The Practical Application of Nondestructive Testing for Feedwater Heater Tubing

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The Role of Eddy Current Testing

- To decrease forced outages due to tube failures
- To minimize losses associated with unavailability
- Early detection of potential failure mechanisms
- Estimate remaining useful life of the tubes
- Planning and budgeting equipment replacement
- Summary of overall unit condition
- Operation strategies
What Is the Rationale for Your Inspection Scope?

• **Baseline (Beginning Life)**
  – Delivery Acceptance
  – Warranty Issues

• **Exploratory (Mid-Life)**
  – Known Damage Mechanisms
  – Suspected New Issues
  – Data Trending

• **Remaining Useful Life (End of Life)**
  – Root Cause Failure Analysis
  – Re-tube/Replacement Budgeting
Steam Erosion
In this case, the stainless tubes are fine and the support plates are eroding leaving the tubes unsupported.
Mechanical Damage

Tube-to-Tube Support Wear and Tube-to-Tube Wear
Stress Corrosion Cracking
OD Circumferential Cracking –
Difficult to Detect with Bobbin Coil Inspection Techniques
OD Axial Cracking –
Easily Detected by Bobbin Coil Inspection Techniques
Majority of FWH’s have U bend type tubes
Damage in the U bend area is rare, typically just inspect the straight lengths
Flexible probes are available if inspection of U bends is required
These probes may also be needed for access to tubes in a tight Hemi-Head
Eddy Current Standards

• Need More than the Basic ASME Standard
Eddy Current Standards

• Calibration standards need to be developed to mimic, as closely as possible, actual damage mechanisms found in feedwater heater tubes
• Machining needs to be controlled and preferably with tooling that is traceable to NIST
• Common supplementary standards include
  – ID Inlet Erosion – For the rare “soft metals” still in service
  – OD Erosion / Wall Thinning
  – Wear Scar Standard – simulating tube-to-tube support fretting
  – Crack Standards – Circumferential and Axial EDM notches
• Eddy current can identify damage and provide hints to what the cause is but should be verified
• Pulling a tube can assist with verifying eddy current techniques
• Pulled tube samples can be evaluated in a metallurgical laboratory to determine root cause of degradation and assist with condition assessment
Why Multiple Frequencies?

• At least 4 frequencies for detecting tube support plates
• Mixing out support plates or unwanted signals
• Quantifying defects – each frequency is optimally sensitive to different damage mechanisms
• More frequencies provide the analyst with a better perspective
• Include both differential and absolute modes
• Steam erosion and tube-to-tube wear undetected by self-comparison differential mode
Why Multiple Frequencies?

More Points of Reference – Better Characterization
Why Multiple Parameters?

Advantages of Mix Channels to Suppress Tube Support Signals
Why Multiple Parameters?

Self Comparison vs. External Reference Differential

Coil Response Due to Steam Erosion

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Eddy Current Testing Variables

• Calibration Standards
  • Basic ASME for calibrating the test system
  • Crack Standards – Axial and Circumferential crack simulations for diagnostics
  • Thinning – For steam erosion, Tube-to-tube wear
  • Wear Scar – For Tube-to-Tube Support wear

• Probe Speed – Too fast will reduce data quality
• Fill Factor – Too small will reduce data quality
• Tube Cleanliness – Impacts accessibility and data quality
Define Your Specification

• Technicians
  – Eddy Current technicians are certified to Company’s program that meets ASNT SNT-TC-1A, ANSI/ASNT CP-189, and ASME Section V requirements. Should also be trained in confined space, first aid, and CPR.

• Deliverables
  – A formal report consisting of 2 electronic copies (CD or DVD) will be delivered within 15 days.
  • The final report includes:
    – A brief summary on the condition of the tubes tested.
    – Any other relative information or recommendations.
    – A list of each tube tested and its condition in excel format.
    – Graphics of Tubes that May be of Interest for Further Review.
    – Quick reference Data-Matrix chart.
    – A color-coded tube sheet map that will graphically display the individual tube condition and very quickly identify any problem areas.
Define Your Specification

• Data Base Management
  – Long term storage of inspection results
  – Used for trending and defining inspection plans
  – Query for specific defects and conditions

• Equipment
  – Should be capable of producing four (4) frequencies.
  – Should be capable of operating in differential and absolute modes
  – Should be calibrated to assure optimal performance

