# API RP-586 Section 1

**Heat Exchanger Tubing Inspection** (First Edition)

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1.0 INTRODUCTION

1.1 Non-Destructive Testing is used extensively for the condition monitoring and remaining life estimates of heat exchanger tubing. This Recommended Practice outlines the principles, applications, capabilities and limitations of commercially available NDE methods for shell and tube and air-cooled heat exchangers. NDE methods are used to inspect tube bundles for the onset and progression of material damage for the fitness for service and remaining life of heat exchanger tubes.

2.0 SCOPE

2.1 This recommended practice is limited to internal inspection of tubing for out of service heat exchangers. Plate heat exchangers, Heat exchanger shells and components and helical tubing are not in the scope of this document. Inspection of plate heat exchangers, heat exchanger shells and components (e.g. channels, cover, nozzle, tubesheet) and helical tubing are not in the scope of this document. See the pressure vessel section of this document (Pressure Vessel section pending).

2.2 This document covers in-service heat exchanger tubing damage mechanisms found in API RP-571 and other applicable codes Codes and specifications. Tube diameters and wall thicknesses will vary according to applicable standards. The NDE methods mentioned in this recommended practice are intended for ferrous, ferromagnetic tubes with outside diameters from 0.500 to 2.000 in. [12.70 to 50.80 mm], with wall thicknesses in the range from 0.028 to 0.134 in. [0.71 to 3.40 mm] or non-ferrous and alloy heat exchanger tubing materials tubes with outside diameters to 31/8 in. (79.4 mm), inclusive, and wall thicknesses from 0.017 in. (0.432 mm) to 0.120 in. (3.04 mm), inclusive, or as otherwise stated in ASTM product specifications or qualified NDE procedures.

2.3 All NDE applications in this document are deployed while the heat exchanger is out of service and with internal access to the heat exchanger tubes. An appropriate level of heat exchanger cleaning and job preparations are assumed for adequate inspection performance (see section 11.0).

3.0 ORGANIZATION AND USE

3.1 The information contained in this Recommended Practice is provided in a format shown below. Heat exchanger design, tube types, materials of construction and damage mechanism failure modes are briefly described in relation to the selection and use commonly accepted NDE method(s) for each heat exchanger design and tubing material combination:
1. Shell and tube and air-cooled heat exchanger designs
2. Heat exchanger tube types
3. Heat exchanger tube materials
4. Heat exchanger damage mechanism failure modes
5. Heat exchanger tube flaws
6. NDE method selection
7. NDE method definitions and descriptions

Detailed information for heat exchanger designs, materials of construction, damage mechanisms and NDE method guidance on use can be found in the referencing literature (see section 4.0).

3.2 NDE method and techniques are defined and explained in Appendix A.

3.3 NDE method and techniques selection tables are shown in Appendix B.

3.4 Competent NDE operators are critical to the data quality of electromagnetic, ultrasonic and other advanced NDE tubing inspection methods. The inspection effectiveness of the NDE methods and techniques of this document are dependent on the training, experience and independent qualification testing of the NDE tubing inspection technician. The NDE operator should be trained and certified to ASNT Level II or III or equivalent in the tubing inspection method(s) deployed. If the tubing inspection method is not supported by an industry recognized certification, the operator should be trained and certified to the equipment manufacturer and/or an approved employer-based training and certification program.

3.5 The owner/user should consider the value of performing a baseline NDE inspection before the heat exchanger is placed in service in order to assist in interpreting in-service inspection data.

4.0 REFERENCES

4.1 NORMATIVE REFERENCES

4.1.1 ASTM E2096/E2096M–16 Standard Practice for In Situ Examination of Ferromagnetic Heat-Exchanger Tubes Using Remote Field Testing

4.1.2 ASTM E309-16 Standard Practice for Eddy Current Examination of Steel Tubular Products Using Magnetic Saturation
4.1.3 **ASTM E243-13 Standard Practice for Electromagnetic (Eddy Current) Examination of Copper and Copper-Alloy Tubes**

4.1.4 **ASTM E426-12 Standard Practice for Electromagnetic (Eddy-Current) Examination of Seamless and Welded Tubular Products, Titanium, Austenitic Stainless Steel and Similar Alloys**

