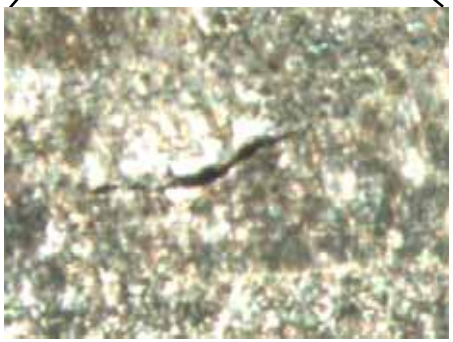
Note:

Training Set Blade “with Known Cracks”

Results with Lower Threshold*

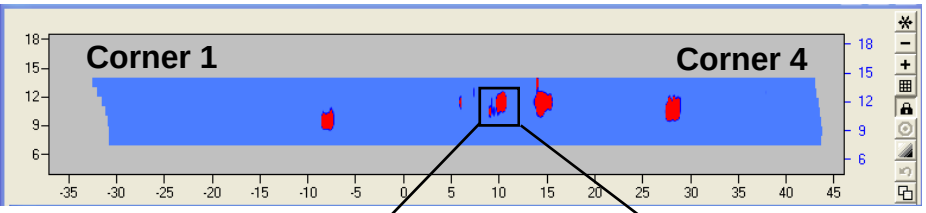
Convex Side

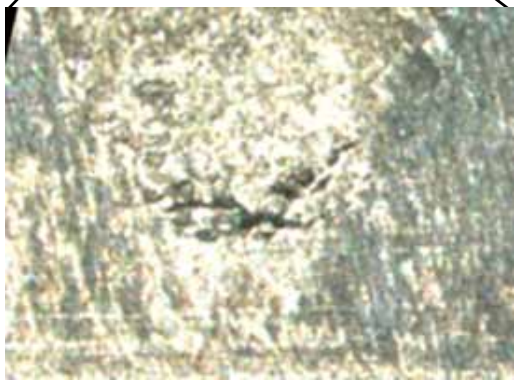




42-mil Crack

Concave Side





75-mil Crack Cluster
(Maximum Crack Length 50 mils)

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

Filtered MWM-Array Results

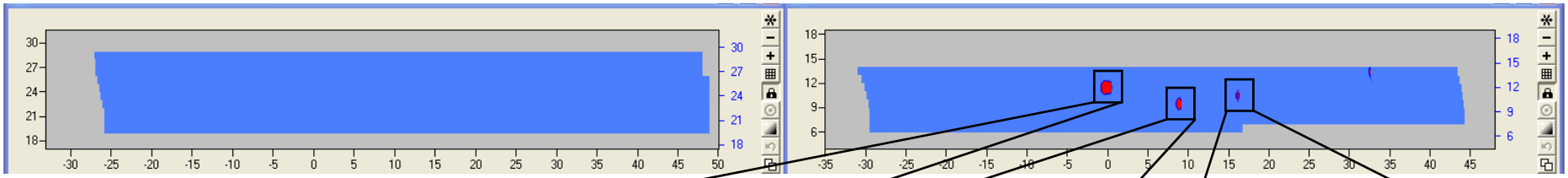
Also Presented at ASNT Fall, Oct 2006

Note:

Training Set Blade Identified as Having “No Cracks”

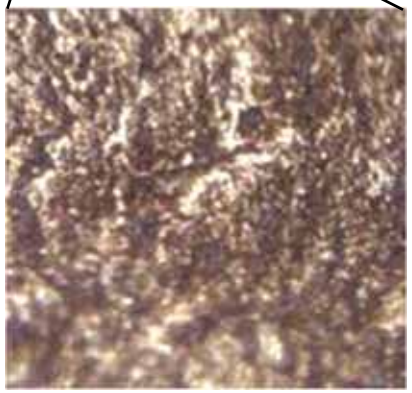
Convex Side

Concave Side



20-mil Crack

15-mil Crack



15-mil Crack

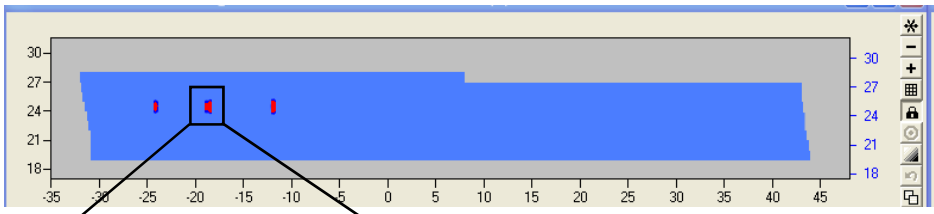
Filtered MWM-Array Results

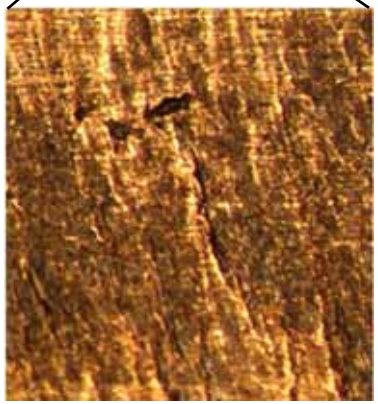
Also Presented at ASNT Fall, Oct 2006

Note:

Training Set Blade Identified as Having “No Cracks”

