The Use of the Low Frequency Electromagnetic Technique to Detect and Quantify the Amount of Magnetite Deposits in Stainless Steel Superheater Tubes Due to Exfoliation

Shawn Gowatski and Gary Miner

ABSTRACT

Many supercritical boilers are designed with austenitic stainless steel tubes in the superheat and reheat sections. The growth of magnetite on a tube's inner diameter wall occurs when the operating temperatures are above 540 °C. After the boiler is taken off line, the scale exfoliates and accumulates in the lower tube bends; this can block steam flow and may result in the tube overheating and ultimately rupturing. The low frequency electromagnetic technique, a non-destructive examination (NDE) procedure to detect and roughly quantify the amount of magnetite in a stainless steel tube, is described in this contribution. This detection method can pinpoint the location of the magnetite within the tube and can size the amount of blockage within 5 %, allowing a marked reduction in the manpower and time required for maintenance.

INTRODUCTION

New supercritical boilers are designed with austenitic stainless steel tubes in the superheat and reheat sections. The steam temperatures are typically higher than 540 °C (1 004 °F).

Under operating conditions, oxides grow on the internal surfaces of steam tubing made of ferritic alloys (for example T11, T22, T5, T9, and T91). The oxide with time will exfoliate and the oxide particles can cause serious problems when they accumulate on downstream pendant superheater/reheater surfaces made of stainless steel. Blockage of the tubes with oxides (magnetite, Fe-Cr spinel) may result in serious overheating tube failures. TesTex, Inc. has worked with the Electric Power Research Institute (EPRI) to develop a procedure to detect and roughly quantify the amount of magnetite in a stainless steel tube. This procedure utilizes the low frequency electromagnetic technique, a non-destructive examination (NDE).

Steam oxide growth, delamination, and exfoliation will not be dealt with in this paper. Interested readers may find detailed information about these issues in [1–5].

LOW FREQUENCY ELECTROMAGNETIC TECHNIQUE

What is the low frequency electromagnetic technique (LFET)? The LFET can be used to detect flaws by inducing a low frequency electromagnetic field into the plate, piping, or tubing to be inspected using a horseshoe-shaped electromagnet (Figure 1). Any flaw in the plate, piping, or tubing will distort the returning field, which is picked up by a sensor. This data is analyzed to determine the condition of the test material. A waveform will show a signal increase from the metal baseline to indicate where wall loss has been detected by the sensor.

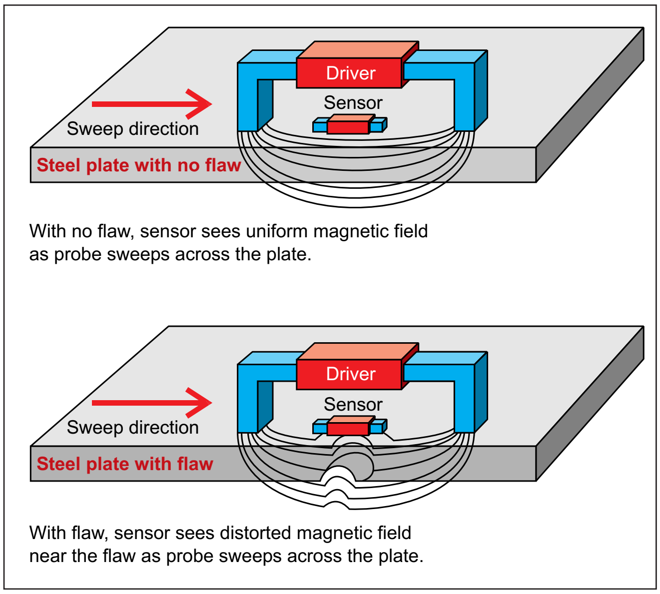

Figure 1:
LFET principle (simplified).