4.1.5 **ASTM E570-15e1 Standard Practice for Flux Leakage Examination of Ferromagnetic Steel Tubular Products**

4.1.6 **ASTM E571-12 Standard Practice for Electromagnetic (Eddy-Current) Examination of Nickel and Nickel Alloy Tubular Products**

4.1.7 **ASTM E690-15 Standard Practice for In Situ Electromagnetic (Eddy Current) Examination of Nonmagnetic Heat Exchanger Tubes**

4.1.8 **ASTM E2906/E2906M-13 Standard Practice for Acoustic Pulse Reflectometry**

4.1.9 **API RP-571 Damage Mechanisms Affecting Fixed Equipment in the Refinery Industry (2011)**

4.1.10 **API RP-572 (2016) Inspection Practices for Pressure Vessels**

4.2 **Informative References**


4.2.2 **9th Edition TEMA Standards**


5.0 **NDE ABBREVIATIONS**

5.1 APR: Acoustic Pulse Reflectometry

5.2 BWG: **Birmingham Wire Gauge**

5.3 ECT: Eddy Current Testing

5.4 ECA: Eddy Current Array **Testing**

5.5 FS-ECT: Full Saturation Eddy Current Testing

5.6 ID: Inside Diameter

5.7 IRIS: Internal Rotating Ultrasonic Inspection System

5.8 MFECT: Multi-Frequency Eddy Current Testing—**Tubing**
5.8 MFL: Magnetic Flux Leakage Testing
5.9 MFA: Magnetic Flux Leakage Array Testing
5.10 NFT: Near Field Testing
5.11 NFA Near Field Testing Array Testing
5.12 OD: Outside Diameter
5.13 PS-ECT: Partial Saturation Eddy Current Testing
5.14 RFT: Remote Field Eddy Current Testing
5.15 RFA: Remote Field Testing Array
5.16 R-ECT: Rotational Eddy Current Testing
5.17 RVI: Remote Visual Inspection
5.18 SECT: Segmented Eddy Current Array Testing

5.1 Definitions:

See Appendix A for NDE definitions.

6.0 HEAT EXCHANGER PURPOSE, DESIGN AND OPERATION

6.1 Shell and Tube Heat Exchanger

Shell and tube Heat exchanger is the most common type of heat exchanger in oil refineries and other large chemical processes, and is suited for higher-pressure applications. This type of heat exchanger consists of a pressure vessel shell with an internal tube bundle that is typically supported by tube sheets and intermittent tube baffles. Heat is transferred from the warmer fluid to the other through the tube walls to the colder fluid with heat transfer taking place from either from tube side to shell side or vice versa. The tube bundle may be composed of several types of tubes: plain, longitudinally finned, low finned, or twisted tube (not in the scope of this document).

6.1.1 Two fluids, of different inlet temperatures, flow through the heat exchanger. One flows through the tubes (the tube side) and the other flows outside the tubes but inside the shell (the shell side). Heat is transferred from one the warmer fluid to the other colder fluid through the tube walls, with heat transfer taking place either from tube side to shell side or vice versa. The fluids can be either liquids or gases on either the shell or the tube side. See figure 1.

6.1.2 The tube pitch (center to center distance of adjoining tubes) is typically a minimum of 1.25 times the tube outer diameter or larger. The A small tube pitch usually limits external inspection access to the accessible outer tubes of a tube bundle. Subsequently NDE inspection of remaining heat exchanger tubes is limited to internal tube inspection methods.

6.1.3 Typically, the ends of each tube are terminated through holes in a tube sheet that is made of the same or different material than the tubes. The tubes are mechanically
rolled or welded into tube sheet face. Tubes may be straight or bent in the shape of a U, called U-tubes. (See figure 2).

6.1.4 Baffles (or Tube Support Plates) used in shell and tube heat exchangers serve two purposes: The first is to direct fluid across the tube bundle, providing an increase in the overall heat transferred. The second purpose is to provide additional tube support to prevent sagging of the tubes (over a long span) and to prevent or minimize the tubes from vibrating within the tube bundle.