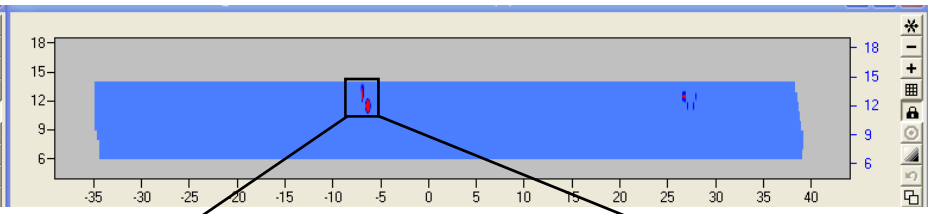
Convex Side





Crack Cluster

Concave Side



25-mil Crack

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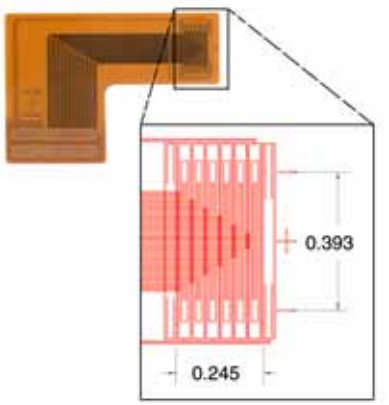
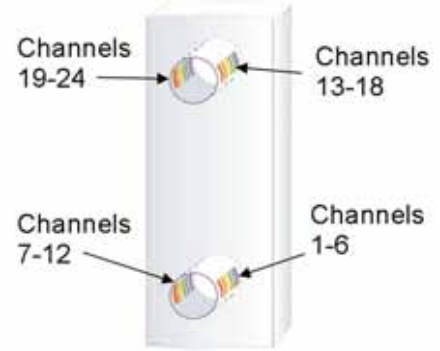
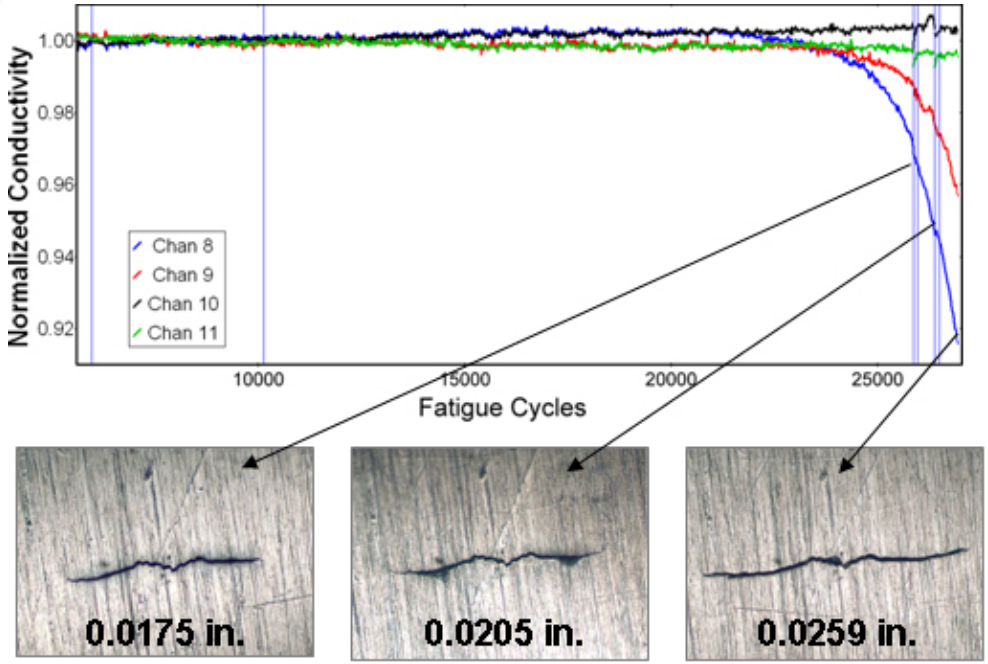
Generation of “Real Crack” Specimens