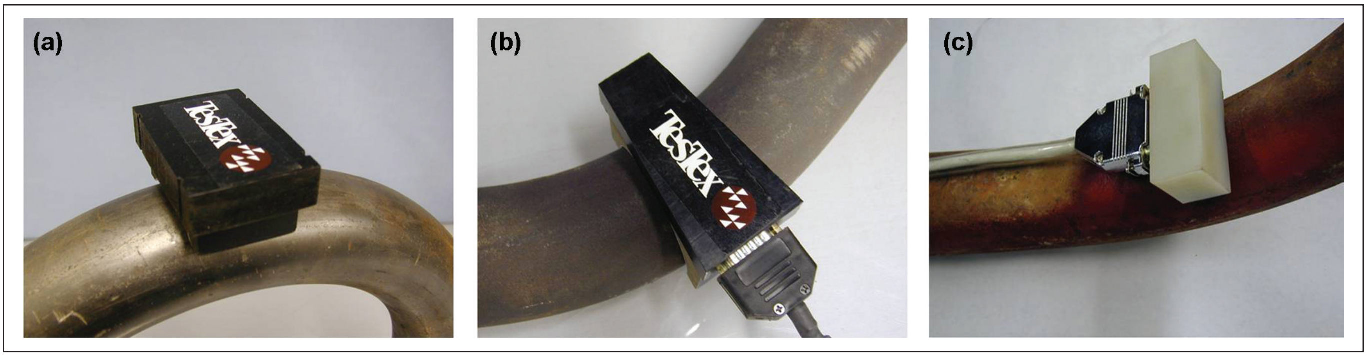

Figure 2:
Specialized bend LFET scanners.

The LFET signal will decrease when magnetite is encountered. The magnitude of the response directly relates to the amount of magnetite present in the tube. In order to produce a valid calibration table, a tube matching the tube specifications of the test unit is procured. By placing known amounts of magnetite into a sample tube, a calibration table can be produced. These phase values can be compared to actual phase responses found during the field examination to determine the amount of magnetite in the tube.

Examples of sensors developed for scanning tube bends are depicted in Figures 2a–2c.

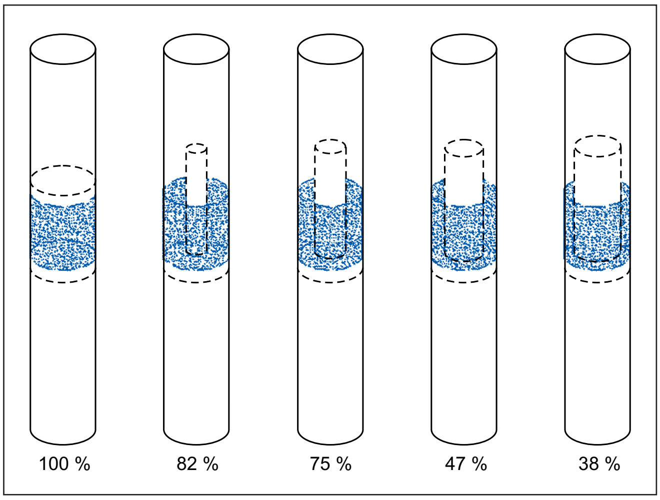

Figure 3:
Test arrangement.

LABORATORY INVESTIGATIONS

To investigate the applicability of the LFET for detecting deposited oxide (magnetite), investigations were carried out with magnetite samples. Stock stainless steel tubes were filled with different amounts of magnetite (100 %, 82 %, 75 %, 47 %, and 38 % of the tube cross section) as shown in Figure 3. The tube outer diameter was 60.2 mm (2.37 in), the wall thickness 3.76 mm (0.148 in); the tube material was Type 304 stainless steel (UNS S30400).

The LFET scans revealed larger phase and amplitude response with increasing magnetite percentage in the tube cross section (see Table 1). In Figures 4–7, LFET waveforms as a function of the extent of magnetite blockage are shown.

Each LFET waveform shown in Figures 4–7 contains 5 windows to interpret the data. The bottom right window shows the raw data as it was collected, and the bottom left window shows the data once it has been cropped. The top left window shows a select channel of data and provides the phase response, and the middle left window is a simulated C-scan. The top right window lists the equipment settings during the examination.

The LFET scanners used contain 4 LFET sensors spaced circumferentially alongside each other. The responses of the sensors are the 4 lines shown in the bottom two windows. When no magnetite is detected, the sensors will provide a relatively flat line. When a magnetite deposit is encountered, the signal will decrease due to the presence of additional metal. The signal decrease is directly proportional to the amount of magnetite present. When wall loss is detected, the signal will increase. The simulated C-scan window changes to a darker blue where the magnetite is detected.