Figure 1: Straight-tube heat exchanger

Figure 2: U-Tube Heat Exchanger
6.2 NDE of Shell and Tube Exchanger Tubing

Most of the electromagnetic NDE techniques provide an estimated tube wall thickness estimation as compared to that of a known calibration tube. The estimated wall thickness is also an average or of the entire wall circumference as the single magnetic field provides a single result for the entire tube circumference. This however can be improved using a “segmented” array probe that uses multiple small electromagnetic test coils around the circumference of the probe. (See Appendix A for details).

6.2.1 The Internal Rotating Inspection System (IRIS) is an effective NDE method for measuring actual tube wall thickness. However ultrasonic tubing inspection requires the highest level of tube cleaning. Tube plugs and a water fill are required to maintain UT coupling. IRIS probe speed is slow; typically 10-25% of that for slower than electromagnetic testing techniques. A balanced approach of complimentary NDE methods such as MFET and IRIS can provide a representative mix of qualitative electromagnetic wall thickness measurements and quantitative IRIS tube wall thickness measurements for a given tube bundle inspection. See section A9.

6.2.1 NDE Methods for Shell and Tube Heat Exchanger Tubing

Shell and tube exchanger tubing is inspected primarily using two different NDE techniques, electromagnetic and ultrasonic. Most of the available techniques are electromagnetic such as eddy current testing (ECT) while IRIS is the most commonly applied ultrasonic technique. The techniques provide different types of results that the user needs to be aware of to adequately evaluate heat exchanger tubing condition.

6.2.2 Common shell and tube heat exchanger tubing NDE methods for straight shell and tube exchanger tubes include: (See Appendix A for method definitions and details).

1. Multi-Frequency Eddy Current Testing (MFECT-ECT)
2. Segmented Eddy Current Array (ECA)
3. Remote Field Eddy Current (RFT)
4. Partial Saturation Eddy Current (PSET)
5. Full Saturation Eddy Current (FSET)
6. Magnetic Flux Leakage Testing (MFL)
7. Magnetic Flux Leakage Array Testing (MFA)
8. Near Field Testing (NFT)
9. Near Field Testing Array (NFA)
10. Internal Rotary Inspection System (IRIS)
11. Acoustic Pulse Reflectometry (APR)
12. Tube end calliper

6.2.3 The Internal Rotating Inspection System (IRIS) is an effective NDE method for measuring actual tube wall thickness. However ultrasonic tubing inspection requires the highest level of tube cleaning. Tube plugs and a water fill are required to maintain UT coupling. IRIS probe speed is slow; typically 10-25% of that for slower than electromagnetic testing techniques. A balanced approach of complimentary NDE methods such as MFET ECT and IRIS can provide a representative mix of qualitative volumetric electromagnetic wall thickness measurements and quantitative IRIS tube wall thickness measurements for a given tube bundle inspection. See section A9.

6.2.4 U-Bend Tubing

U-bend tubing can be inspected by remote visual inspection. Each of the straight tube NDE methods mentioned in 6.2.2 can partially inspect the straight sections of the U-tube. The U-bend itself is not inspectable by these techniques unless a special probe configuration is used. Special probes may be found in the multi-Frequency eddy current, partial saturation EC, and RFT single exciter coil categories. Acoustic Pulse Reflectometry can detect blockage >15% of the tube diameter or through wall holes in U-bends regardless of type of tubing material.

6.2.5 Detailed inspection method selection is discussed in the NDE METHOD BY DAMAGE MECHANISM Failure MODE CATEGORY, TUBE TYPE & MATERIAL in section 10.0 below.

6.3 Air Cooled Heat Exchangers

An air-cooled heat exchanger (ACHE) contains a tube bundle of straight, single pass finned tubes that terminating terminate in header boxes. See figure 3 and 4. The fins are most commonly spirally wound aluminum strips with 275 to 433 fins/m. There are two main types of wound fin which are usually known as L-fin and G-fin. There are several variations of the former type—single, overlapped, and knurled, with increased differential expansion between the fin and the core tube with increasing temperature. which increases with temperature due to differential expansion between the fin and the core tube. Embedded fins (G-fins) are wound into a groove in the core tube which is then peened back to provide a mechanical bond. This gives better heat transfer but
requires a thicker core tube. Integral fins extruded from an aluminum or galvanized steel sheath are often used. Embedded fins are less common. Core tubes may be carbon steel, stainless steel or various alloys and are usually of one inch in diameter. Tube lengths vary to suit the installation, which can be over the span of a pipe rack, but generally do not exceed 50 feet (15 m).

