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Monitoring Diffusion Coating Aging with Multi-Frequency Eddy Current MWM Sensors

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Diffusion Coatings

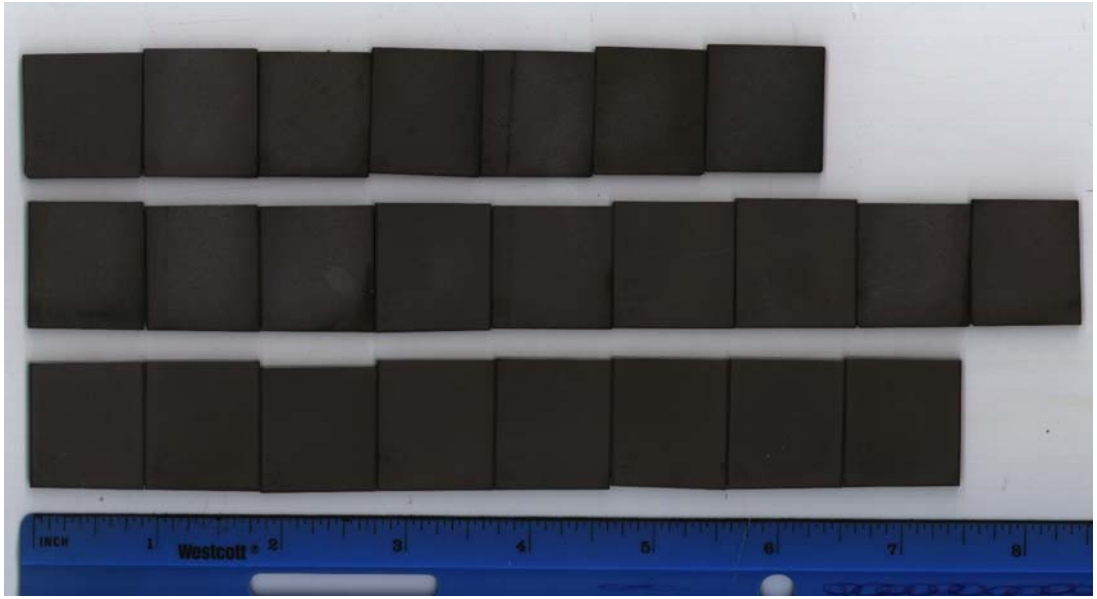
- Widely used to protect hot gas path components in land-based gas turbines and jet engines
- Aging affects protective properties of nickel aluminide and platinum aluminide coatings
- Effective nondestructive evaluation of the aged coatings is critical for refurbish/replace/run decisions

Objective

- Investigate the capability of model-based eddy current sensors to monitor aging of nickel aluminide and platinum aluminide coatings

Specimens

- 28 specimens with aluminide coating
- 28 specimens with platinum aluminide coating
- Each specimen: 25 mm x 25 mm squares



Thermal Exposure

- Four specimens in each group – baseline
- The other specimens exposed to 1-hr thermal cycles (T_{max} = 2000°F)
- Number of thermal cycles: 20, 50, 100, 200, 300, 400
- Four replicates exposed to the same number of thermal cycles

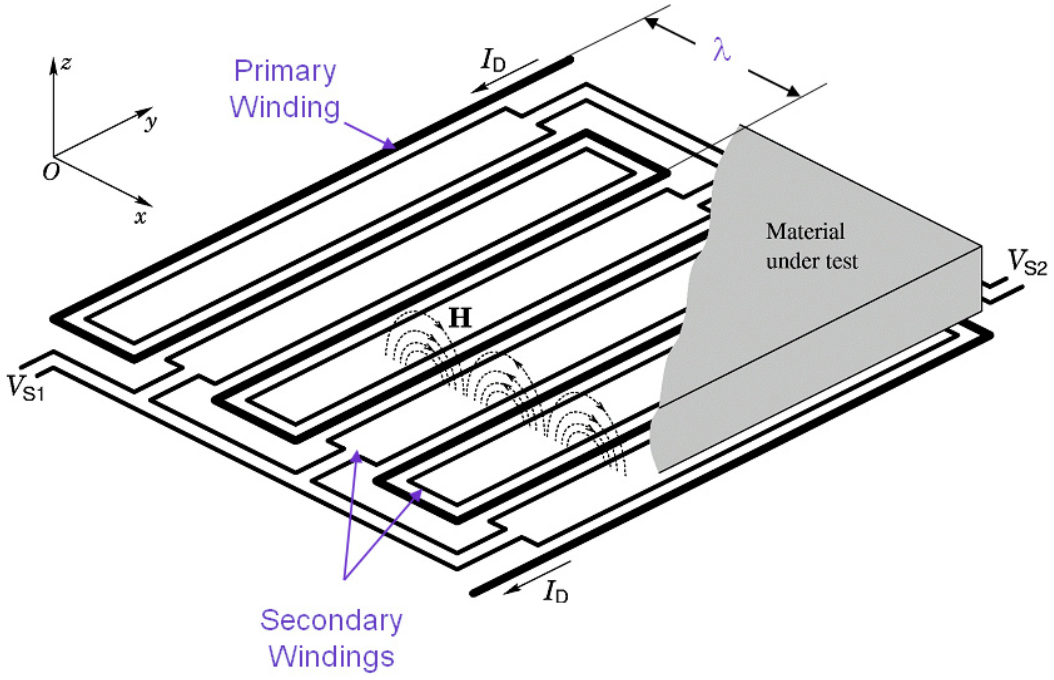
Measurement Method

- Multifrequency electrical conductivity measurements (2-16 MHz)
- Eddy current Meandering Winding Magnetometer
- Two-unknown model (conductivity and lift-off in an infinite half space material)