The laboratory investigation results were very promising. For this reason, the decision was made to investigate the suitability of the LFET for detecting magnetite deposits in the field.

Magnetite Blockage [%]	Phase Response	Amplitude Response
100	12.65	243
82	12.17	233
75	11.72	218
47	11.01	200
38	6.25	143

Table 1:
Test results.

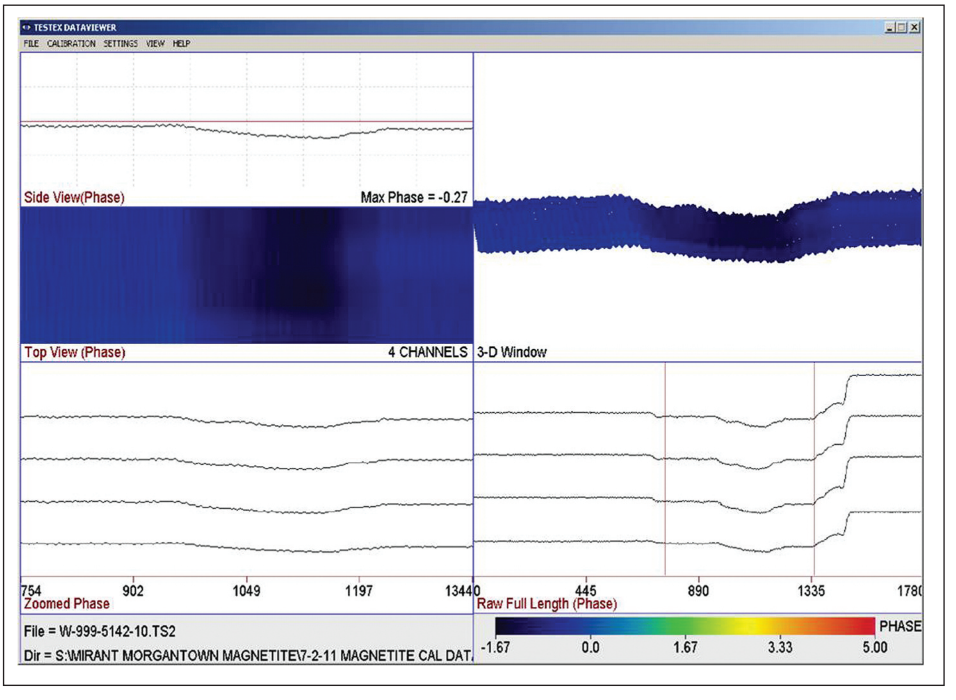

Figure 4:
LFET waveform with 10 % blockage of magnetite.