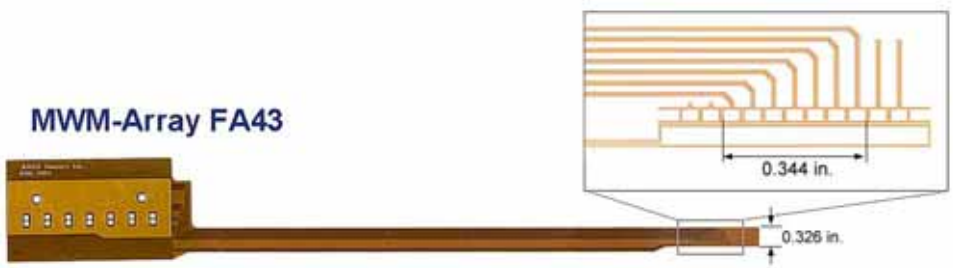
MWM-Array FA75

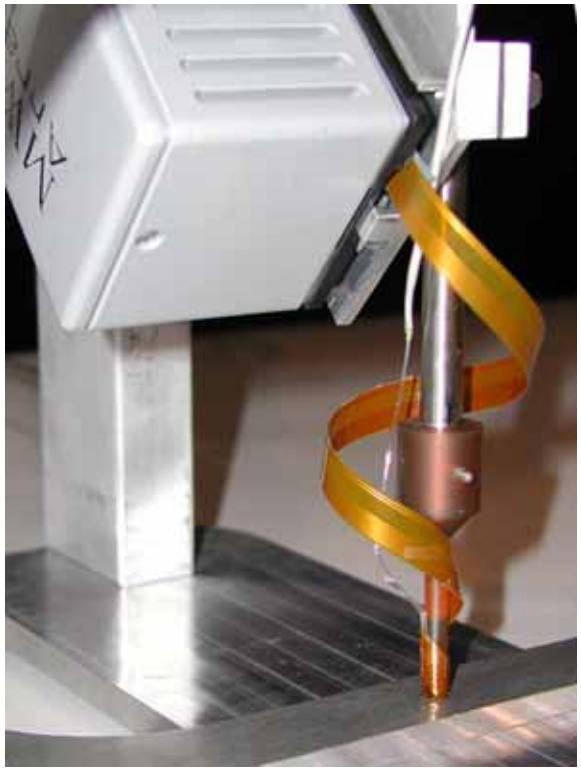


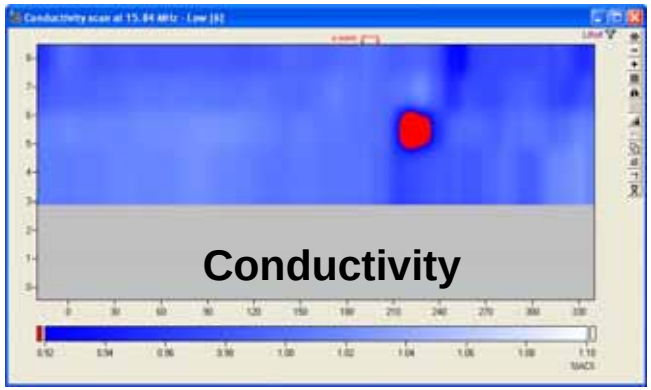


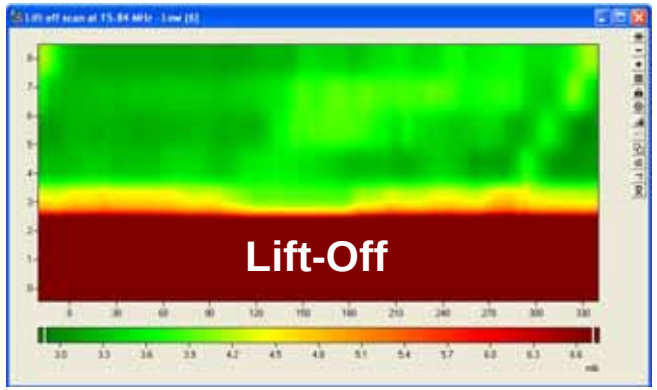


MWM-Array Scans for Bolt Hole Inspection



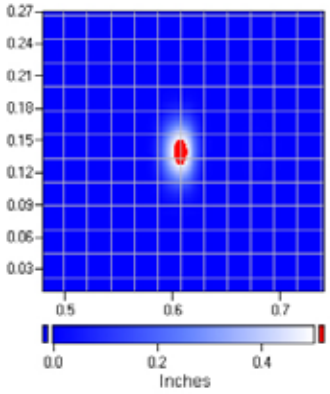


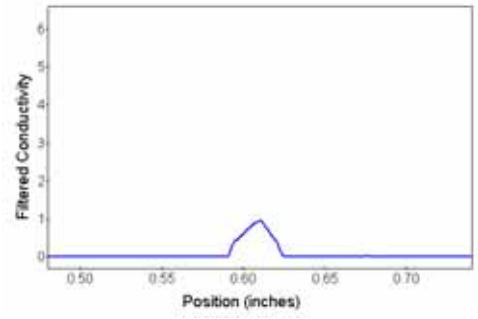




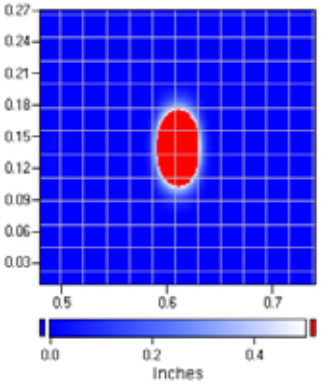
Time Sequenced Images of Crack Growth

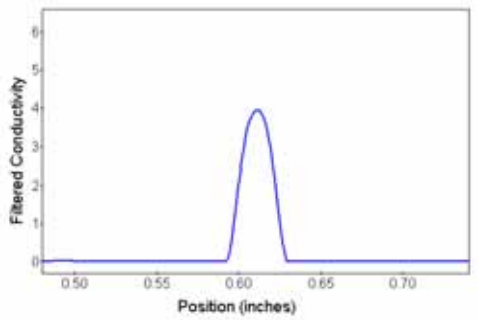
24,840 cycles
0.017 in.



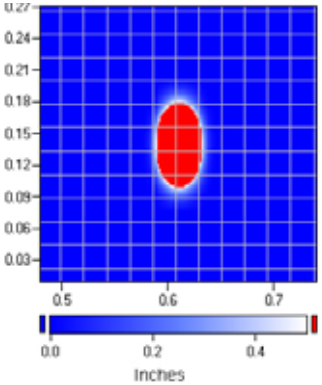


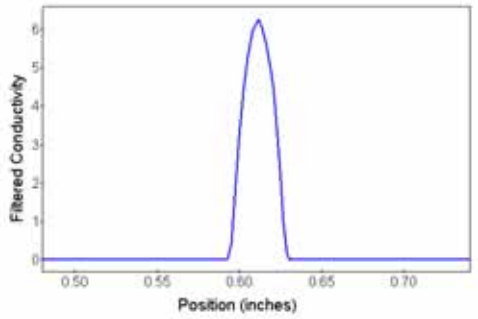
25,348 cycles
0.0205 in.





25,907 cycles
0.0259 in.