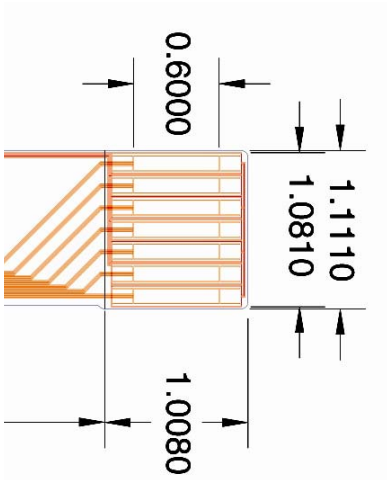
JENTEK GridStation Setup with 7-Channel Instrument and 7-Channel MWM-Array Probe

Single Channel MWM Probe with Interchangeable Tips

Meandering Winding Magnetometer (MWM®)

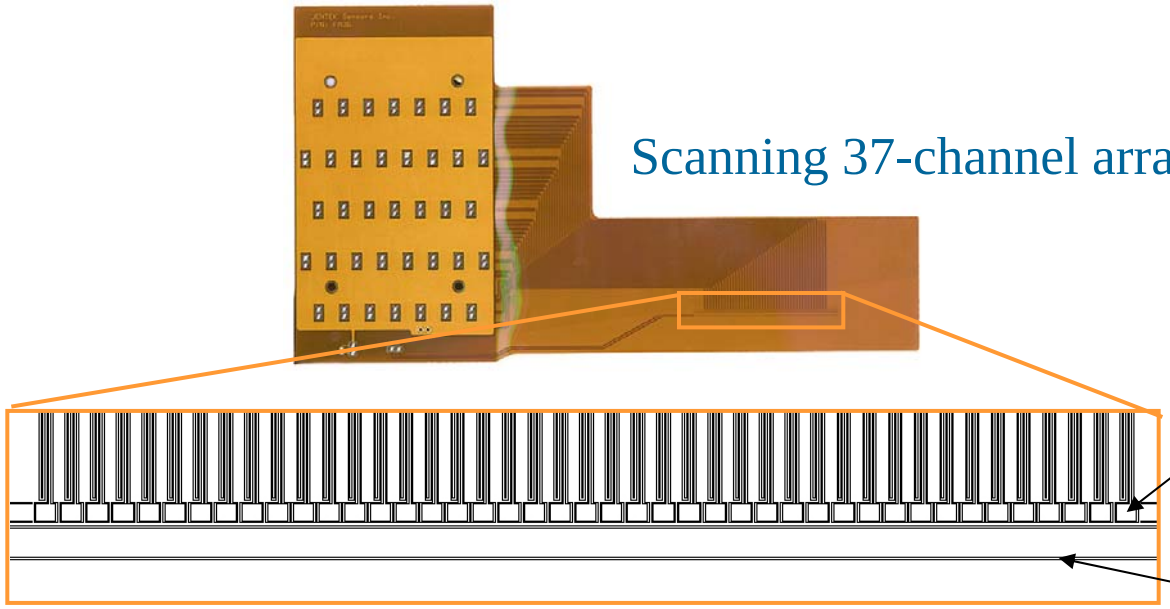


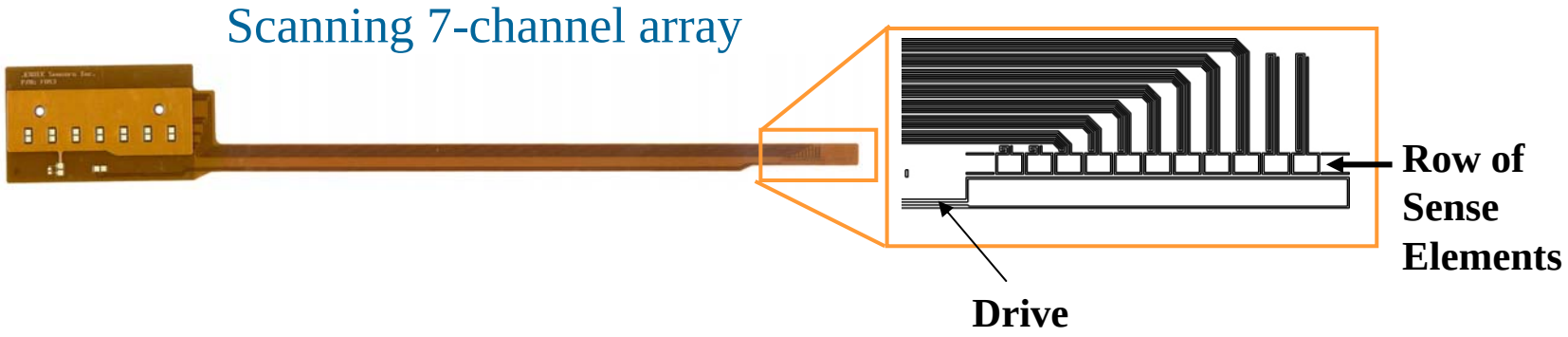
- Thin, flexible
- Conformable to complex geometries
- Surface mountable
- Configurable into arrays



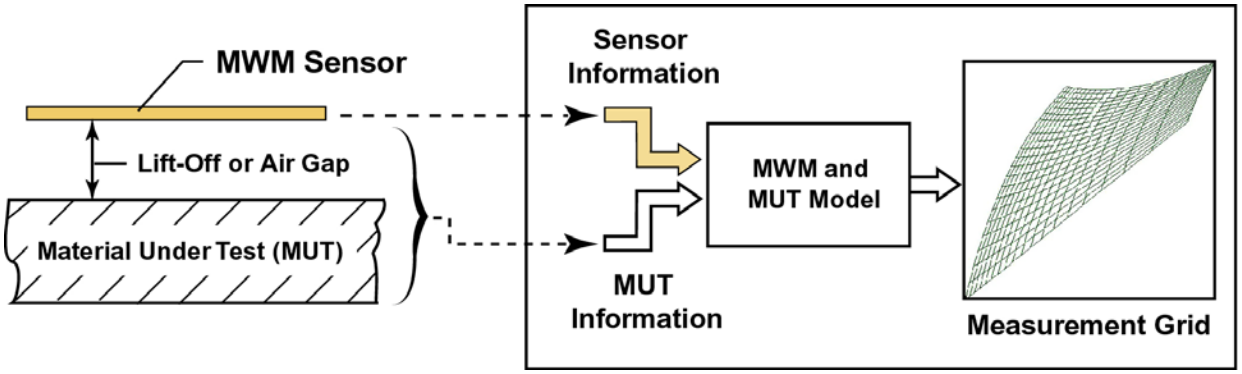
Transfer Impedance = Secondary Voltage / Primary (input) Current

