TUBING INSPECTION USING MULTIPLE NDT TECHNIQUES

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ABSTRACT

This article describes the use of advanced tubing inspection NDT methods for boiler and heat exchanger equipment in the petrochemical industry to supplement major turnaround inspections. The methods presented include remote field eddy current, magnetic flux leakage, internal rotary inspection system (IRIS) and eddy current. Cost savings include lower inspection costs, lower turnaround costs, avoiding lost production, and allow better planning of inspection and maintenance intervals. To achieve these savings and improve integrity, the owner-user must understand the capabilities and pitfalls of the NDT technologies in order to select, apply and interpret the results of these methods. A methodology of providing rapid qualitative screening techniques before applying slower quantitative techniques is presented to maximize heat exchanger integrity while minimizing inspection costs.

INTRODUCTION

The petrochemical industry depends on many heat exchangers and boilers for efficient operation. As these components consist of many tubes tightly held together, they are very hard to inspect visually or with normal ultrasonic or radiographic thickness measuring techniques. Inspections used to take two to three weeks to assess the condition of a boiler or heat exchanger. New NDT Technology has developed portable equipment that combines simple operation, reliable flaw detection, and easy reporting. In the past, tests were limited to visual inspection and destructive testing (splitting) of small-bore tubing in heat exchangers and boilers. Based on total number of tubes inspected at that time, engineering decisions normally led to either a risky approach involving possible unscheduled shutdowns or a too conservative approach where tubes were plugged or replaced too early at a high cost to the petrochemical industry. As a result the local petrochemical industry now adopts and uses field portable inspection systems to thoroughly inspect small-bore tubing. These field portable systems provide the capability of four NDT techniques, which are Remote Field Eddy Current Testing (RFT), Eddy Current Testing (ET), Magnetic Flux Leakage (MFL), and Ultrasonic- Internal Rotary Inspection System (IRIS). They all operate on one hardware and software platform. These systems allow for fast screening (around 400 tubes per day) with one technique with the ability to simply change a probe head and validate accurately defective areas with a more accurate method. In this manner high risk or over conservatism in replacement decisions can be avoided. Detail description of each technique will be explained below.

REMOTE FIELD EDDY CURRENT TECHNIQUE

Remote Field Eddy Current Inspection is an electromagnetic technique that is well adapted to the inspection of small-bore ferromagnetic tubes such as carbon steel. In industry, it is now the method of choice for boilers and heat exchangers tube examination because of its low frequency (typically 50-1000Hz).
The basic RFT probe [1] consists of two coils in a send-receive configuration (Figures 1A, 1B & 1C). The exciter coil, energized with a low frequency alternating current, sends a signal to the detector coil spaced around two and half tube diameters away. The field emitted by the exciter coil passes through the tube wall to the outside of the tube, propagates axially, and then transits back through the wall to arrive at the detector coil. Where the tube grows thin, there is effectively less shielding. Hence the field arrives with less time delay (greater phase) and less attenuation (greater amplitude). Phase and amplitude traces are generated as the probe is pulled through the tube and are used to detect and size metal loss
RFT uses a low frequency signal which allows electromagnetic energy to penetrate the tube walls so that external and internal flaws can be detected with approximately the same sensitivity.