6.3.1 Header boxes are normally rectangular in cross-section and may have either threaded plugs opposite each tube, or removable cover plates for out of service cleaning and inspection access. The air is moved over the tubes in a single crossflow pass by axial flow fans for a forced or induced air draught.

![Figure 3. Typical forced draught air cooled heat exchanger](image)

![Figure 4: O.D. of Finned Air Cooled Heat Exchanger tubes - Fouled vs. Clean](image)
6.3.2 Air cooler ACHE-tubes cannot be inspected from the exterior except for exposed tubes where limited access areas between the tube sheet and the start of the tube fins. Radiography may be used for spot external inspection of accessible outer most tubes.

6.3.3 Erosion-corrosion at the tube inlets (tube end thinning) is a common problem with air-cooled heat exchangers. This damage can be found by visual inspection through the header-box plug holes, or directly if the header box has a removable cover plate. Fiber optic devices and borescopes may be used for this type of inspection. Tube end thinning may also be measured by special mechanical calipers.

6.3.4 Tube roll leaks at the tube sheet and vibration induced cracking are covered in API RP-572.

6.4 NDE of Air Cooler Tubing

The preferred NDE methods for air cooler heat exchanger tubes include: (See Appendix A for method definitions and details).

1. Near Field Testing Array
2. Near field Testing
3. Magnetic Flux Leakage Testing
4. Magnetic Flux Leakage Array Testing
5. Internal Rotary Inspection System
6. Visual Inspection
7. Tube end calliper
8. Acoustic Pulse Reflectometry

6.4.1 The Internal Rotating Inspection System (IRIS) is an effective NDE method for measuring actual tube wall thickness. However ultrasonic tubing inspection requires the highest level of tube cleaning, tube plugs and water fill is required to maintain UT coupling, and IRIS probe speed is slow; typically 10-25% of that for electromagnetic testing. IRIS probe speed is slow, typically 10-25% of that for slower than electromagnetic testing techniques. A balanced approach of complimentary NDE methods such as MFET ECT and IRIS provide a representative mix of qualitative volumetric electromagnetic wall thickness measurements and quantitative IRIS tube wall thickness measurements for a given tube bundle inspection. See section A9.
6.4.2 A detailed Inspection method selection is discussed in the NDE METHOD BY DAMAGE MECHANISM FAILURE MODE CATEGORY, TUBE TYPE & MATERIAL section 10.0 below.

7.0 TUBING FORMS

The following tubing forms are used for shell and tube or air-cooled heat exchangers. (See referencing materials for details)

1. Straight tube non-finned (Prime Surface)
2. Straight tube finned (aluminum or galvanized steel fins)
3. Straight tube skip finned, rolled fins
4. Straight tube skip finned, rolled fins, internally and externally integral finned
5. U-bend tubes
6. Twisted tube Ferrous and non-ferrous
7. Helical tubes

7.1 Tubing Materials and Electromagnetic Properties

The following tubing materials are typically used for shell and tube and air-cooled heat exchangers with finned or non-finned, 0.375”-1.00” diameter, 12-18 BWG (Boiler Wall BWG).

1. Carbon Steel, (welded), (cold drawn), no fins (ferromagnetic)
2. Carbon Steel, (welded), aluminum or galvanized steel fins (ferromagnetic)
3. Duplex SS, no fins (ferromagnetic)
4. Austenitic Austenitic SS, welded or non-welded, no fins (non-ferromagnetic except for permeability increases from work hardening or metallurgical changes)
5. Admiralty Brass, no fins (non-ferromagnetic)
6. Admiralty Brass, integral fins (non-ferromagnetic)
7. Copper, integral fins (non-ferromagnetic)
8. Copper (non-ferromagnetic)
9. Copper Nickel (non-ferromagnetic)
10. Titanium (non-ferromagnetic)
11. Inconel (non-ferromagnetic)
12. Hastelloy (non-ferromagnetic)
13. Monel (Ferromagnetic at ambient temperature, non-ferromagnetic at elevated temperatures)