Scanning Multichannel MWM-Arrays

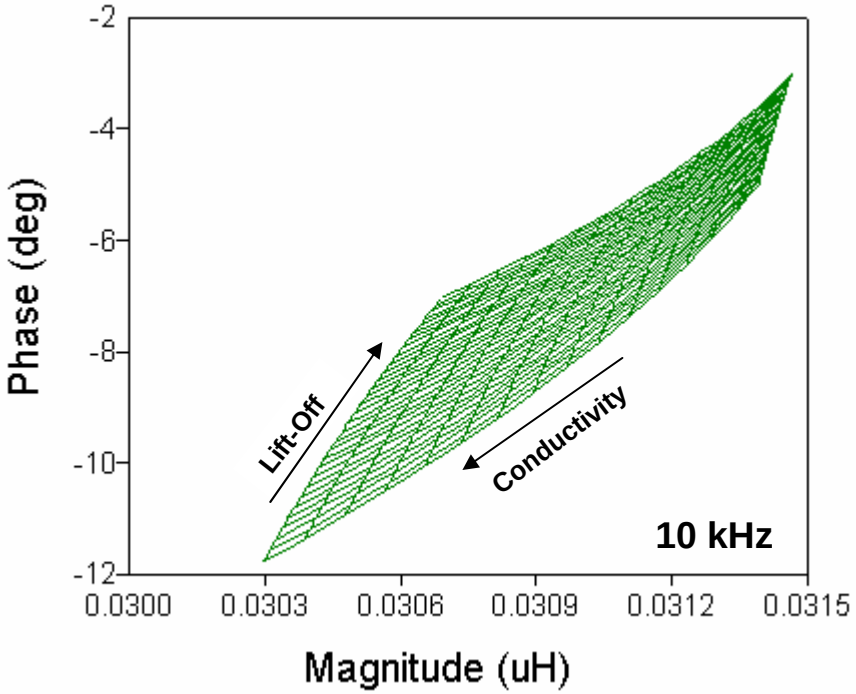


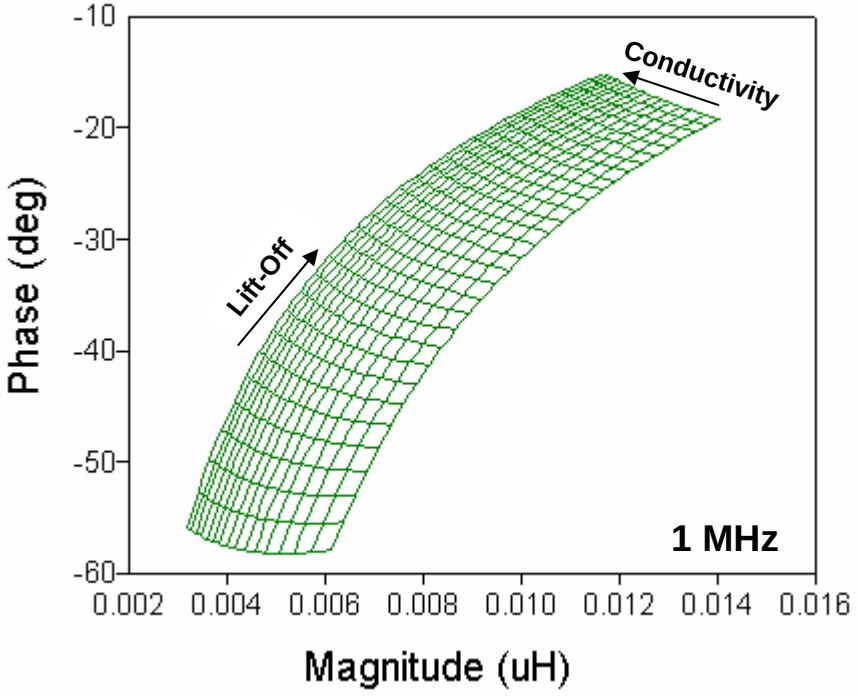


Conductivity / Lift-off Measurement Grids



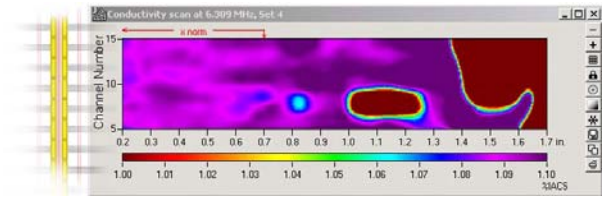
Example Grids for the MWM-FS35 Sensor and Aluminum



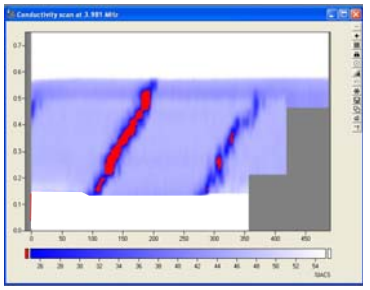


Example Applications

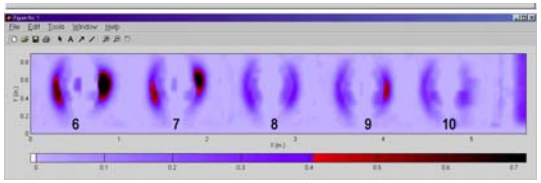
- Engines/Gas Turbines
  - –Crack Detection
- Coatings
  - –TBC, Bond Coat, & Substrate Characterization
- Alpha Case Detection
- Structures
  - –Crack Detection (Hole scans, etc)
  - –Stress and Fatigue Monitoring
  - –Residual Stress and Fatigue Damage Mapping
  - –Prognostics & Health Management
  - –Cold Work QA
- Corrosion Damage Mapping
- Weld Characterization



