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Demonstration of Detection of Magnetite in Boiler Tubes Using Electromagnetic Inspection Technology

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EPRI Project Manager

P. Zayicek

ELECTRIC POWER RESEARCH INSTITUTE
3420 Hillview Avenue, Palo Alto, California 94304-1338 ▪ PO Box 10412, Palo Alto, California 94303-0813 ▪ USA
800.313.3774 ▪ 650.855.2121 ▪ askepri@epri.com ▪ www.epri.com

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1300 West W.T. Harris Blvd
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Principal Investigator
P. Zayicek

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PRODUCT DESCRIPTION

The Electric Power Research Institute (EPRI) sponsored a demonstration of the detection of magnetite in boiler tubes using electromagnetic inspection technology at Wisconsin Public Service's Weston 4 Power Plant. This activity was funded by EPRI Program 63, Boiler Life and Availability Improvement.

New supercritical boilers are designed with austenitic stainless steel boiler tubes in the superheat and reheat sections that operate at temperatures above 1005°F (540°C). At these elevated temperatures, stainless steel boiler tubes will produce magnetite on the inside surface of the tube. When the boiler is taken off-line and the boiler tubes cool, the internal magnetite scale can exfoliate and accumulate in the lower tube bends. Large amounts of loose scale in the tube bends can block steam flow, resulting in overheating and, ultimately, rupture of the tubes. In the absence of a proven nondestructive examination (NDE) detection technique, utilities experiencing exfoliation of new tubes have resorted to cutting the complete population of the potentially affected tubes to remove any accumulated magnetite scale as a precaution against tube failure.

Results and Findings

Development of a reliable NDE technique for identification of magnetite buildup in lower tube bends would benefit utilities experiencing exfoliation in stainless steel boiler tubes. The demonstration activity at the Weston 4 Power Plant featured two electromagnetic NDE inspection techniques capable of detecting and quantifying exfoliated magnetite scale blockages in lower tube bends. The availability of this inspection technology from commercial inspection providers eliminates the need to cut the entire tube population to check for magnetite buildup as a mitigation technique against tube failure.

Challenges and Objectives

The demonstration of the electromagnetic NDE inspection technique for detecting magnetite in lower tube bends is significant for two reasons. First, it allows the operator to efficiently locate and quantify exfoliated magnetite in lower tube bends. Second, it eliminates the need to cut open the entire tube population and perform the weld repair effort associated with cutting 100% of the tubes.

Applications, Value, and Use

Electromagnetic inspection has been demonstrated to be effective for detecting exfoliated magnetite in lower tube bends, and the technology is capable of quantifying the amount of magnetite in relative terms. Future work with this technology should include revisiting calibration procedures and/or refining the sizing algorithm. Future field demonstrations should include improved magnetite collection methods to better correlate NDE inspection measurements with the actual magnetite removed.

EPRI Perspective

Collaboration among EPRI, the electric utility industry, and NDE inspection service providers facilitates development of unique solutions to industry challenges. The impetus for demonstrating the electromagnetic inspection technology for the detection of magnetite in boiler tubes was to demonstrate an alternative to cutting the entire tube population to visually inspect for magnetite accumulation. Adoption of the demonstrated technology can reduce the length of maintenance outages related to magnetite accumulation in lower tube bends and potentially improve boiler availability.

Approach

This demonstration was supported by EPRI Program 63, Boiler Life and Availability Improvement. EPRI has extensive experience with field demonstrations of NDE technologies. Collaboration with electromagnetic inspection technology service providers leveraged existing data acquisition systems for use in this demonstration. Application of the technology at the Weston 4 Power Plant provided real-world conditions for the evaluation of the technology.

Keywords

Electromagnetic inspection technology
Magnetite exfoliation
Nondestructive inspection
Supercritical boilers

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The Demonstration of Detection of Magnetite in Boiler Tubes using Electromagnetic Inspection Technology was funded by Program 63, Boiler Life and Availability Improvement Program. EPRI acknowledges Wisconsin Public Service, Weston Power Plant, Unit 4 for their support and cooperation in facilitating this demonstration activity.