8.0 TUBING FAILURE MODES

See API RP-571 DAMAGE MECHANISMS EFFECTING Fixed Equipment in the REFINING Industry. Primary tubing failure from these damage mechanisms include: (See API RP-571 for details).
1. Uniform Internal or external wall loss
2. ID or OD pitting
3. ID grooving
4. Galvanic corrosion
5. Erosion
6. Erosion/Corrosion
7. Impingement external wall loss
8. Tube end erosion
9. Cracking (thermal, fatigue, environmental (e.g. Stress Corrosion Cracking))
10. OD baffle wear (baffle fretting)
11. Dents, gouges
12. Vibration damage: Tube to tube, tube to shell,
13. Metallurgical changes, dealloying, sigma phase in duplex stainless steel,
14. Tubing weld defects: Lack of penetration, non-fusion, porosity, cracks, foreign material deposits, permeability.
15. Tube to tube sheet weld cracking
16. Through wall holes
18. Tube blockage Tube warpage

9.0 TUBING INSPECTION TECHNIQUES

(See Appendix A for detailed technique descriptions)

1. Multi-Frequency Eddy Current Testing-Tubing
2. Segmented Eddy Current Array
3. Rotational Eddy Current
4. Full Saturation Eddy Current Testing
5. Partial Saturation Eddy Current
6. Remote Field Testing
7. Remote Feld Testing Array
8. Nearfield Testing
9. Near Field Array
10. Internal Rotating Ultrasonic Inspection System
11. Magnetic Flux Leakage Testing/Magnetic Flux Leakage Array
12. Visual Inspection (see API RP-572)
13. Remote Visual Inspection
14. Acoustic Pulse Reflectometry
15. Tube end calliper
10.0 NDE METHOD BY DAMAGE MECHANISM FAILURE MODE CATEGORY, TUBE TYPE & MATERIAL (avg. tube cleanliness = 0.80 fill factor). See Section 11

10.1 Carbon Steel with no fins (ferromagnetic)

1. RFT for ID or OD general or localized wall loss, pitting, circumferential and axial cracking. Does not distinguish tube side.
2. RFT Arrays are the same as RFT except for greater sensitivity to circumferential small pits, cracking in multiple orientations and less sensitivity to unwanted baffle and tube sheets responses. Does not distinguish tube side.
3. IRIS for ID/OD general or localized wall loss and pitting. Identifies tube side. Does not detect cracking. Does not detect through wall holes due to a total loss of back wall reflection. A tube extender or insertion adapter can be used with IRIS to inspect the bare tube area between the header box and the fins.
4. MFL for the detection and qualitative sizing of ID or OD general or localized wall loss, pitting, fretting, and is fairly effective for circumferential cracking. Can distinguish between ID and OD flaw orientations side and position when coils have variable winding that compare external and internal responses based on signal amplitude.
5. MFL Array is the same as MFL except better sensitivity to smaller pits and circumferential cracking by providing circumferential extent.
6. NFT detects ID tube side damage only, including general or localized wall loss, pitting, and axial cracking.
7. NFT Array is the same as NFT except better sensitivity to smaller pits, while providing clock position and circumferential extent of flaws.
8. RVI for detection and optional sizing of ID flaws only. Does not detect general wall loss unless distinguishable features are detected by the 2 dimensional remote image. Special RVI equipment may be used to detect such corrosion.
9. Mechanical inside diameter calipers can be used to detect and measure tube end expansion or wall loss.
10. Twisted tube testing requires a contour compliant eddy current array with a low noise slip ring.

10.2 Carbon Steel, with aluminum or galvanized steel fins (ferromagnetic)

1. NFT for establishing ID tube side damage only: General wall loss, pitting, and axial cracking damage only.
2. NFT Array is the same as NFT except better sensitivity to smaller pits and providing information about flaw clock position and circumferential extent.
3. IRIS for the detection and sizing of ID or OD general wall loss or pitting Does distinguish tube side Will not detect cracking or through wall holes due to a total loss of back wall reflection. A tube extender or insertion...
adapter can be used with IRIS to inspect the bare tube area between the header box and the fins.