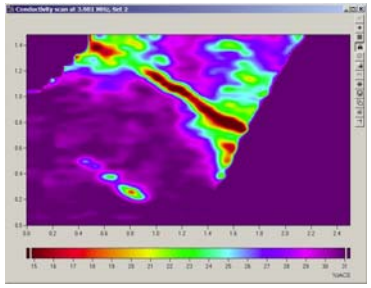
Engine Disk Slot Crack Detection



Bolt Hole Scans

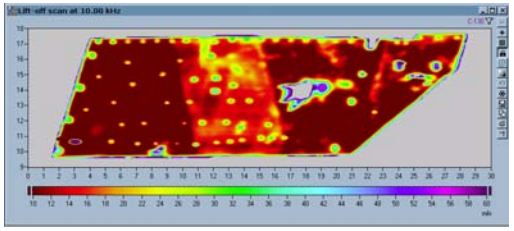


727 Third Layer Cracks

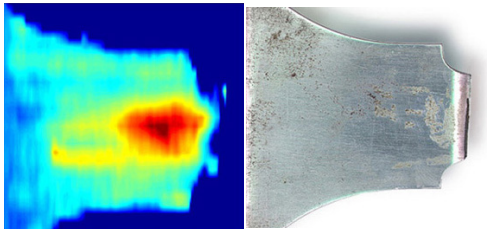


Aluminum Bending Fatigue Damage

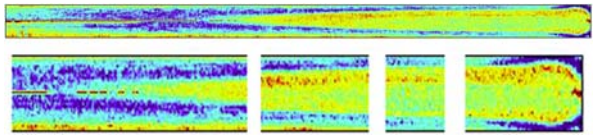
Cold Work QA



Corrosion - C-130 Flight Deck Chine Plate



Residual Stress Distribution in Steel (applicable to landing gear)