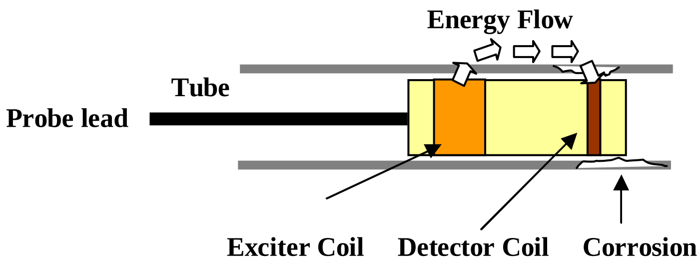


Figure 1A - Schematic of RFT probe

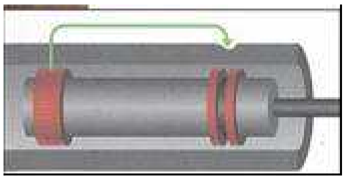


Figure 1B - RFT Field inside boiler tube

Figure 1C - Actual RFT boiler probe

Flaw sizing with RFT is done using the Voltage-Plane curves (Figure 2). These curves are used to size tube wall loss but not pits. The curves relate flaw depth, flaw length, and the flaw circumference to the phase of the remote field signal. Inaccuracies result because the geometry of the actual flaw is not defined as in the calibration defects. Ultrasonic IRIS is therefore used to verify the RFT measurements.

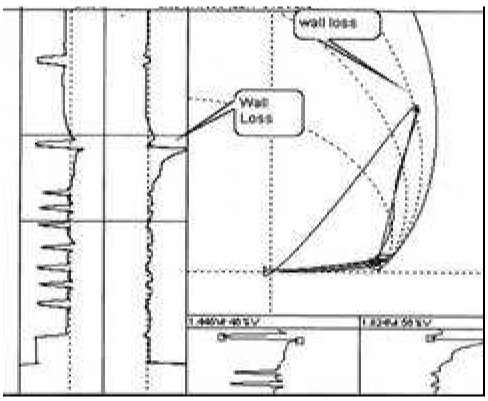


Figure 2 – Voltage-Plane Curve

EDDY CURRENT TECHNIQUE

Eddy Current technique is an electromagnetic technique that is adapted to the inspection of small-bore non-ferromagnetic heat exchanger tubes such as stainless steel, titanium, copper, brass, copper-nickel alloys, inconel, etc.

Eddy Current (ET) [2] is based on the principles of electromagnetic induction. This process includes a test coil (Figures 3A & 3B) through which a varying or alternating current is passed. A varying current flowing in a test coil produces a varying electromagnetic field about the coil. This field is known as the primary field. When an electrically conductive test object is placed in the primary field, an electrical current will be induced in the test object. This current is known as the **eddy current.** Eddy current flow in the test material produces a secondary electromagnetic field in the material that opposes the primary electromagnetic field. The magnitude of the secondary electromagnet field is directly proportional to the magnitude of the eddy current. When eddy current varies, secondary electromagnetic field also varies. Hence the impedance of the coil changes as the electromagnetic field interacts with the material. Characteristic changes in test object such as conductivity, permeability and geometry will cause eddy current to change. Variations of eddy current are reflected to the test coil by changes in the primary electromagnetic field.

Figure 3A - Eddy Current Probes

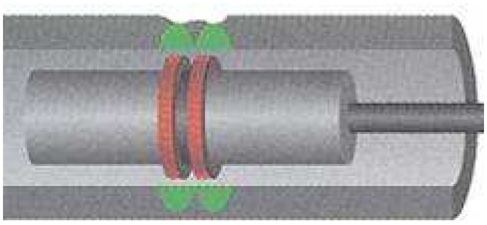


Figure 3B - Eddy Current Field inside small-bore tube

Typical eddy current instrument contains 4 frequencies in both differential and absolute modes. The differential mode detects pits and cracks and the absolute mode detects gradual wall loss. The multi frequency testing is done for two reasons:

1. To differentiate between defects and metallic deposits. This is essential because metallic deposits can produce eddy current signals that resemble defect signals. Improper resolution of signals will result in unnecessary plugging of tubes.
2. To detect defects under the support plates. This is done by using a two-frequency mix to cancel the support plate signal and detect defects under the support plate

FLUX LEAKAGE TECHNIQUE

Magnetic Flux Leakage Technique is an electromagnetic technique [3] that is adapted to the inspection of small-bore ferromagnetic heat exchanger tubes such as carbon steel. The MFL probe consists of a magnet with two types of magnetic pickups: coil type and Hall element (Figure 4). The coil type sensor picks up the rate of change of flux while the Hall type picks up absolute flux. The coil detects small defects that cause perturbations in the flux (see Fig 4). The rate of change of flux induces an output voltage (Faraday's Law) which is read by the MFL instrument. The Hall element sensor is used to detect gradual wall loss.
The output of the MFL coils is related to change of flux caused by the defect, but not the defect size. Hall Element measures the absolute flux and can be used for sizing wall loss type flaws (not pits).