4. MFL for the detection and qualitative sizing of ID or OD general or localized wall loss, pitting, and possibly circumferential cracking. Can distinguish between ID and OD flaw orientations side and position when coils have variable winding that compare external and internal responses based on signal amplitude. Does not respond to non-conductive external fins.

5. MFL Array is the same as MFL except better sensitivity to smaller pits, & circumferential cracking, while providing circumferential extent.

6. RVI for detection and optional sizing of ID flaws only. Does not detect general wall loss unless distinguishable features are detected by the 2-dimensional remote image. Special RVI equipment may be used to detect such corrosion.

7. Mechanical inside diameter calipers can used to detect and measure tube end expansion or wall loss.

10.3 Duplex Stainless Steel with no fins (ferromagnetic)

1. PSECT General wall loss, pitting in free span, cracking axial or circ. Loses sensitivity at ferromagnetic support plate

2. FSECT pitting, general wall loss (not accurate on ferromagnetic support plates), cracking axial or circ. IRIS for general wall loss ID, OD. Does not detect cracking or through wall holes due to a total loss of back wall reflection. A tube extender or insertion adapter can be used with IRIS to inspect the bare tube area between the header box and the fins.

3. RFT for general wall loss and large pitting, cracking axial to circ. Less sensitive to axial cracks. ID or OD but does not distinguish between tube sides when coils have variable winding that compare external and internal responses based on signal amplitude.

4. RFT array can detect smaller pits than RFT while providing clock position and circumferential extent.

5. High Frequency RFT (14-32 KHz) to detect sigma phase metallurgical anomalies. Not available in an RFT array.

6. NFT for establishing damage side (based on presence or absence of ID indications)

7. RVI for detection and optional sizing of ID flaws only. Does not detect general wall loss unless distinguishable features are detected by the 2 dimensional remote image. Special RVI equipment may be used to detect such corrosion.

8. Mechanical inside diameter calipers can used to detect and measure tube end expansion or wall loss.
10.4 Duplex Stainless Steel with aluminum fins (ferromagnetic)

1. **PSECT** General wall loss, pitting in free span, cracking axial or circ. Loses sensitivity at ferromagnetic support plate.
2. **IRIS** for general for ID wall loss, OD. **IRIS** should not be used for OD wall loss on finned tubes due to signal noise from the tube fins. Does not detect cracking or through wall holes due to a total loss of back wall reflection. A tube extender or insertion adapter can be used with **IRIS** to inspect the bare tube area between the header box and the fins.
3. **NFT** for establishing ID tube side damage only: General wall loss, pitting, and axial cracking damage only. An 85% fill factor is preferred.
4. **NFT Array** is the same as **NFT** except better sensitivity to smaller pits, provided flaw clock position and circumferential extent. An 85% fill factor is preferred.
5. **RVI** for detection and optional sizing of ID flaws only. Does not detect general wall loss unless special **RVI** equipment is used unless distinguishable features are detected by the 2-dimensional remote image. Special **RVI** equipment may be used to detect such corrosion.
6. Mechanical inside diameter calipers can be used to detect and measure tube end expansion or wall loss.

10.5 **Austenitic** Stainless Steel with no fins (non-ferromagnetic)

1. **MFECT** bobbin coil for ID or OD general corrosion, pitting, or axial cracking.
2. **MFECT array probe** for general corrosion, pitting and cracking at any orientation ID or OD. (e.g. chloride stress corrosion cracking) **IRIS** for ID or OD general wall loss or pitting. Does not detect through wall holes due to a total loss of back wall reflection. A tube extender or insertion adapter can be used with **IRIS** to inspect the bare tube area between the header box and the fins.
3. **RVI** for detection and optional sizing of ID flaws only. Does not detect general wall loss unless special **RVI** equipment is used unless distinguishable features are detected by the 2-dimensional remote image. Special **RVI** equipment may be used to detect such corrosion.
4. Mechanical inside diameter calipers can be used to detect and measure tube end expansion or wall loss.
5. High frequency **RFT** for detecting Sigma Phase damage. Low TRL Technology Readiness Level.
6. Twisted tube testing requires a contour compliant eddy current array with a low noise slip ring (Low commercial availability with conventional ECT and RFT)