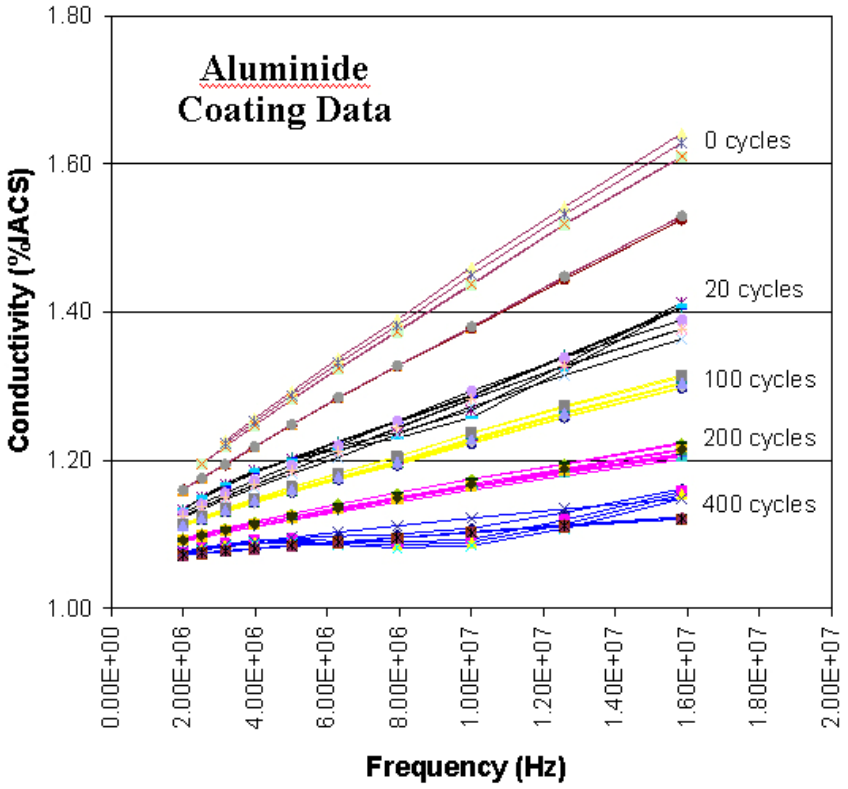


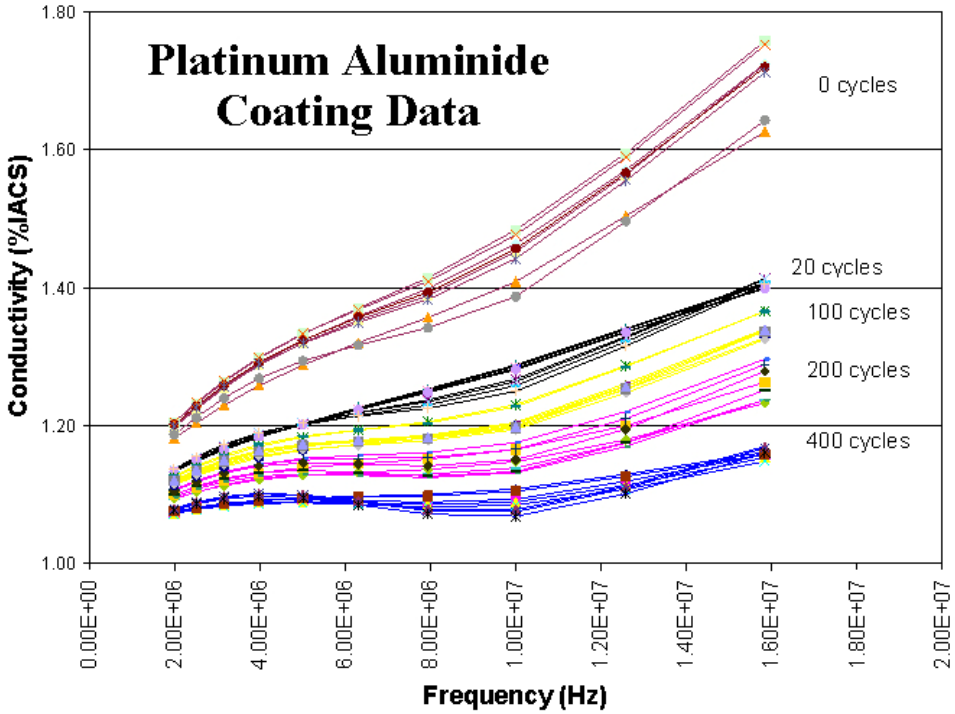
Friction Stir Welds

MWM and IDED Characterization of Hot-Gas Path Components

- Diffusion coatings
- MCrAlY coatings
- TBC
- Crack detection
- Hot corrosion

MWM Measured Conductivity vs. Frequency



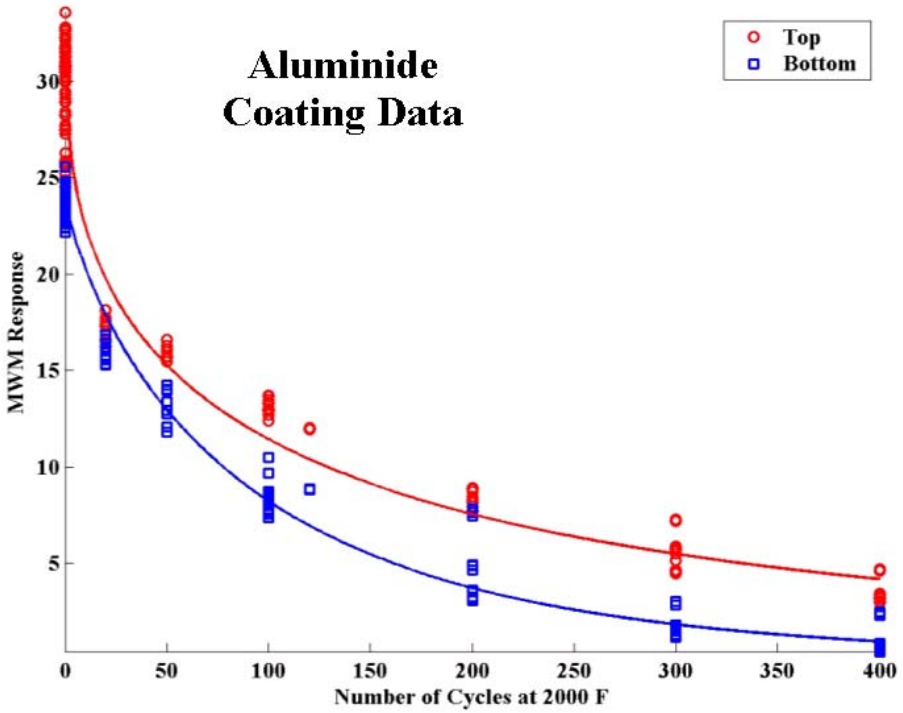


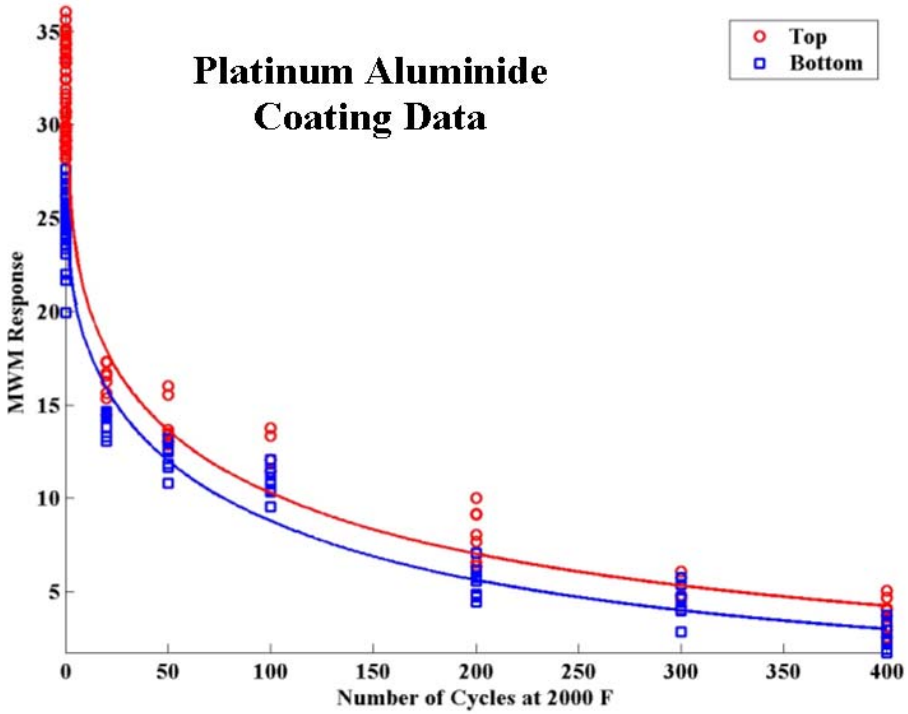
Two repeated MWM measurements on different days

MWM Frequency Response Parameter

- Multifrequency conductivity function that can capture near-surface material condition

MWM Response vs. Number of Thermal Cycles





"Top" and "bottom" refer to the coating on opposite sides of each specimen

Aluminum Reservoir

- Aluminum distribution from point-by-point EDS measurements
- Integrated available aluminum (IAA)
- IAA was determined from a summation of excess Al content at the various distances from the surface