• Testing priorities should be for accuracy and repeatability over speed and cost
## Collected Tube Data

### Section Identification
- **Row**
- **Tube**

### Percent Amount of Wall Loss

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<tr>
<th>Section</th>
<th>Row</th>
<th>Tube</th>
<th>Volts</th>
<th>Degree</th>
<th>%</th>
<th>Ind Code</th>
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### Indication Code
- **NDD**
- **IND**
- **PLG**

### Location
- **Location**
  - Location of defect beginning at the common tube end (depends on Extent)
  - Inlet/Outlet end + 12.34 inches

### Extent
- **CTE-I/O**

### Volts
- **Size of the defect**

### Degree
- <40 typically indicates an inside defect
- >40 typically indicates an outside defect

### Channel
- Channel defect was sized on:
  - Channel 1 typically indicates a free span indication
  - Channel P1 typically indicates a defect at tube support

### Extent
- Directionally indicates the tube test (in this case, the tube was tested Common Tube End to Inlet/Outlet End). Analysis is done in the opposite direction of the test

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Evaluated Eddy Current Data

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The Importance of Cleaning

• Tubes must be clean in order to avoid false signals or masked defects. If required, ensure that the tube cleaning regimen chosen can remove deposits as near as possible to the tube surface.
Side-By-Side Comparison of Fouling Impact

Row 16, Tube 14

Tube Ineffectively cleaned on left

Row 16, Tube 14

Same tube following effective cleaning

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Review of the Various Inspection Methods
Eddy Current Testing (ECT) is a nondestructive test technique based on inducing electrical currents in the material being inspected and observing the interaction between those currents and the material. Eddy currents are generated by electromagnetic coils in the test probe, and monitored simultaneously by measuring the probe’s electrical impedance.
Eddy Current Testing

• Eddy Current is applicable to non-ferrous materials.
  – Copper
  – Brass
  – Copper-Nickel
  – 300 Series Stainless
  – Titanium
  – Inconel / Hastelloy
Eddy Current Testing

• Eddy Current Advantages
  • High speed inspection with a bobbin coil
  • Detects pits, cracks, wear, wall thinning and more
  • Repeatable examination
  • Reliable data

• Eddy Current Disadvantages
  • Circumferential cracks hard to find with conventional bobbin exam
  • Special interest exams can be costly $$/time
Eddy Current Testing

Diagnostic Testing Methods
Remote Field Testing

- Remote field testing is a Driver – Pickup, Through - Transmission technique.
- The exciter coil generates the magnetic field that penetrates the tube wall.
- The pickup coils detect changes in the remote field.
Remote Field Testing

• Remote field probes have their pickup coils set at ~ 2.5 to 3 times the tube OD to ensure that only the indirect field is picked up.
• Defects in the tube wall affect the primary magnetic field causing a reading in the pickup coils.
Single-Exciter Probe

Simplified magnetic flux path
Transition zone
Direct field
Indirect or remote field
Magnetic flux lines

Exciter coil
Pickup coils, absolute/differential

Single-excitier model shown

Absolute response

Differential response
Advantages and Limitations of Remote Field Testing

• Remote field testing is a method to inspect ferrous tubes (e.g. carbon steel and Cr-Mo).

• Remote field testing is slower 4”-12” probe speed and less sensitive to local defects than conventional Eddy Current.

• Overall wall-loss is detectable from 10% of the nominal wall thickness and up.
Advantages and Limitations of Remote Field Testing

- Although this method can detect both internal and external defects it can not distinguish between internal and external defects.
- A pit under a support plate can not be detected. Determination of defect depth is more difficult for defects under support plates.
- Defects just behind the tube sheet can only be detected when a special dual exciter probe is used. Defects under the tube sheet cannot be detected.
- The size of the probe in relation to the internal diameter (fill factor) is not as critical as in ET, A 60% - 70% FF is common.
- Inspection of finned tubes has numerous limitations.
• Eddy Current Testing is but one important component in achieving the perfect balance of efficiency and reliability for feedwater heaters.

• The impact of chemical deposits on Eddy Current Testing is often underestimated and can mask underlying problems leading to eventual tube failure.

• Contracting with an experienced company with cross-discipline expertise in non-destructive testing and tube cleaning is not only smart, but cost-effective.

• Testing priorities should be for accuracy, trending, and repeatability over speed and cost.