10.6 **Austenitic SS** with fins (non-ferromagnetic)

1. **MFECT** for ID or OD general corrosion, pitting or axial cracking ID or OD. Use a prime Frequency that is high enough not to see fins.
2. MFECT array probe for general corrosion, pitting and cracking at any orientation ID or OD
3. IRIS for general wall loss ID, OD at a loss of accuracy. Does not detect through wall holes due to a total loss of back wall reflection. A tube extender or insertion adapter can be used with IRIS to inspect the bare tube area between the header box and the fins.
4. PSEC for general wall loss, pitting or cracking when ferromagnetic deposits or permeability are present.
5. RVI for detection and optional sizing of ID flaws only. Does not detect general wall loss unless special RVI equipment is used. Distinguishable features are detected by the 2-dimensional remote image. Special RVI equipment may be used to detect such corrosion.
6. Mechanical inside diameter calipers can used to detect and measure tube end expansion or wall loss.

10.7 Copper alloy with no fins (non-ferromagnetic)

1. MFECT bobbin coil for ID or OD general corrosion, pitting or axial cracking, dealloying
2. MFECT array probe for ID or OD general corrosion, pitting, axial or circumferential cracking and de-alloying.
3. IRIS for general wall loss ID, OD. Does not detect through wall holes due to a total loss of back wall reflection. A tube extender or insertion adapter can be used with IRIS to inspect the bare tube area between the header box and the fins.
4. RVI for detection and optional sizing of ID flaws only. Does not detect general wall loss unless special RVI equipment is used. Distinguishable features are detected by the 2-dimensional remote image. Special RVI equipment may be used to detect such corrosion.
5. Mechanical inside diameter calipers can used to detect and measure tube end expansion or wall loss.

10.8 Copper alloy (brass Cu-Ni, admiralty brass) with non-integral fins (non-ferromagnetic)

1. MFECT bobbin coil for ID or OD general corrosion, pitting or axial cracking, dealloying
2. MFECT array probe for ID or OD general corrosion, pitting, axial or circumferential cracking and de-alloying.
3. IRIS for general wall loss ID, OD
4. RVI for detection and optional sizing of ID flaws only. Does not detect general wall loss unless special RVI equipment is used.
5. Mechanical inside diameter calipers can used to detect and measure tube end expansion or wall loss.
10.9 Copper alloy (brass Cu-Ni, admiralty brass) with integral fins (non-ferromagnetic)

1. MFECT bobbin coil for ID or OD general corrosion, pitting or axial cracking, dealloying
2. MFECT array probe for ID or OD general corrosion, pitting, axial or circumferential cracking and de-alloying.
3. RVI for detection and optional sizing of ID flaws only. Does not detect general wall loss unless special RVI equipment is used - distinguishable features are detected by the 2-dimensional remote image. Special RVI equipment may be used to detect such corrosion.
4. Mechanical inside diameter calipers can be used to detect and measure tube end expansion or wall loss.

10.10 Competent NDE operators are critical to the data quality of electromagnetic, ultrasonic and other advanced NDE tubing inspection methods. The inspection effectiveness of the NDE methods and techniques of this document are dependent on the training, experience and independent qualification testing of the NDE tubing inspection technician. The NDE operator should be trained and certified to ASNT Level II or III or equivalent in the tubing inspection method(s) deployed. If the tubing inspection method is not supported by an industry recognized certification, the operator should be trained and certified to the equipment manufacturer and/or an approved employer based training and certification program.

10.11 The owner/user should consider the value of performing a baseline NDE inspection before the heat exchanger is placed in service in order to assist in interpreting in-service inspection data.

10.12 The owner/user should consider the value of performing a baseline NDE inspection before the heat exchanger is placed in service in order to assist in interpreting in-service inspection data.

11.0 Preparing Tube Bundles for ID Tube Inspection

Tube cleanliness can have a significant impact on the performance and probability of detection of some NDE methods. The IRIS technique generally provides the most accurate data however it requires rigorous cleaning. Electromagnetic technique accuracy decreases exponentially with tube fouling. For example, a 39% wall loss feature may result in an estimated 20 to 59% wall loss.