CONTENTS

1 BACKGROUND

A demonstration of electromagnetic inspection technology for detection of magnetite in boiler tubes was conducted at the Wisconsin Public Service, Weston Power Plant, Unit 4 facilities, March 25-27, 2009. EPRI, Russell NDE Systems, and TesTex staff worked with Weston staff to collect inspection data on 29 pendants of the secondary superheat outlet tubes. After analysis of the inspection results, several tubes were identified with varying degrees of magnetite blockage. Weston staff cut open the identified tubes and collected the magnetite found in each tube. A report of the correlation of the inspection data is included.

New supercritical boilers are designed with austenitic stainless steel boiler tubes in the superheat and reheat sections that operate at temperatures above 1005°F (540°C). At these elevated temperatures, stainless steel boiler tubes will produce magnetite on the inside surface of the tube. A typical arrangement of these tubes is shown in Figure 1-1. When the boiler is taken off-line and the boiler tubes cool, the internal magnetite scale can exfoliate and accumulate in the lower tube bends. Large amounts of loose scale in the tube bends can block steam flow resulting in overheating and, ultimately, rupture of the tubes [1]. Utilities experiencing exfoliation of new tubes have resorted to cutting the complete population of the potentially affected tubes to remove any accumulated magnetite scale as a precaution against tube failure (see Figures 1-2a and 1-2b). Development of a reliable nondestructive examination (NDE) technique for identification of magnetite buildup in lower tube bends would benefit utilities experiencing exfoliation in stainless steel boiler tubes.

Figure 1-1
Pendant of secondary superheat outlet tubes

Figure 1-2a
Magnetite flakes in lower tube bend

Figure 1-2b
Wet magnetite in lower tube bend

Inspection Technology

EPRI Program 63, Boiler Life and Availability Improvement Program, funded Russell NDE Systems, Inc. and TesTex, Inc. to demonstrate their respective electromagnetic inspection technologies for detection of magnetite in boiler tubes at Weston Unit 4. The secondary superheat outlet tubes were 1.75 in. in diameter and the inspection probes used by both inspection groups were constructed to scan the prescribed diameter. The inspection probes scanned the outside surface of the tubes for detection of magnetite accumulation within the tubes. The inspection probes used by both inspection groups require a relatively smooth and consistent scan surface for data collection. Minimal tube surface preparation was required to accommodate inspection at Weston Unit 4.

Russell NDE Systems uses a through-transmission electromagnetic technique for the detection and quantification of magnetite blockage in superheater tubes (see Figure 1-3). An encircling probe in a clam shell configuration consists of a single exciter and a set of five detector coils (see Figure 1-4). A Ferroscope 308, coupled with the probe, is used for data acquisition.

Figure 1-3
Russell NDE Systems electromagnetic inspection probe on secondary super heater outlet tube

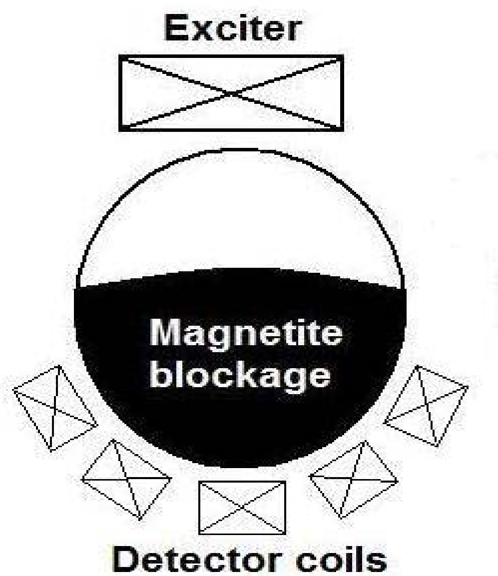

Figure 1-4
Schematic of exciter and detector configuration of Russell NDE Systems inspection probe

The electromagnetic through-transmission signal is influenced by the magnetite blockage and characterized by changes in signal phase and magnitude. The technique will operate through a frequency range of 27 Hz to 4 kHz. For detection of magnetite in boiler tubes, the optimal frequency is 2.5 kHz.