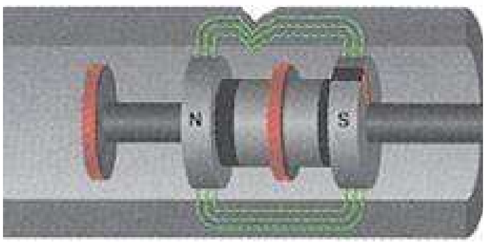


Figure 4 – MFL Probe showing magnetic leakage field

ULTRASONIC IRIS TECHNIQUE

Ultrasonic Internal Rotary Inspection System (IRIS) is based on the principle of measuring thickness using ultrasonic waves. The IRIS probe [4] consists of an ultrasonic transducer that is lined up in the centerline of the tube and incident on a rotating mirror (Figures 5A & 5B). The mirror reflects the beam in the radial direction as it rotates in the tube. The IRIS probe scans the entire circumference of the tube as it is pulled out of the tube.

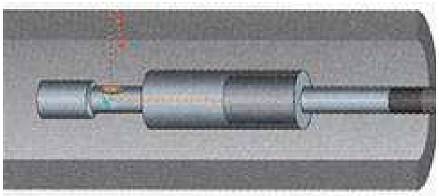


Figure 5A - Schematic of IRIS probe

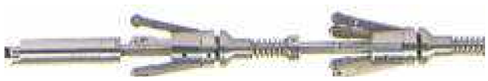
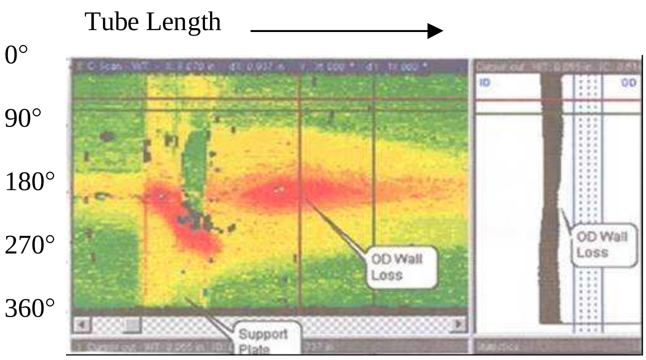


Figure 5B - Actual IRIS boiler probe

The IRIS method is mostly used for inspection of carbon steel tubes and is sometimes used in non-ferromagnetic tubes for defect verification. The method is very accurate for thickness measurement as well as detecting ID and OD pits. IRIS will, however, miss pinholes and cracks. The IRIS display includes the cross-section of the tube and a C-scan of the tube (see Figure 6).



C-scan Presentation Cross Section

Figure 6 - IRIS display includes the C-scan and the tube cross-section - OD wall loss in carbon steel tubing

CALIBRATION

We will focus on RFT and IRIS techniques due to the nature of the field case study that we will discuss in this paper.

To calibrate the instrument for RFT [5] testing, a calibration tube must be of same material and size to be tested. The calibration tube contains man made defects to simulate corrosion. Normally, the man made defects are used with various depths such as 20%, 40%, 60%, to establish calibration curves. The calibration curves are used to compare unknown signals to artificial defects to estimate actual wall loss. For IRIS [6] testing, calibration must be done on known wall thickness of same material tube (see Figures 7A &7B).

Figure 7A **-** RFT Calibration Run

Figure 7B **-** Technicians calibrating for RFT & IRIS

FIELD TRIALS

Field trials of this system were conducted on more than eight thousands tubes of several high pressure boilers at several locations in local petrochemical industries. The examinations were performed on ferrous tubing exhibiting general corrosion and pitting.