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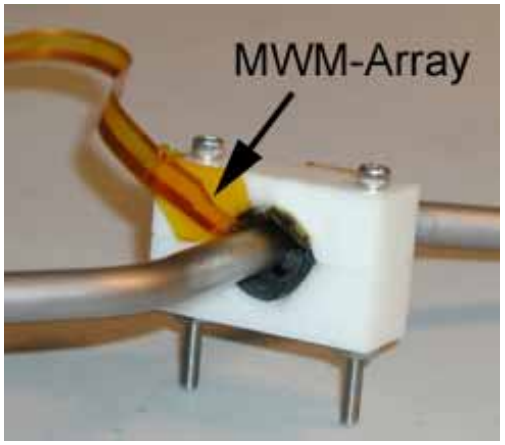
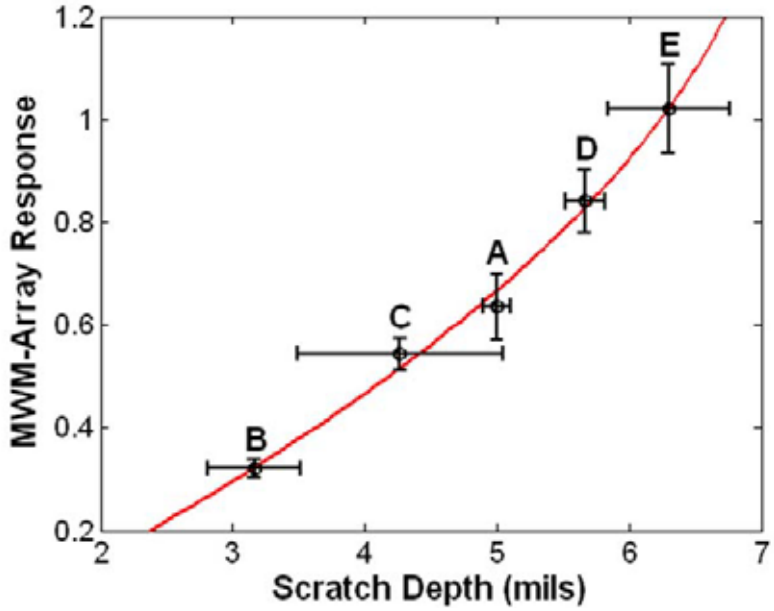
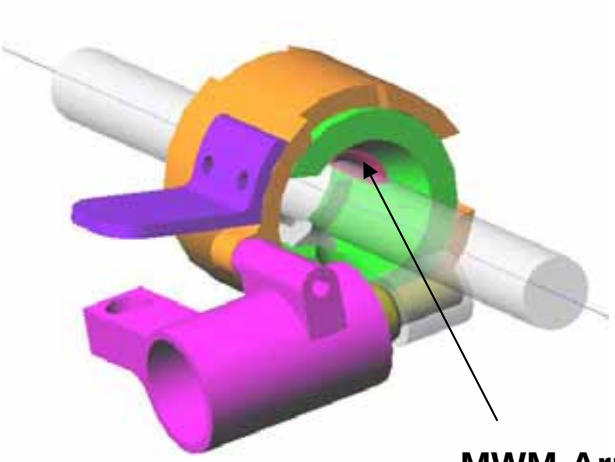
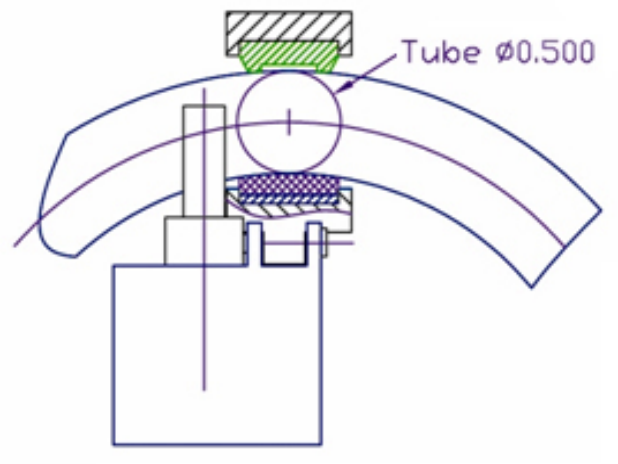
Tubing Inspection for Mechanical Damage