Due to the need for rotation of the inspection probe during field inspection to navigate past obstacles, an experiment was conducted to determine the effect of exciter/detector position, as related to relative magnetite blockage position, on the measurement of the blockage. Figure 1-5 shows the probe orientation relative to the magnetite blockage for three scenarios.

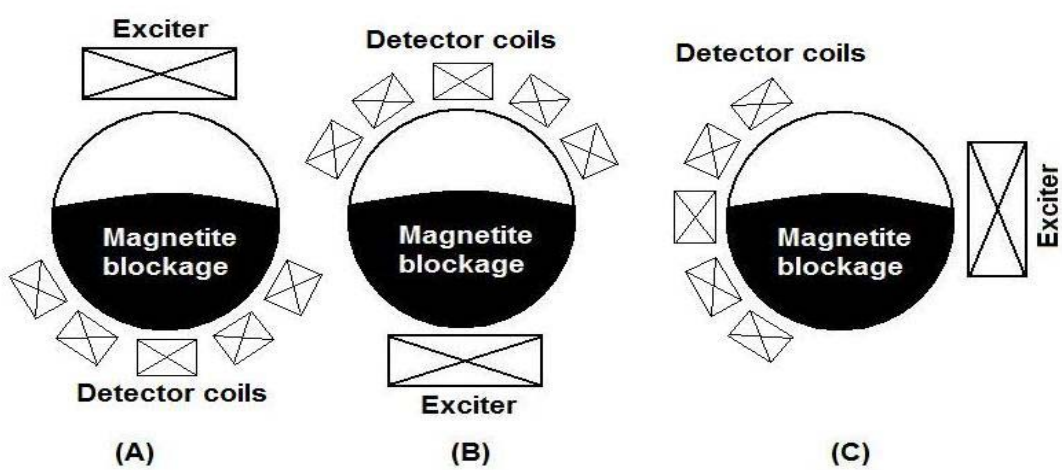

Figure 1-5
Probe orientation relative to magnetite blockage

Measurements were recorded at orientations A, B, and C with blockages of 35%, 53%, 72% and 100%. The resulting measurements indicated that the sensitivity of the array probe was not substantially influenced by probe orientation. The equivalent percentage of blockage variation was less than ±10% over the range [1].

The Russell NDE software displays the data as a strip chart, voltage plane and color map as shown in Figure 1-6. The color map shows localized areas of flake accumulation where yellow is minor accumulation, red indicates medium blockage and black would be completely blocked.