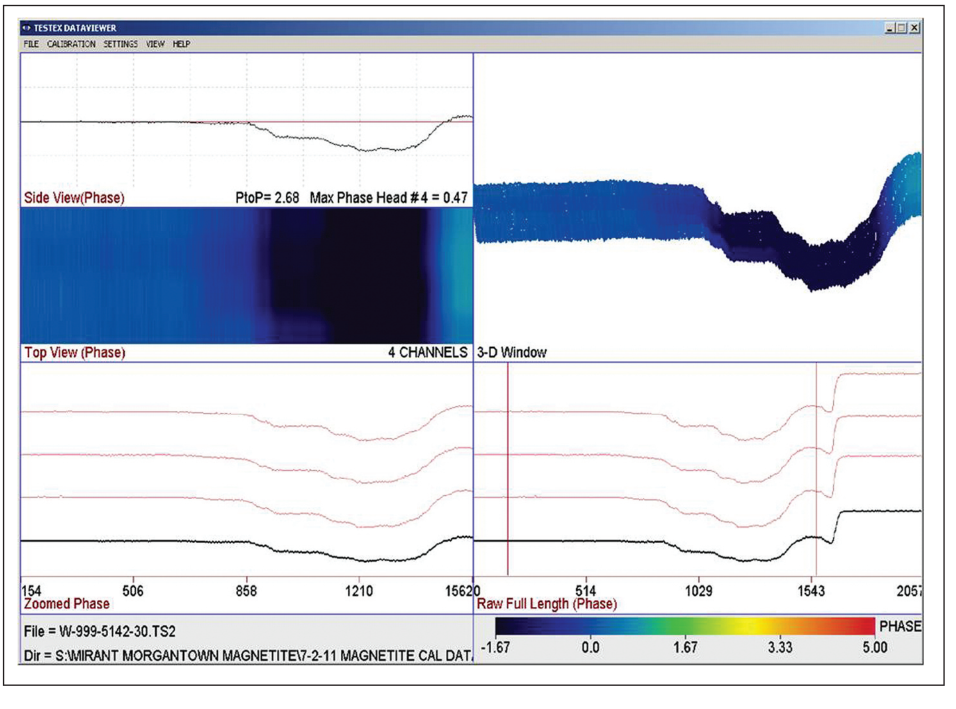

Figure 5:
LFET waveform with 30 % blockage of magnetite.

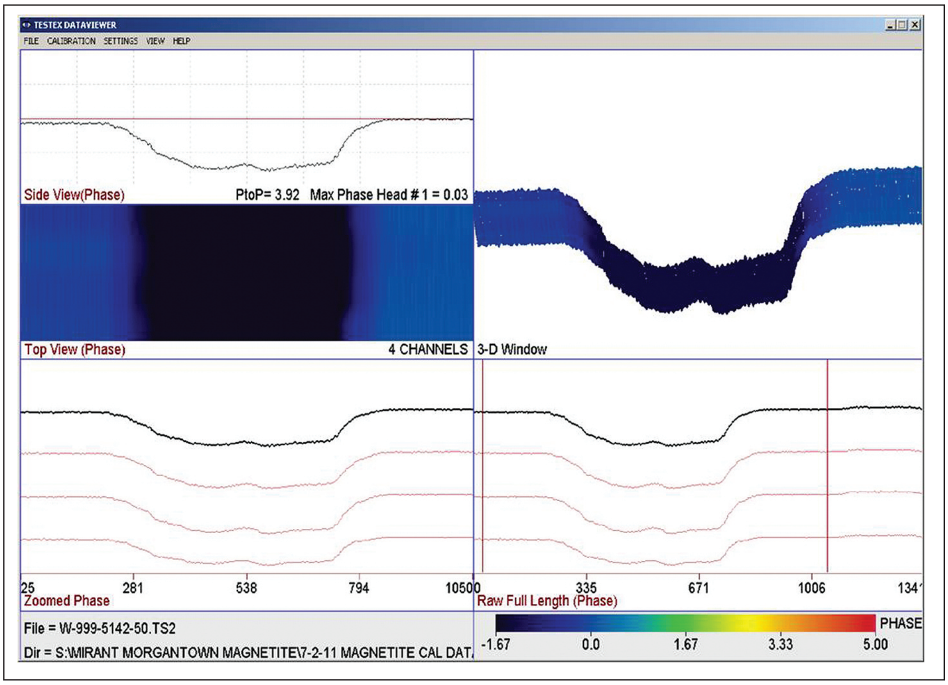

Figure 6:
LFET waveform with 50 % blockage of magnetite.