The trials were successfully completed and general corrosion and pitting corrosion were easily detected.

INSPECTION TECHNIQUES

The tubes were screened with RFT to locate areas of wall loss. These areas were then followed up with IRIS to determine actual wall loss. The RFT method is relatively quick to perform but cannot detect pitting unless a sizable volumetric wall loss is associated. On the other hand, IRIS provides a map of the tube wall thickness and can detect internal wall loss or external wall loss. The RFT results are given in percentage of wall loss, as this is averaged around the whole circumference, while IRIS results are given as the minimum wall thickness reported for a tube area.

EXAMINATION RESULTS

Generating tubes:

RFT and IRIS were used to examine this section of the boiler. The analysis of the examination data showed indications on 6 tubes out of 1206. The minimum wall thickness measured was 0.078”. “T” min was 0.0965”.

Boiler Side Wall:

This section of the boiler was examined using IRIS and RFT. The analysis of examination data revealed no indications on any of the 100 tubes tested..

Screen tubes:

RFT and IRIS were used to examine this section of the boiler. The analysis of examination data revealed indications on only 2 tubes out of 68. The minimum wall thickness measured was 0.110". "T" min was 0.0965".

Furnace Side:

This section of the boiler was examined using RFT. The analysis of examination data revealed no indications on any of the 108 tubes tested. It should be noted that the extent of the testing on these tubes includes only the Roof and Side wall sections. The Floor section of these tubes could not be examined because of the limited length of the probe cable.

Baffle Wall:

This section of the boiler was examined using IRIS. The analysis of examination data revealed no indications on any of the 85 tubes tested. .

Boiler Rear Wall

IRIS was used to examine 1 of 24 tubes on this section of the boiler. The analysis of examination data revealed no indications. The remaining 23 tubes could not be tested as the RFT and IRIS probes did not fit into the tubes.

Color Printout Samples of the RFT& IRIS Examinations

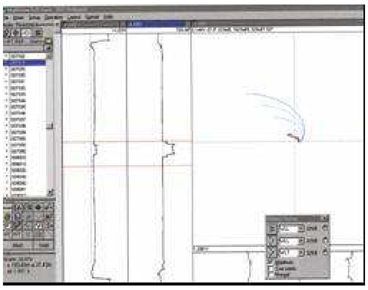


Figure 8A – RFT Indication of 32% Wall Loss

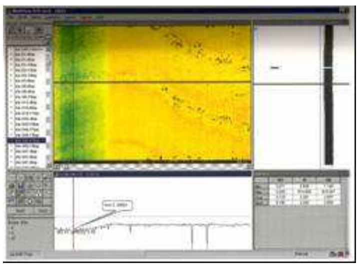


Figure 8B –IRIS Indication of corrosion

CONCLUSIONS

Based on the results of the field trials data, a system providing multiple NDT techniques provides a qualitative and fast screening (around 400 tubes per day) with one technique with the ability to simply change a probe head and validate accurately defective areas with a more quantitative method. In this manner high risk or over-conservatism in replacement decisions can be avoided.

INSPECTION RECOMMENDATIONS

For boiler tubing inspection use:

- RFT as screening technique covering 100% of tubing
- IRIS as a measuring tool to verify RFT indications and to measure tube wall thickness and to determine pitting size. This is used only on the tubes previously identified by RFT.

For heat exchanger tubing inspection use:

- MFL as screening technique covering 100% of exchanger ferrous tubing looking for small size corrosion pitting.
- RFT as screening technique covering 100% of exchanger ferrous tubing looking for large size corrosion pitting and wall thinning.
- ET as screening technique covering 100% of exchanger non-ferrous tubing looking for small size/large corrosion pitting, cracks and wall thinning.
- IRIS as a measuring tool to verify MFL, RFT & ET indications and to measure tube wall thickness and to determine pitting size. This is used only on the tubes previously identified by the above screening techniques.

ACKNOWLEDGEMENT

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