Aluminum Reservoir

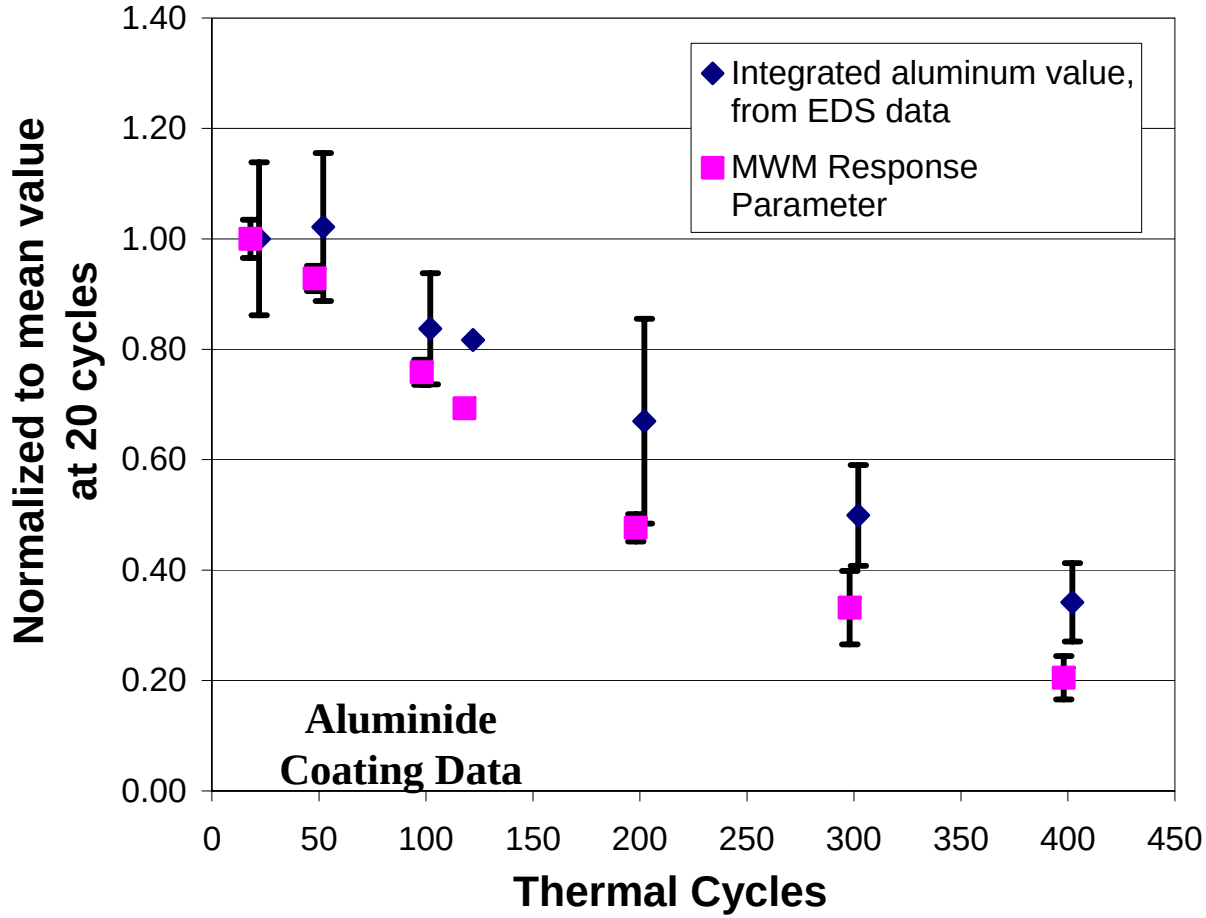
- IAA was calculated as

$$\Sigma \left(Al_{i,9+} - Al_{sub}\right)$$

Where $Al_{i,\,9+}$ is the local aluminum content (from EDS) exceeding 9 percent

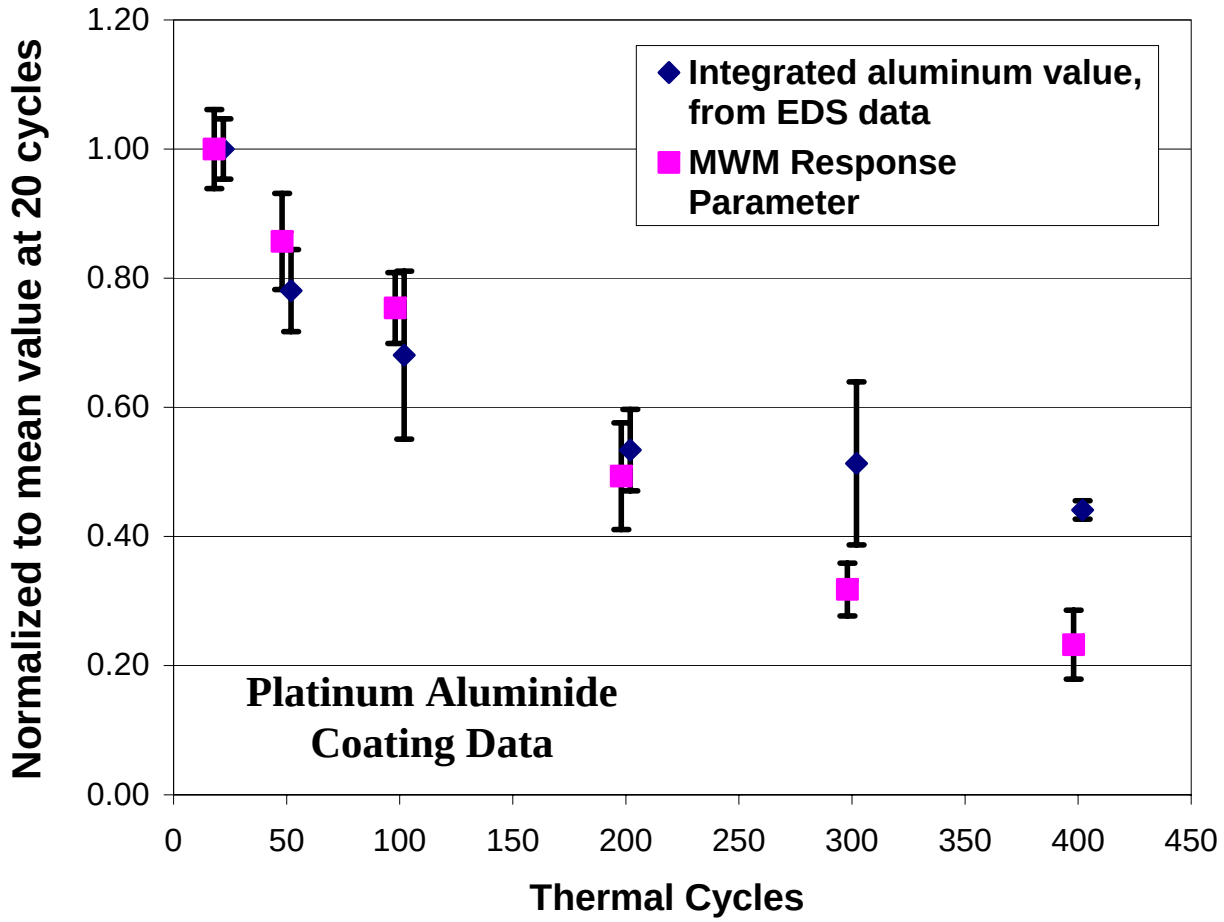
Al_{sub} is the aluminum content in the substrate