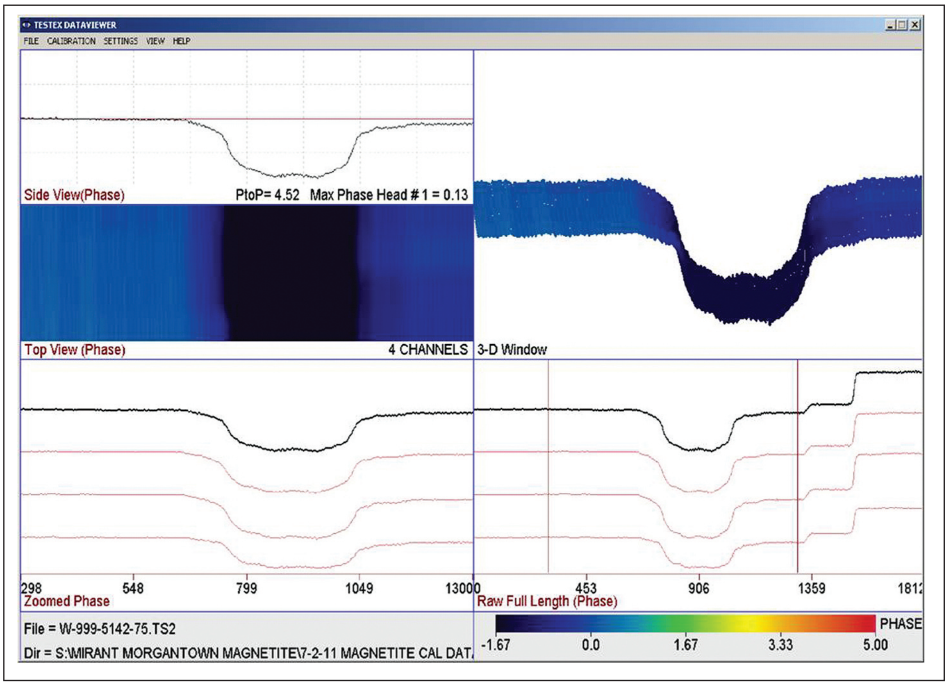

Figure 7:
LFET waveform with 75 % blockage of magnetite.

CASE STUDY

The LFET (frequency: 1 000 Hz) was applied to inspect secondary superheater outlet tubes in a unit experiencing problems with magnetite deposits in bottom superheater tube bends. The secondary superheater section consisted of 29 assemblies (Figure 8) with 32 vertical runs per assembly. Altogether, 25 assemblies (800 tubes) were evaluated.

Tube data:	Material	TP347H (UNS S34709)
	Outer diameter	44.45 mm (1.75 in)
	Wall thickness	8.64 mm (0.34 in)

Figure 8:
Superheater assemblies.

Inspection Results

Out of 800 tubes evaluated, 83 tubes showed signs of magnetite deposits, 33 tubes a moderate signal change, and 4 tubes a significant signal change. Figures 9–12 are examples of the collected waveforms.

After the evaluation, the tubes were split open at the center of the U-bend and the magnetite was extracted using a magnet. The most severe signal corresponded nicely to the largest amount of removed magnetite deposits.

The LFET is capable of differentiating between dry and wet magnetite. Figures 13–14 show the dry and wet magnetite particles with corresponding LFET waveforms.

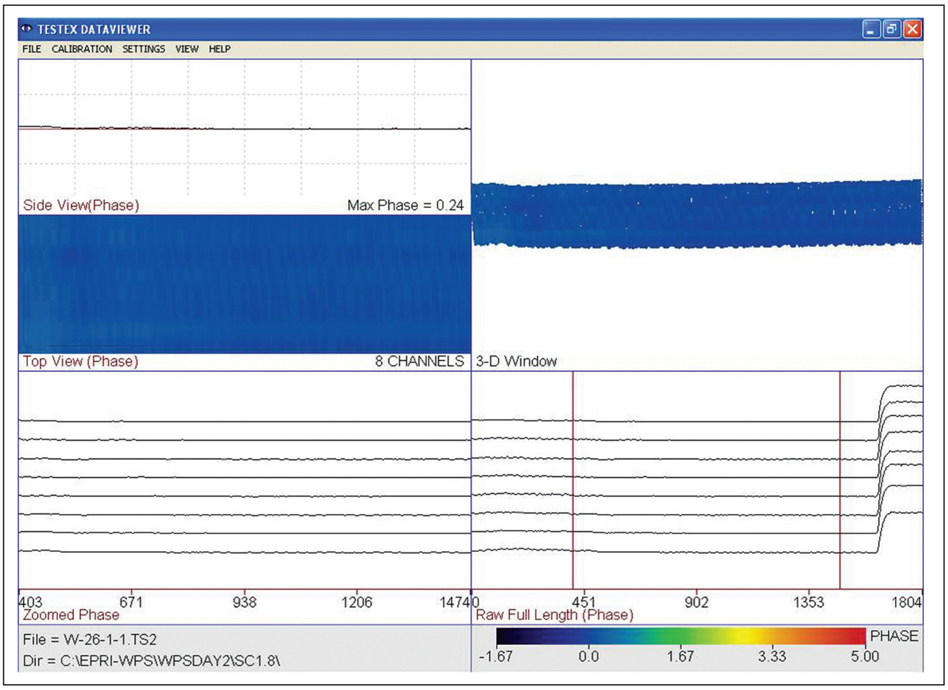

Figure 9:
Waveform showing no signs of deposited magnetite.