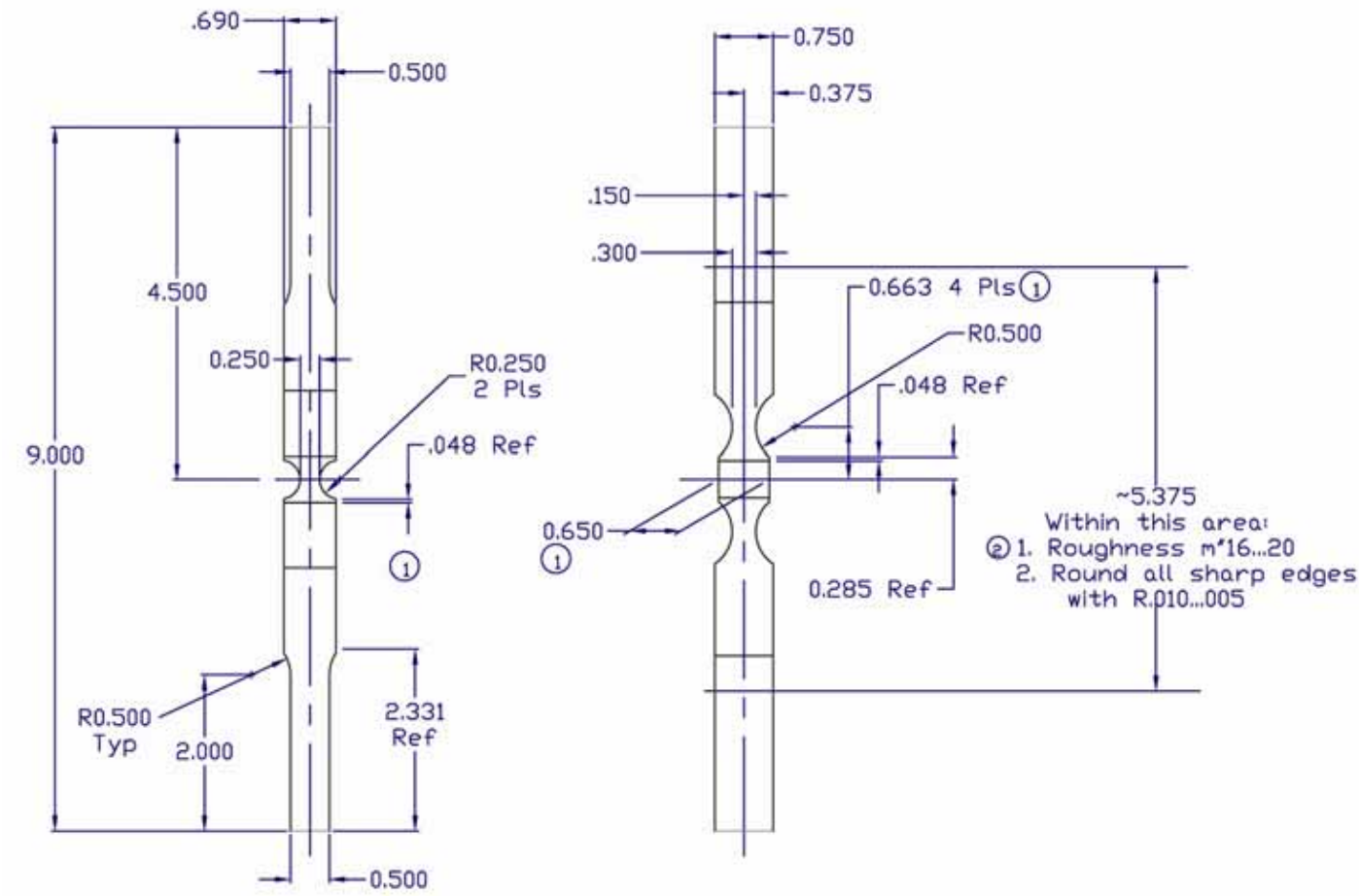


MWM-Array Sensor

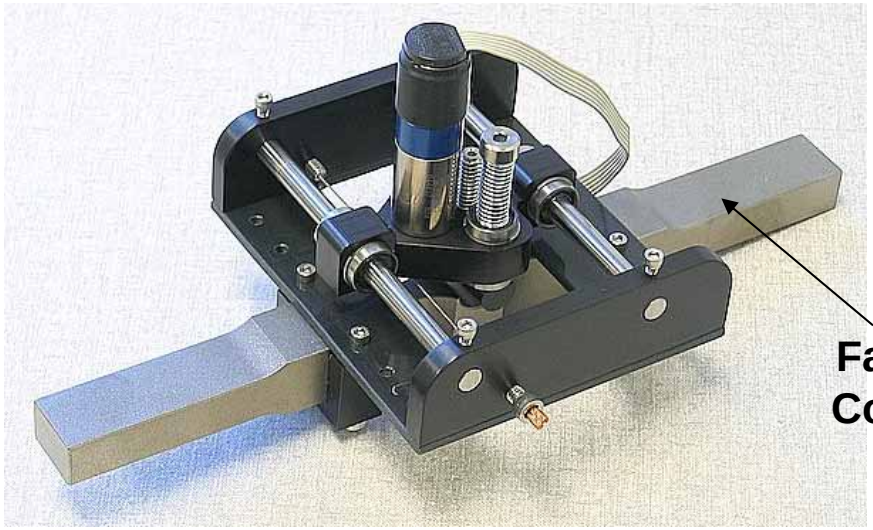


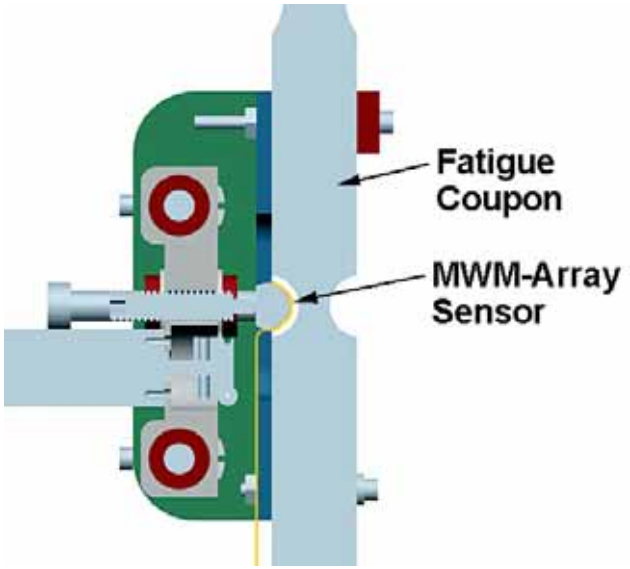
Ti-6Al-4V Fatigue Coupon Tests

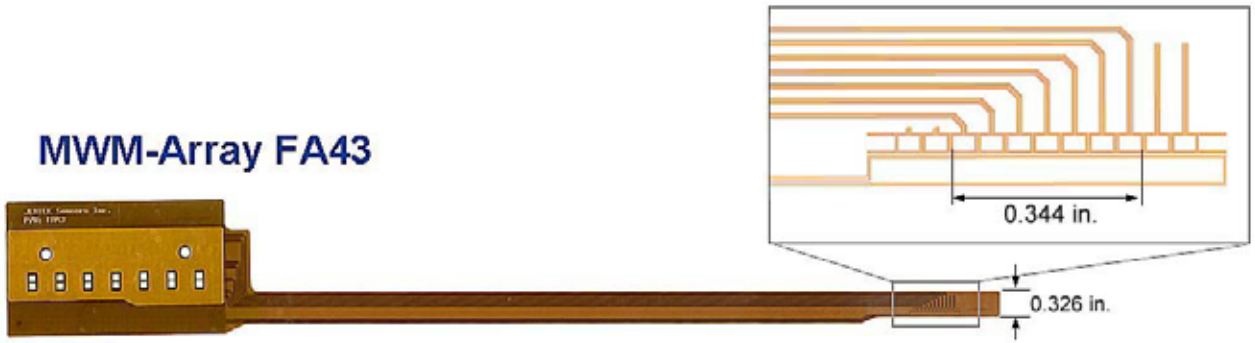
for Permanently Mounted & Scanning MWM-Arrays