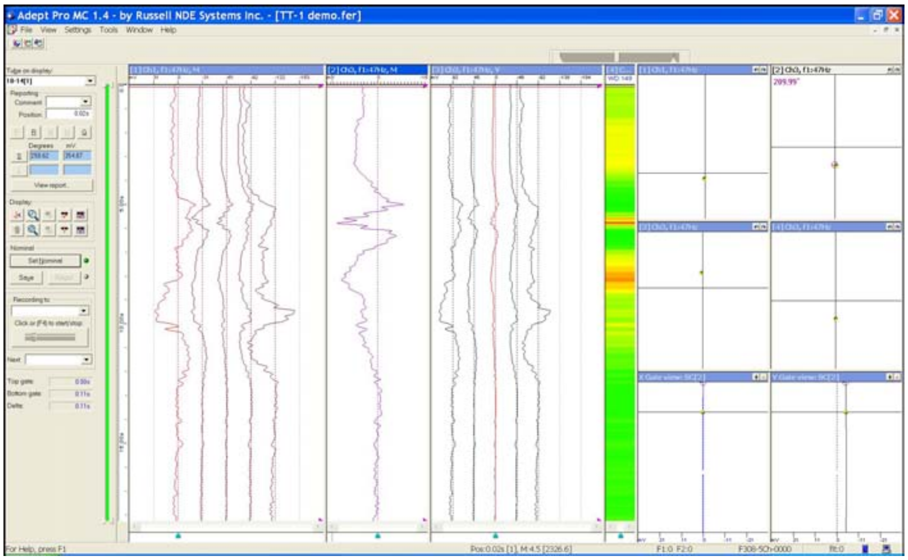

Figure 1-6
Russell NDE software display of blocked tubes

TesTex, Inc. uses a Low Frequency Electromagnetic Technique (LFET) for detection of magnetite in boiler tubes by scanning along the outside surface of the tube. The scanner contains no magnets. It is forgiving to uniform surface scale and is a dry non-contact method. The technology has been used to measure wall loss in a tube, pipe, or plate, and also to detect welds through coatings, ERW (electric resistance welds), and deposits. By adjusting the frequency level, magnetic and non-magnetic metals can be inspected. The technology can inspect through coatings up to 1/4 in. thick. A schematic of the probe is shown in Figure 1-7.

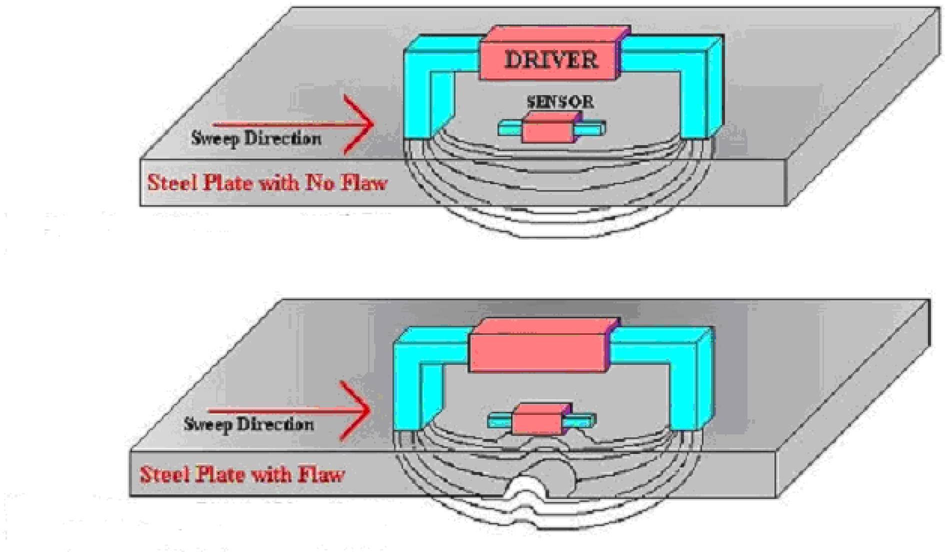

Figure 1-7
Schematic of TesTex, Inc. Low Frequency Electromagnetic Technique (LFET) inspection probe. Top image shows uniform electromagnetic field in absence of flaw. Bottom image shows distorted magnetic field due to influence of flaw.

The LFET functions by injecting an electromagnetic signal into the boiler tube material. A scanner is moved along the test piece at a constant speed of approximately 4 in. per second. TesTex inspects the tubes with a specially designed tube bend scanner. While one technician is moving the scanner, a second technician is watching the computer as the data is acquired. The return signal strength is measured and stored for reference. Suspicious signals are rescanned. If the signal repeats, the location is marked for further investigation. For the demonstration at Weston Unit 4, suspected magnetite areas were also scanned with the TesTex crown scanner to verify the data. Any changes in the signal, resulting from magnetite blockage in the tube, are noted and the distorted signals are compared to a calibration table to determine the amount of magnetite deposits. TesTex uses the TS2000 for data acquisition.