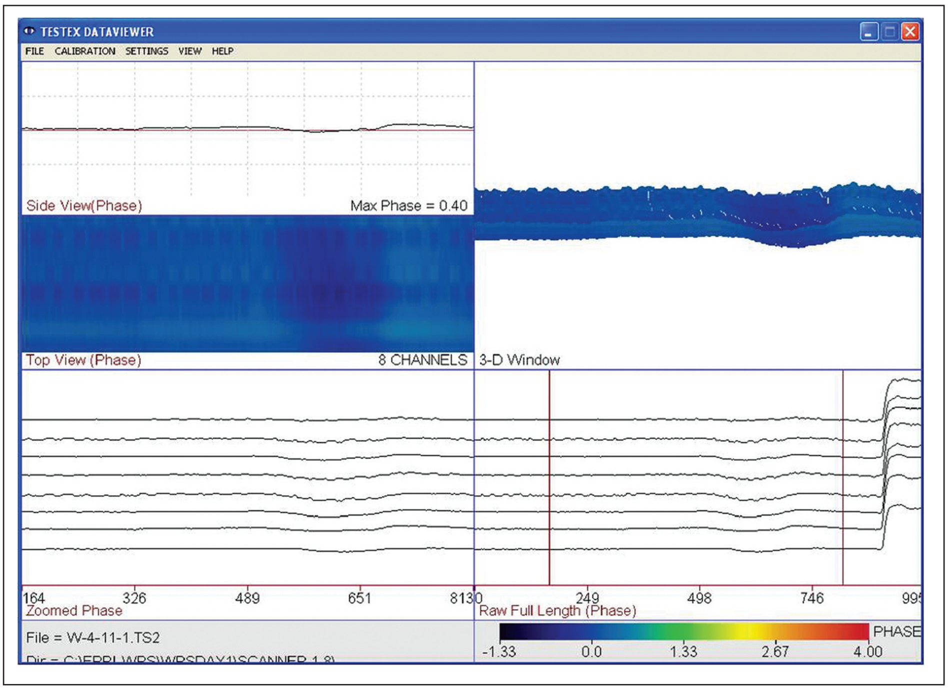

Figure 10:
Waveform showing minimal signs of deposited magnetite.

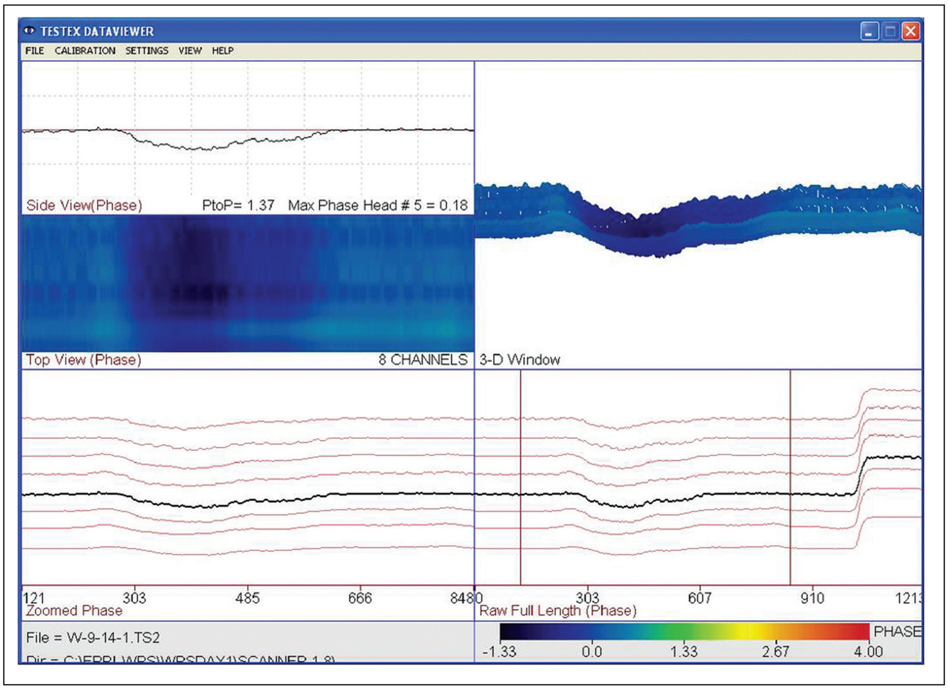

Figure 11:
Waveform showing moderate signs of deposited magnetite.