Normalized MWM Frequency Response and EDS-Based IAA vs. Thermal Cycles



The error bars correspond to ± one standard deviation of the values for each exposure

Normalized MWM Frequency Response and EDS-Based IAA vs. Thermal Cycles



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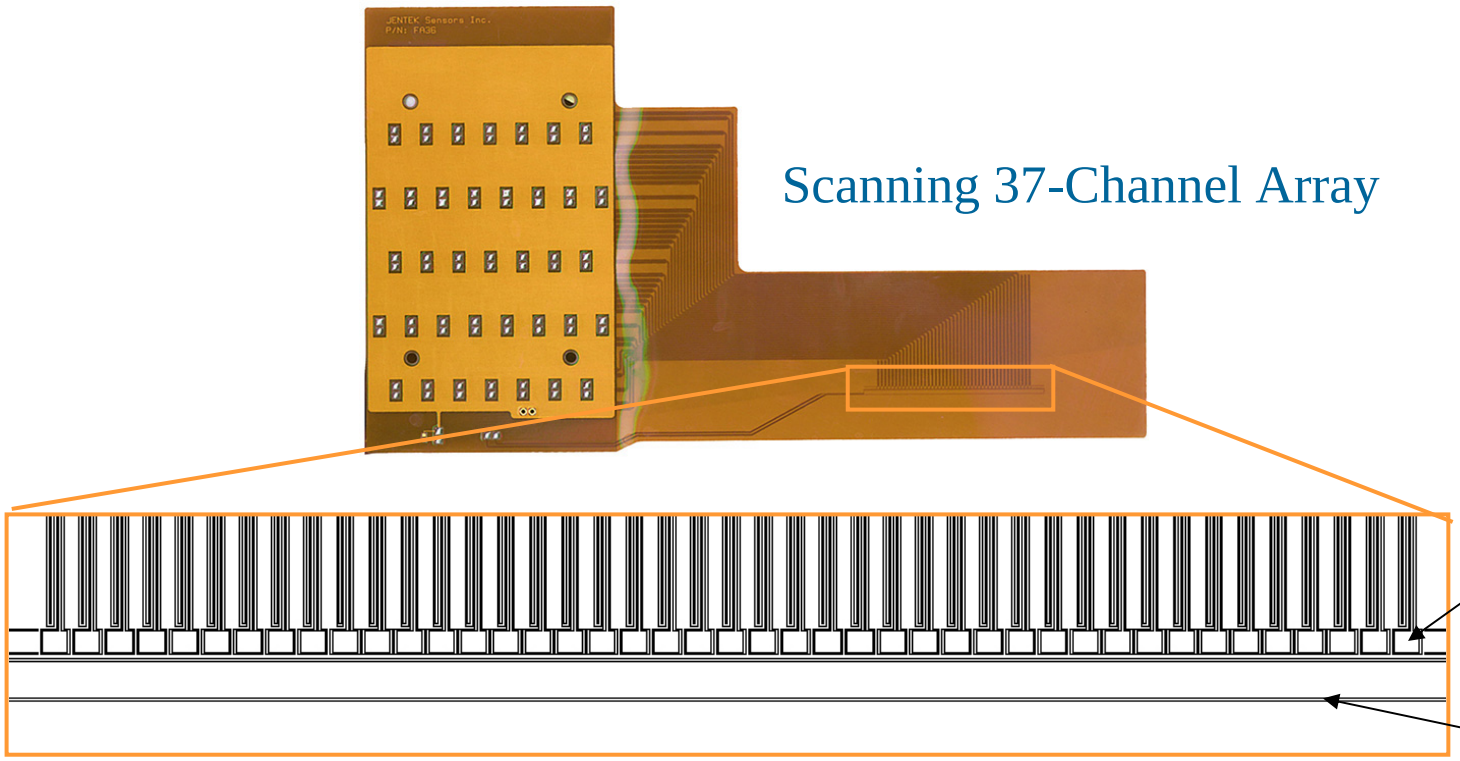
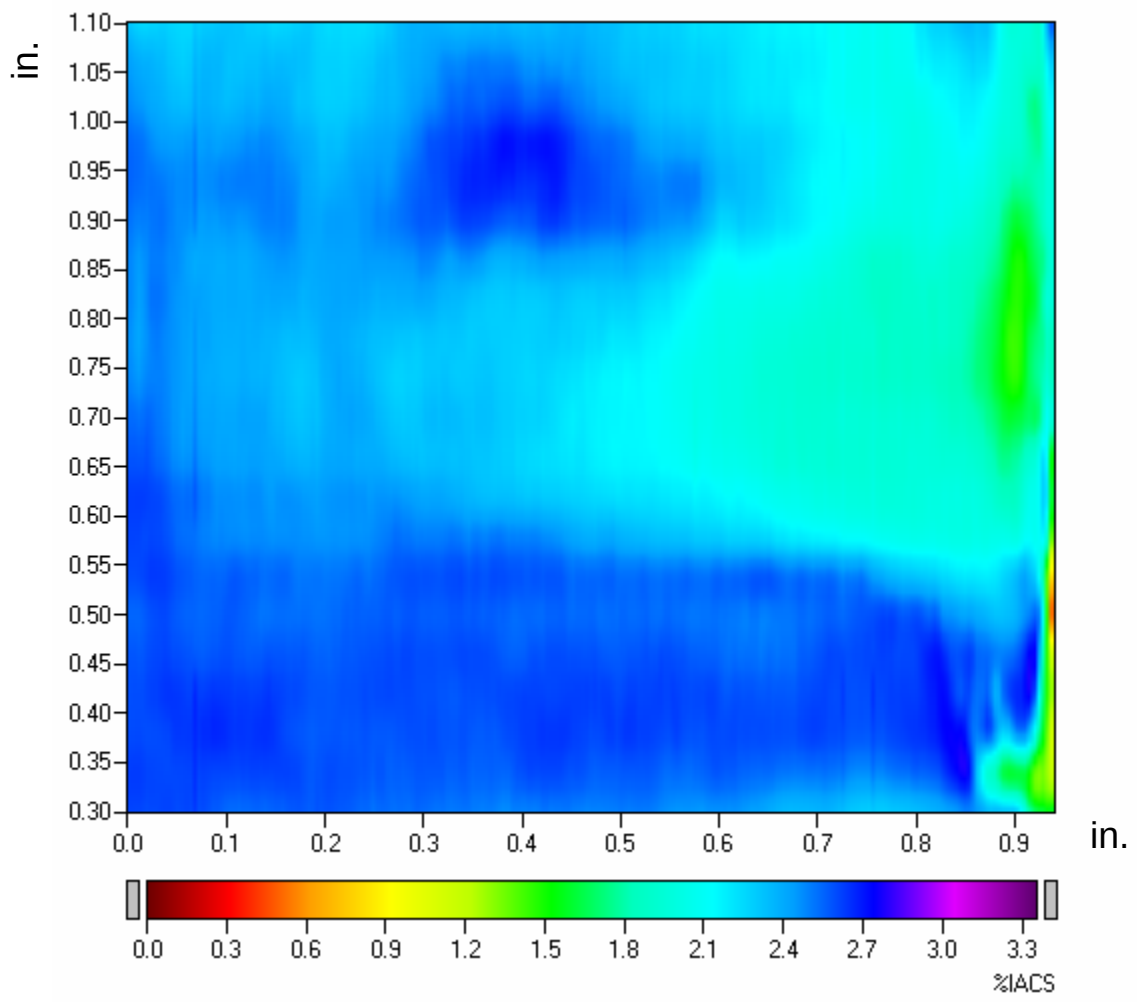
Scanning Multichannel MWM-Array



