NDE technologies for the examination of heat exchangers and boiler tubes – principles, advantages and limitations

H M Sadek

Several NDE examination methods are currently being used to inspect heat exchangers and boiler tubes. The tube material of this equipment is made from various ferromagnetic and non-ferromagnetic alloys. The tubes’ sizes vary from 0.5-3.5 inches in outside diameter and from 0.028-0.120 inches in wall thickness.

This paper outlines the principles, applications, advantages and limitations of each of the following NDE methods used for these inspections:
- Eddy Current (ET).
- Remote Field Eddy Current (RFT).
- Partial Saturation Eddy Current (PSET).
- Flux Leakage (FL).
- Internal Rotating Ultrasonic Inspection (IRIS).
- Laser-Optic.

Eddy current examination method

Principles

This method employs a probe (bobbin type) that contains one or more AC coils, which induces an electrical field around the tube. The impedance of the coil/coils changes as the electromagnetic field interacts with the material being tested.

The coil is placed in the tube and the instrument is calibrated on a reference standard having known, machined discontinuities. The probe is pulled through the tube and variations in coil impedance are recorded. These changes, which are related to the types and sizes of discontinuities, can be displayed on a screen for final analysis and evaluation.

Phase analysis and signal amplitude are utilised to assess the depth, origin and size of flaws.

Conventional eddy current examination can be performed in either the differential or absolute modes. The differential mode detects small discontinuities such as pitting and cracking, whereas the absolute mode detects wall loss.

Advantages
1. Inspection speed up to approximately 60 feet per minute.
2. Distinguishes between ID and OD flaws.
3. Reliability and accuracy of test results.
4. Can detect gradual wall thinning and localised flaws.
5. Provides both phase and amplitude information.
6. U-bend tubes can be inspected with some radius limitation.
7. Permanent records can be obtained on test results.
8. By using multi-frequency techniques, flaws under the support plates (baffles) can be found and evaluated accurately.

Limitations
1. Limited to only non-magnetic tube material.
2. Application is limited to 3 inch tube sizes and 0.125 wall thickness.
3. Test instrumentation, systems and software packages could be very expensive.
4. Requires high inspection skills for data analysis and evaluation.
5. Pin holes are difficult to detect and evaluate.
6. Discontinuities adjacent to end sheets are difficult to detect.
7. Tubes must be cleaned.

Remote field eddy current examination method

Principles

The remote field inspection method is based on the transmission of an electromagnetic field through the tube material. The exciter coil generates eddy currents at a low frequency in the circumferential direction.

The electromagnetic field transmits through the thickness and travels on the outside surface. A receiver coil placed in the remote field zone of the exciter picks up the field. The separation between the two coils is two to four times the tube’s inside diameter.

Any flaws or defects in the vicinity of the exciter or the receiver coil will cause a disturbance in the through-transmission path. Discontinuity sizing with remote field eddy current is carried out using the voltage plane curves. These curves measure wall loss and relate discontinuity depth, length and circumference to the phase of the remote field signal.

Advantages
1. Can inspect ferromagnetic tubes up to 3.5 inches in diameter with 0.125 inches wall thickness.
2. Inspection speed (up to approx. 40 feet per minute).
3. Can detect large-area discontinuities such as steam erosion and baffle wear.
4. Amplitude changes in the signals sensed are not speed-sensitive.
5. Flexible probes can be used to inspect and travel through U-bend areas.
6. Permanent records can be obtained on test results.

Limitations
1. Some limitation to distinguishing ID from OD defects.
2. Evaluation of small flaws such as pits can be difficult.
3. Impingement erosion and wall loss detectability is limited to approximately 20% and greater.
4. Requires high inspection skills for data analysis and evaluation.
5. Instrumentation and test probes can be very expensive.
6. Tubes must be cleaned.
7. Inaccuracy in test results could occur if a discontinuity encountered differs in geometry from calibration discontinuities.
8. Flaws under support plates and adjacent to end sheets can be difficult to detect.

Partial saturation eddy current examination method

Principles

This inspection is applicable to partially ferromagnetic materials such as nickel alloy or ferritic austenitic and thin ferromagnetic materials such as ferritic chromium molybdenum stainless steel.

The full saturation probe contains conventional eddy current coil and a magnet. The magnetic field of the magnet saturates the material. Once saturated the relative permeability of the material drops to one.

The strength of the magnets used for saturation is very critical in this technique. Weaker magnets will not saturate the material and will produce a high noise to signal ratio.

The application of a full saturation eddy current technique depends on the permeability of the material, tube thickness and diameter.

Advantages

1. Inspection speed up to approximately 60 feet per minute.
2. Distinguishes between ID and OD flaws.
3. Reliability and accuracy of test results.
4. Non-ferromagnetic and slightly ferromagnetic tubes can be examined.
5. Permanent records can be obtained on test results.
6. Sizing of outside surface discontinuities can be done similar to conventional eddy current.