MWM-Array Scanner for Fatigue Tests

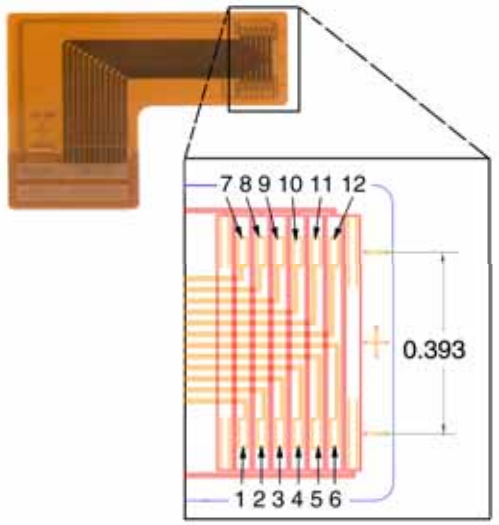


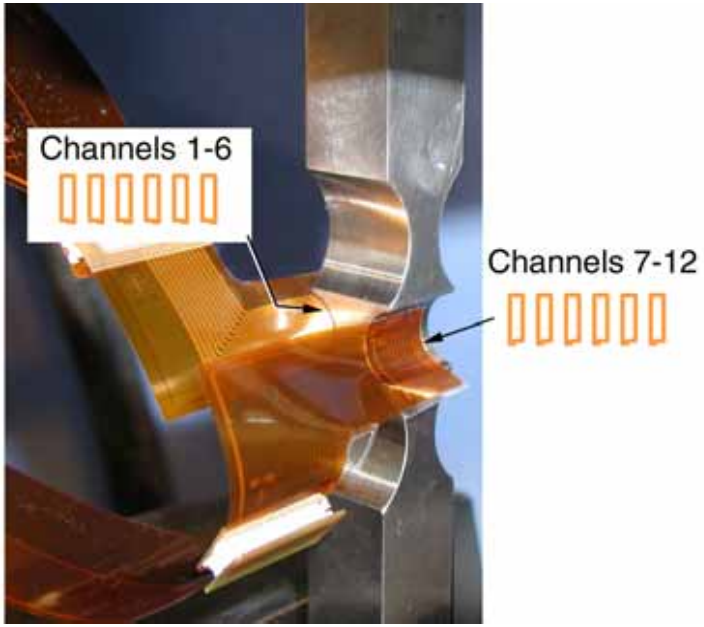


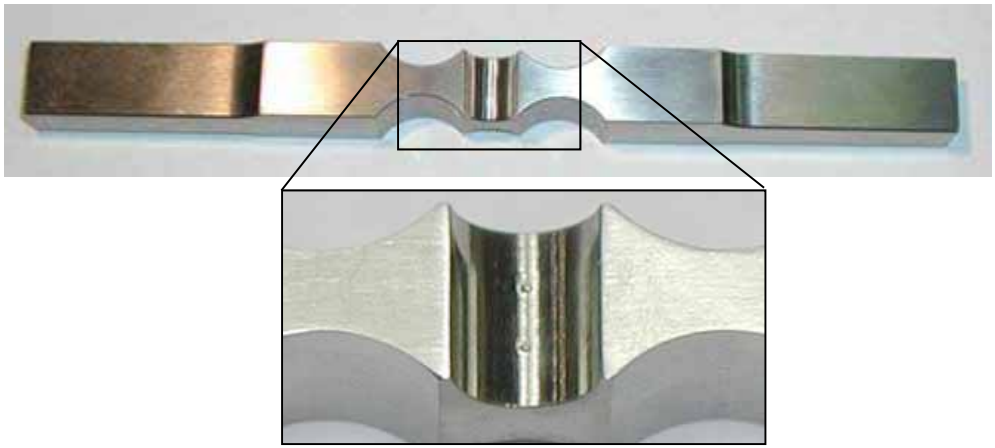


Surface Mounted MWM-Array Sensors