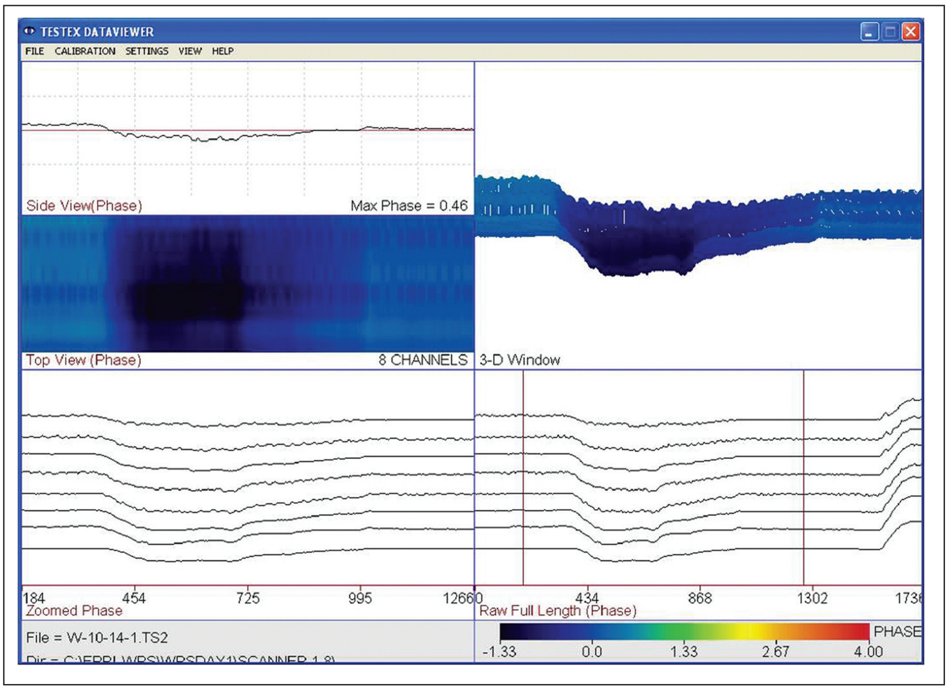

Figure 12:
Waveform showing significant signs of deposited magnetite.

(a) (b)

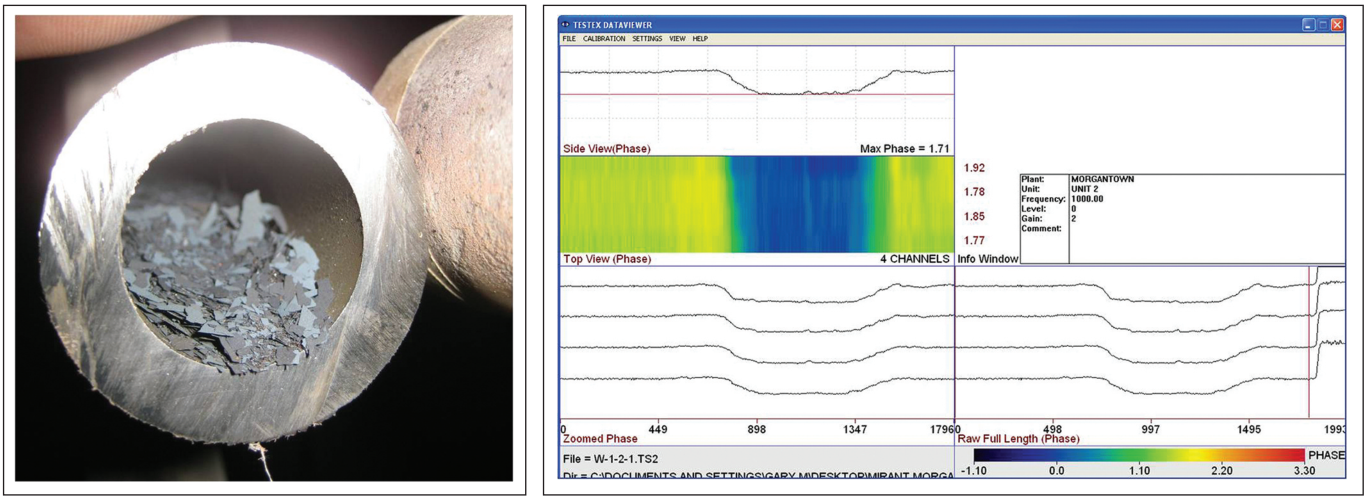

Figure 13:
Dry magnetite.
(a) photograph
(b) corresponding waveform

(a) (b)