Limitations

1. Ensuring that the tube material is fully saturated.
2. Inside surface discontinuities cannot be sized with signal phase analysis. The depth of the discontinuity does not influence the phase.
3. Tubes must be cleaned.
4. Instrumentation and test probes can be very expensive.
5. Requires high inspection skills for data analysis and evaluation.

Flux leakage examination method

Principles

The probe consists of a magnet and two flux leakage sensors, which set up a flux field in the tube wall as it passes through the tube. The field fluctuates when it encounters a flaw. The flux rate fluctuation effect is picked up by the coils and displayed on the display apparatus and chart recorder.

A Hall effect element can be added as a combined-type probe, which is used to detect absolute flux such as gradual wall loss. The output of the Hall effect detector depends on the orientation of the sensor in the probe relative to the discontinuity and whether the location of the discontinuity is on the inside or outside surface.

The output of the magnetic flux leakage coils is related to the change of flux caused by the discontinuity but not the discontinuity size.

Advantages

1. Distinguishes ID from OD flaws.
2. Can inspect ferromagnetic tubes up to 3.5 inches in diameter and 0.120 inches wall thickness.
3. Permanent records can be obtained on test results.
4. Instrumentation can withstand adverse field conditions.
5. Can detect flaws under support plates as well as flaws adjacent to end sheets.

Limitations

1. Detectability is limited to flaws 20% and greater.
2. Very sensitive to inspection speed. Accuracy of test results can fluctuate with probe speed.
3. Instrumentation and probes could be very expensive.
4. Tubes must be cleaned. Scale or deposit can fill a flaw which will make it difficult to qualify its depth.
5. Requires high inspection skills for data analysis and evaluation.
6. Inspection speed up to approximately 15 feet per minute.
7. Longitudinal or axial flaws can be detected.
8. Cannot accurately size discontinuities.

Internal rotating ultrasonic inspection method

Principles

This examination method employs an ultrasonic immersion pulse echo technique. The ultrasonic transducer is contained in a test head, which fits into and is centered in the tube to be inspected.

The ultrasonic pulses are emitted along a path parallel to the tube axis. A rotating 45-degree mirror then reflects these pulses so that they are directed radially on to the tube wall.

Reflections from the inner and outer walls follow the same path back to the transducer. The time interval between the first echo – from the internal surface of the tube – and the first echo – from the outside surface of the tube – can be used to represent the tube wall thickness.

As the mirror rotates, the ultrasonic beam is traversed around the tube circumference and each successive pulse is mapped out as a horizontal scan line on the instrumentation screen. A typical system can generate approximately 190 readings per revolution and approximately 2400 revolutions per minute.

Advantages

1. 100% tube inspections converge (end to end).
2. Wall loss and pit detectability’s accuracy and sizing plus or minus 0.002 inch.
3. Can examine both ferromagnetic and non-ferromagnetic tubes.
4. Distinguishes ID from OD flaws.
5. Can inspect tube sizes up to 3.0 inches with wall thickness up to 0.25 inches.
6. Can inspect U-bend tubes with some radius limitations.
7. Final reports with applicable software can be generated instantly.
8. Permanent records can be obtained on test results.

Limitations

1. Coupling medium (water) is needed at all times.
2. Tubes must be thoroughly cleaned.
3. Test speed is approximately 15 feet/minute.
4. Instrumentation and probes could be very expensive.
5. Requires high inspection skills for data analysis and evaluation.
6. Cannot detect circumferential cracks.

Laser optic examination method

Principles

This inspection method utilises the principle of optical triangulation. The probe used in laser-based surface mapping systems employs a minute laser beam that is projected onto the surface of the tube and operates like a ‘laser caliper’, measuring the internal dimensions of the tube rather than merely indicating the presence of a flaw.

By rotating the laser sensor as the probe is drawn through the tube, a detailed and quantitative map of the inside surface topography is generated.
A small beam of light is projected at near-normal incidence onto the target surface. Receiving optics image this spot of light onto a single-axis lateral-effect photo detector.

Due to the fact that receiving and transmitting optics are at different angles, changes in target proximity are converted to lateral movement on the photo detector. The displacement of the light spot on the detector is equal to the depth of a pit.

**Advantages**
1. Can detect and quantify inside surface of tubing for physical anomalies such as corrosion and deformation.
2. Can inspect approximately 18 tubes (8 metres in length).
3. Can inspect tubes with sizes from 0.44 inches up to 5.5 inches.
4. Real-time inspection.
5. Permanent records can be obtained on test results.
6. The system can sample several thousand data points during an inspection.

**Limitations**
1. Sensitive and applied to only ID flaws.
2. The probe is durable and must be handled with care.
3. Instrumentation and probes can be very expensive.
4. The tubes must be cleaned.
5. New tubes made of stainless steel, for example, are difficult to inspect due to mirror-like surface condition.
6. Cannot provide wall thickness measurements.

In conclusion, no single NDE technique can be applied for testing all heat exchangers or boiler tubing materials. Perhaps in some applications, more than one technique is needed.

NDE inspectors should be aware of the advantages and limitations of each examination method. Proper technique selection leads to reliable tests and achievement of accurate results.

**References**