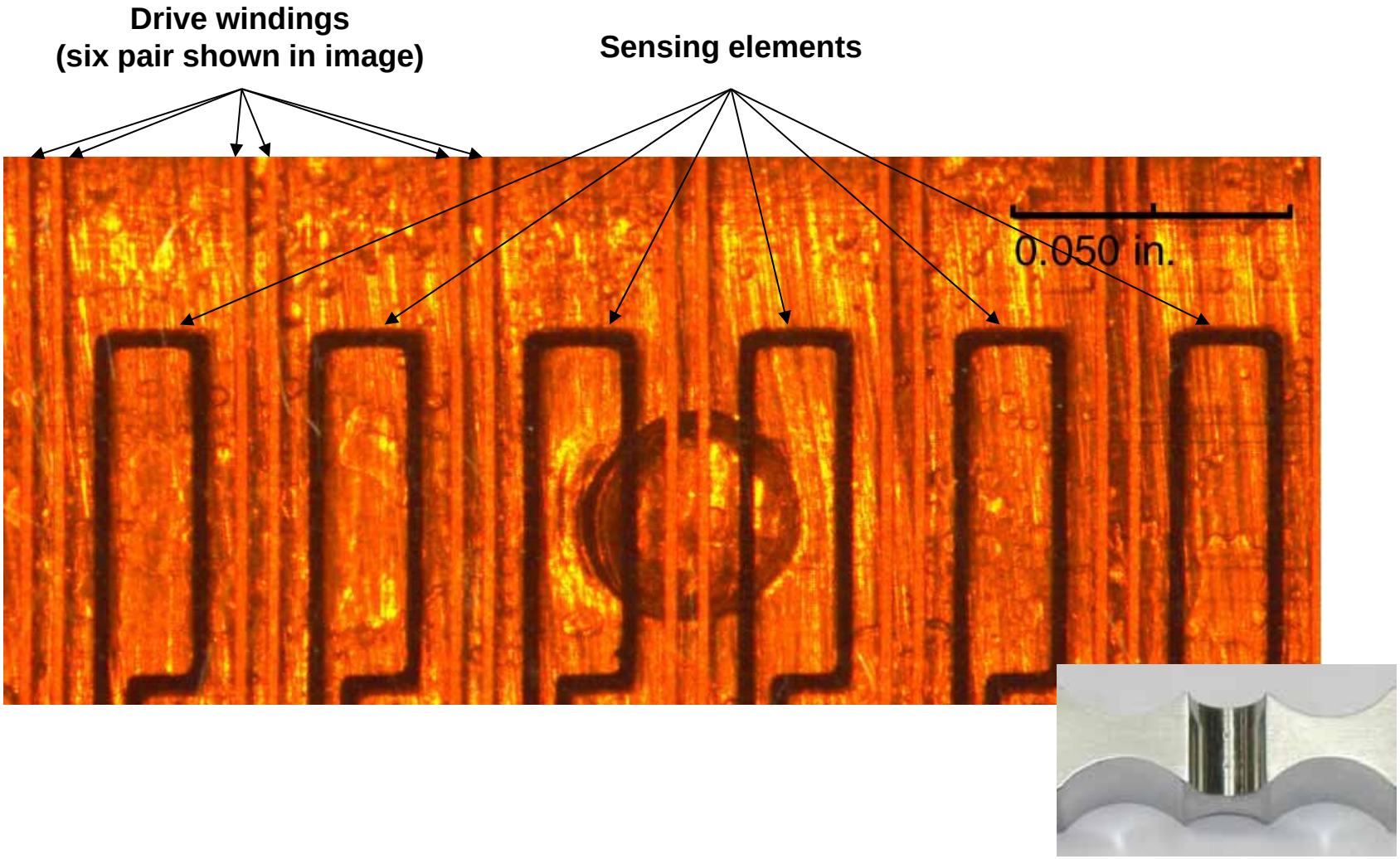
MWM-Array FA75





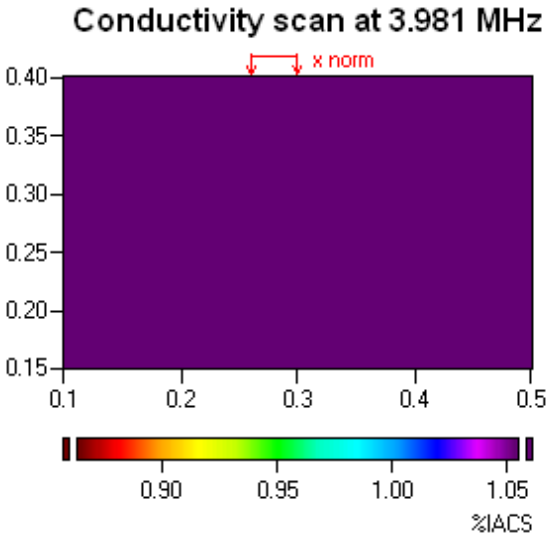


Photograph Showing MWM-Array Placement on Mechanical Damage (Ding) Specimen

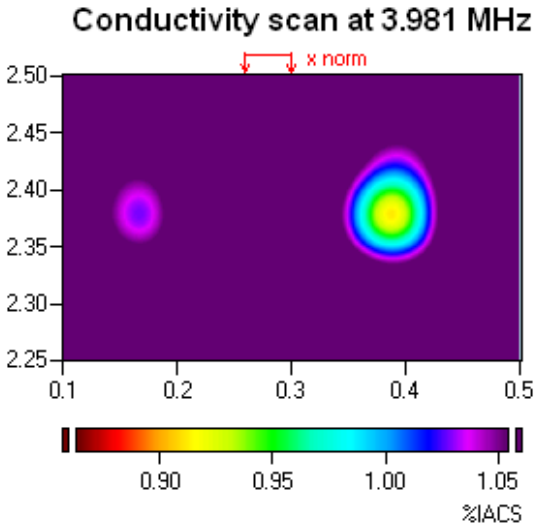