MWM-Array Conductivity Image of an Aged Turbine Component



ASTM Standard

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.

1. Scope

1.1 This practice covers the use of conformable eddy-current sensors for nondestructive characterization of coatings without standardization on coated reference parts. It includes the following: *(1)* thickness measurement of a conductive coating on a conductive substrate, *(2)* detection and characterization of local regions of increased porosity of a conductive coating, and *(3)* measurement of thickness for nonconductive coatings on a conductive substrate or on a conductive coating. This practice includes only nonmagnetic coatings on either magnetic ($\mu \neq \mu_0$) or nonmagnetic ($\mu = \mu_0$) substrates. This practice can also be used to measure the effective thickness of a process-affected zone (for example, shot peened layer for aluminum alloys, alpha case for titanium alloys). For specific types of coated parts, the user may need a more specific procedure tailored to a specific application.

1.2 Specific uses of conventional eddy-current sensors are

D 1186 Test Methods for Nondestructive Measurement of Dry Film Thickness of Nonmagnetic Coatings Applied to a Ferrous Base

D 1400 Test Method for Nondestructive Measurement of Dry Film Thickness of Nonconductive Coatings Applied to a Nonferrous Metal Base

E 376 Practice for Measuring Coating Thickness by Magnetic-Field or Eddy-Current Electromagnetic Methods

E 543 Practice for Agencies Performing Nondestructive Testing

E 1004 Test Method for Electromagnetic (Eddy-Current) Measurements of Electrical Conductivity

E 1316 Terminology for Nondestructive Examinations

G 12 Test Method for Nondestructive Measurement of Film Thickness of Pipeline Coatings on Steel

2.2 *ASNT Documents:*[3]

SNT-TC-1A Recommended Practice for Personnel Qualifi-

Conclusions

- Single-channel MWM sensors and multi-channel imaging MWM-Arrays provide new capabilities for inspecting gas turbine components
- These sensors permit tracking of features of interest for a population of components
- These conformable sensors allow convenient manual and automated inspection on complex surfaces

Conclusions (cont.)

- MWM technology can differentiate between as-manufactured coating condition and the various conditions of aged samples
- MWM sensors and MWM-Arrays provide a means of characterizing aged nickel aluminide and platinum aluminide coatings
- Multiple frequency MWM technique can be implemented for characterization of diffusion coatings and base metals before and after component refurbishment

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