The TesTex standard tube bend scanner has a 3/4 in. lip on each side of the contoured section of the scanner which aids in keeping the scanner aligned on the tube. TesTex also has a crown scanner that does not contain this lip and is used primarily for tube scanning of crossover tubes or in other areas with limited scanning access. The crown scanner has the same electromagnetic characteristics as the standard tube bend scanner. More effort is required when scanning with the crown scanner to maintain alignment on the tube.

Figure 1-8 shows a TesTex LFET inspection probe on a secondary super heater outlet tube.

Figure 1-8
TesTex LFET inspection probe on a secondary super heater outlet tube

Figure 1-9 shows representative waveforms from a boiler tube with magnetite deposits, using the TesTex system. The data is displayed in five different windows. The bottom right window displays the raw collected data. The bottom left window shows the zoomed in data. The window located on the left side in the middle is a simulated C-Scan. The top left window shows the largest phase responses and can be considered a B-Scan. The top right window provides a 3-D color-coded picture.

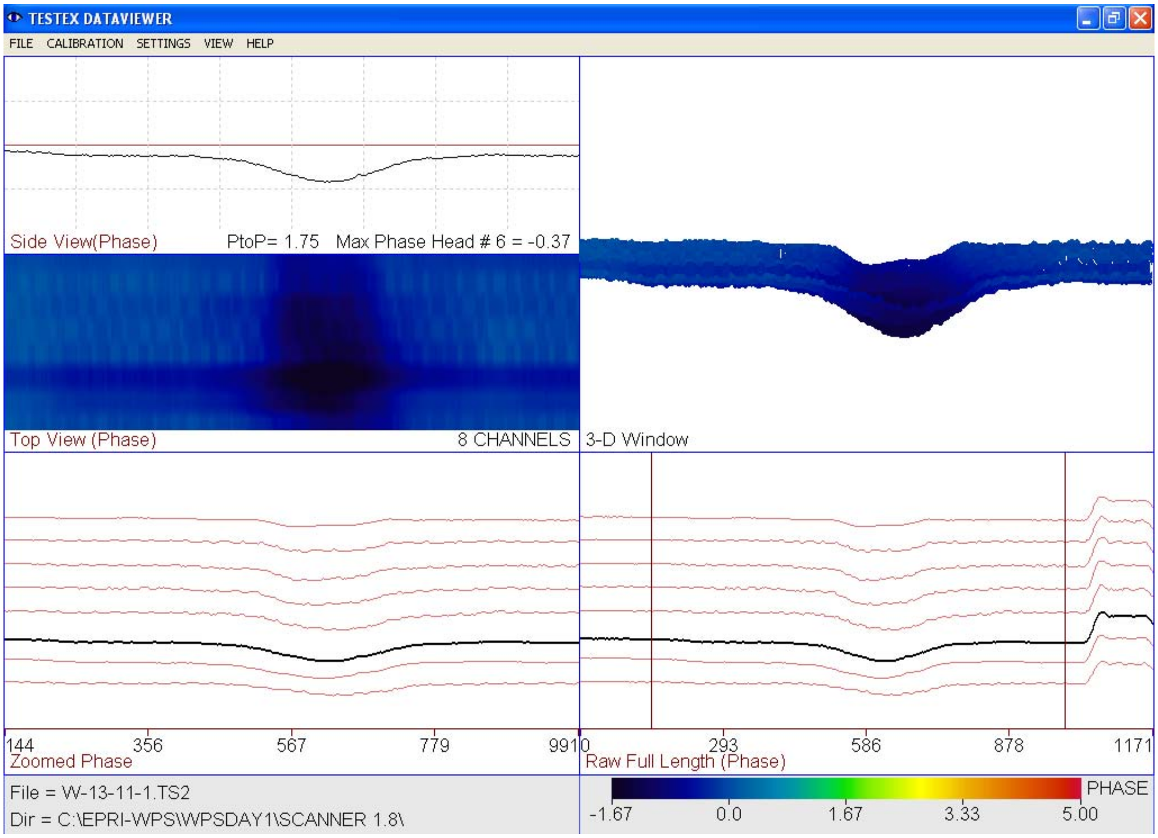

Figure 1-9
Waveform collected from tube with magnetite deposits by TesTex. The deposits are located where the signal drops in the middle of the waveform.