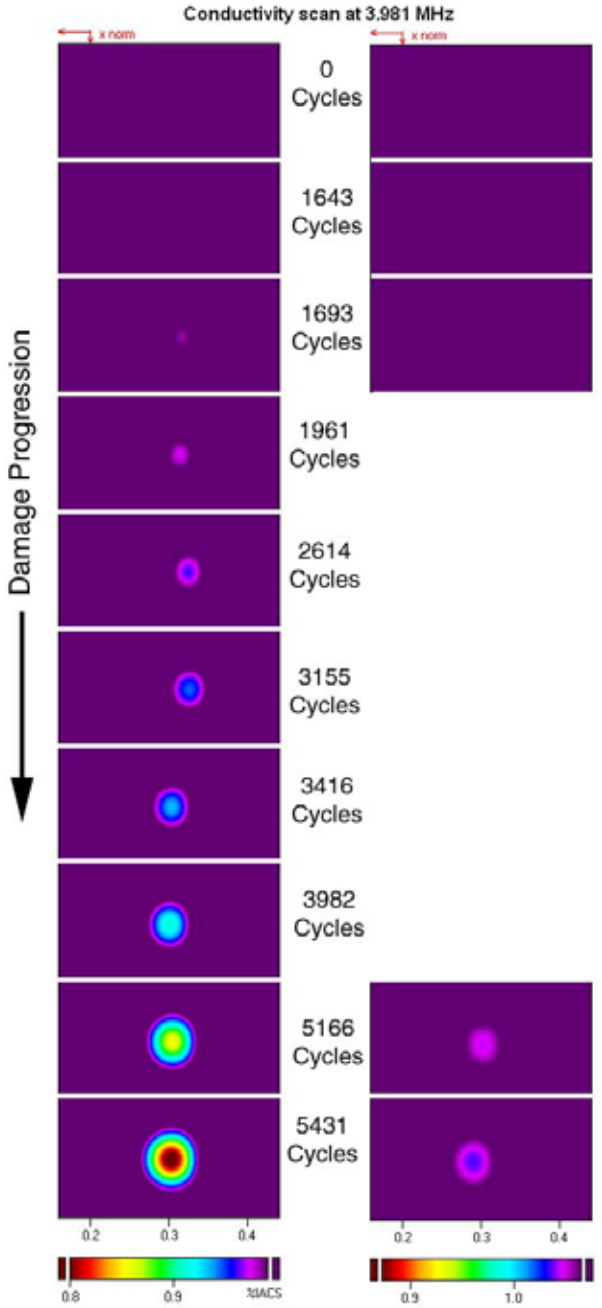
Scanning MWM-Array Results

Before Fatigue Cycling



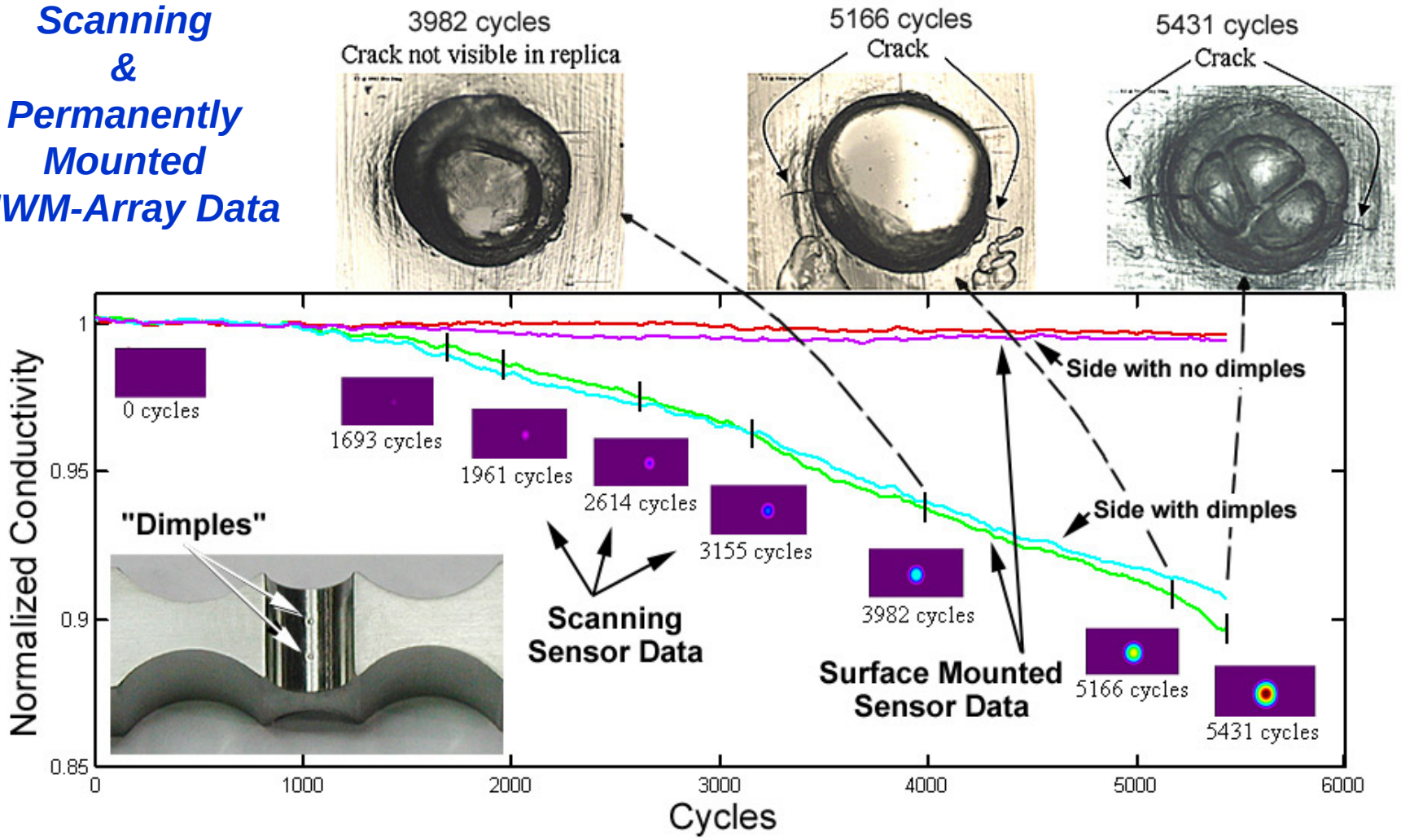
After Fatigue Cycling





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