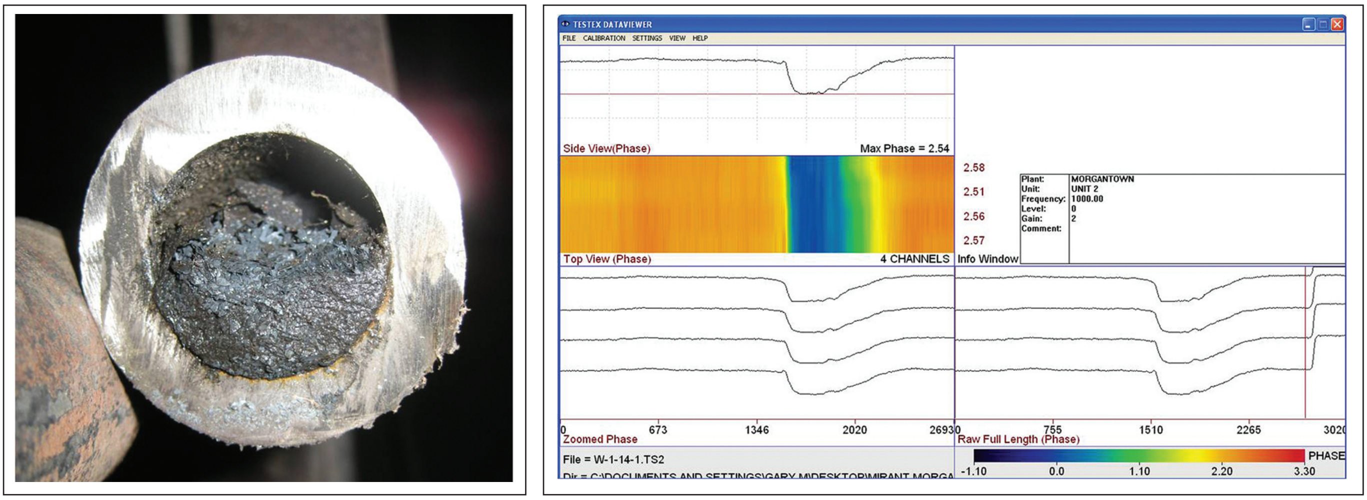

Figure 14:
Wet magnetite.
(a) photograph
(b) corresponding waveform

CURRENT STATUS

To date, TesTex, Inc. has conducted 21 magnetite inspections at 10 power plants in the United States. Superheaters with Type 304 stainless steel (UNS S30400), Type 321 stainless steel (UNS S32100), and Type 347 stainless steel (UNS S34700) have been successfully examined. The developed calibration method can size the amount of blockage within 5 %. The detection method can pinpoint the location of the magnetite within the tube. Under optimal conditions, a 2-man team can test up to 1 000 bends in a twelve-hour shift.

Based on signal patterns, differentiation between wet and dry magnetite is possible (wet magnetite gives a larger phase response than dry magnetite).

The major advantage for the operator is the fact that the LFET can pinpoint the location of magnetite deposits. Upon completion of the inspections, operators can take the results and cut open the tubes with magnetite to remove these deposits. The tubes are then welded back into place. In this way, a marked reduction in the manpower and time required for maintenance may be realized. Several utilities have found the LFET inspection method to be an effective tool to help them manage their magnetite issues.

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Gary Miner (A.D., Pennsylvania State University, University Park, PA, U.S.A.) began at TesTex, Inc., Pittsburgh, PA, U.S.A. as a field service engineer, where his duties included performing non-destructive testing inspections on boilers, heat exchangers, piping, aboveground storage tanks, pressure vessels, etc. using remote field electromagnetic testing, low frequency electromagnetic technique, and eddy current and ultrasonic testing. A quality assurance manager since 2004, he now oversees the corporate quality program, the safety program, the training program, and the operations of all field service work in the U.S., Canada, Argentina, and Trinidad.

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