Weston Unit 4 Demonstration

Weston Unit 4 is a new supercritical boiler designed with austenitic stainless steel boiler tubes (347H material) in the superheat and reheat sections that operate at temperatures above 1005°F (540°C). At these elevated temperatures, stainless steel boiler tubes will produce magnetite on the inside surface of the tube. The unit has experienced significant exfoliation in the reheat and superheat boiler tubes. Previously, all of the potentially affected tubes were cut in the lower section to remove the magnetite. Figure 1-10 shows a tube cut for removal of magnetite.

Figure 1-10
shows a tube cut for removal of magnetite

EPRI Program 63, Boiler Life and Availability Improvement Program, supported Russell NDE Systems and TesTex at Weston Unit 4 in demonstration of their respective electromagnetic technologies for detection of magnetite. The demonstration focused on the secondary superheat outlet tubes.

Weston Inspection Results

Magnetite was detected in numerous tubes. The project team agreed to select some representative tubes for further investigation. After completion of the inspection, the project team requested 11 tube bends be accessed and have the magnetite removed to correlate electromagnetic measurements with the “truth.” The plant provided data on 8 of the 11 tube bends (either through still images or video). Both inspection companies provided measurement values, expressed as percentage of blockage for each tube, based on their inspection. The still photos and video showed the extent of magnetite after removal from the tube with a magnet, not as it was positioned in the tube bend (a video-probe would be required to see the magnetite in-situ). Without the benefit of a video-probe, it is difficult to determine if the magnetite was concentrated in the tube bend or distributed in the tube bend and the horizontal run. No quantitative measurement of the magnetite (weight or volume) was provided. Based on the video and still photos, we were able to make a relative correlation between the magnetite removed and the results provided by the inspectors. The inspection results are shown in Table 1-1.

Table 1-1
Results of electromagnetic inspection of selected Weston Unit 4 boiler tubes

Pendant	Tube	Connects To	TesTex Call	Russell Call	Image of Removed Magnetite
10	14	3	30-50%	12.2%	
26	22	27	<10%	28%	
19	14	3	30-50%	24%	

Table 1-1 (continued)
Results of electromagnetic inspection of selected Weston Unit 4 boiler tubes

Pendant	Tube	Connects To	TesTex Call	Russell Call	Image of Removed Magnetite
13	11	4	30-40%	17%	
26	1	16	0%	3%	
26	16	1	<10%	21%	

Table 1-1 (continued)
Results of electromagnetic inspection of selected Weston Unit 4 boiler tubes

Pendant	Tube	Connects to	TesTex Call	Russell Call	Image of Removed Magnetite
25	15	2	10-30%	19%	
25	2	15	0%	19%	

It should be noted that the pictures included in the chart above show all of the magnetite removed from the elbow and horizontal run in that section. The inspection numbers provide an indication of tube blockage in that section. Since the location of the magnetite was not recorded in-situ, prior to removal, correlation of tube blockage with the indicated percentage of blockage becomes difficult. However, the levels of blockage for each tube, as indicated by the individual inspection teams, is relatively consistent with the amount of magnetite removed. The preliminary assessment is that the electromagnetic technology used by the inspectors is effective for detection of magnetite in the boiler tubes. It is suggested that additional lab work is required to more accurately quantify the amount of magnetite present. This may simply require a revised calibration process or analysis algorithms. One of the lessons learned from this demonstration is that future field exercises should more accurately document the magnetite, *in situ,* to effect more meaningful correlation of inspection data and presence of magnetite.

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REFERENCE

1. *Program on Technology Innovation: Device for Quantification of Magnetite Exfoliation in Stainless Steel Boiler Tubes*. EPRI, Palo Alto, CA: 2008. 1018471.

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3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 • USA
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