There are numerous methods of cleaning heat exchanger tubulars in preparation for inspection, but they can be roughly grouped into four categories: hydro-blasting, abrasive blasting, chemical cleaning and other methods (e.g. tube scrapers/pigs, tube brushes). The method chosen will depend largely on the degree of cleanliness required for the selected inspection method, but also on cost, availability, safety, speed, and degree of corrosion or fouling present in the tubulars.
11.1 **Hydroblasting** is perhaps the most widely used method. The cleaning is accomplished by directing water into each tube separately with a cleaning lance that usually has a proprietary tip on the end of the lance for multiple-directional flow to increase the efficiency and effectiveness of the cleaning process. Hydroblasting can be classified into at least four categories, depending upon pressure:

1. **Low pressure hydroblasting (less than 10k psi)** is the simplest, least expensive method. It can be used to clean tubes having relatively soft fouling and/or to open plugged tubes (done without a flow directional tip).

2. **Medium pressure hydroblasting (up to 20k psi)** can be more expensive, slower and more complex than lower pressure hydroblasting. It can remove most fouling and corrosion products when using appropriate flow directional tips.

3. **High-pressure hydroblasting (up to 30k psi)** can be used for heavily fouled or blocked tubes. It produces a high level of cleanliness, but the higher the pressure, the slower the process.

4. **Ultra-high pressure hydroblasting (up to 40k psi)** can be used for tubes that cannot be adequately cleaned with normal high pressure hydroblasting. It is the slowest, most complex (track-mounted and remotely operated) and the most expensive of the four hydroblasting methods.

11.2 **Abrasive Blasting** utilizes solid particles with or without water as a carrier. Either wet or dry abrasive methods may be more effective at removing hard scales and corrosion products where hydroblasting has not achieved adequate cleanliness, e.g., cooling water deposits. Abrasive blasting is costlier than hydroblasting because of the added complexity of introducing the abrasive and having to clean it up. Also, with dry blasting, there are the potential disadvantages of producing unhealthy dust and static electricity if there is still some hydrocarbon present in the tubes. Furthermore, the operator error could introduce excessive erosion of the tubing walls. Other methods such as tube scrapers, pigs, tube brushes and tube wire buffers may be used.

11.3 **Chemical Cleaning** can break down hard deposits, blockage and other cleaning challenges without or in conjunction with hydroblast or abrasive blast cleaning methods. There are two methods of chemical cleaning: one using vats of chemicals for dipping the bundle and other the being in-situ with the chemicals pumped through the bundle. In-situ cleaning has some applications for specialized cleaning needs and the advantage of being done in-situ.

11.4 Most electromagnetic inspection methods require hydroblast, grit blast or chemical cleaning where no more than 15% of the tube ID is obscured by deposits or other debris for most electromagnetic techniques.
11.5 Tubing probe Fill Factor (FF) is a critical component of job preparation and provides proof of correct of tube cleanliness. FF is as measure of the magnetic coupling between the coil and tube surface. In general, a uniform and small lift-off is preferred for achieving better detection sensitivity to defects. The fill factor is calculated by:

\[ FF = \frac{PD^2}{TD^2} \times 100 \]

- FF = fill factor
- PD = outside probe diameter
- TD = tube inside diameter

A large fill factor (e.g. 85%) is desirable for optimal NDE performance (70% for RFT/RFA). See table 1 for probe diameters and fill factors for common tube diameters and wall thicknesses.

<table>
<thead>
<tr>
<th>TUBE OD</th>
<th>WALL</th>
<th>PROBE DIA</th>
<th>TUBE OD</th>
<th>WALL</th>
<th>PROBE DIA</th>
<th>FILL FACTOR</th>
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<td>0.5832</td>
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<td>0.4905</td>
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<td>0.109</td>
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<td>1.500</td>
<td>0.109</td>
<td>1.1819</td>
<td>0.850</td>
</tr>
</tbody>
</table>

Table 1: Probe diameters and fill factors for common tube dimensions

11.6 Dummy Probes are used to validate tube clearances necessary for the fill factor values in table 1. Selectable gauging probe casings are attached to a standard eddy current probe cable and pushed down the tube to qualify tube cleanliness, detect dents or other obstacles ahead of the NDE tubing test. See figure 5.
11.7 Ferromagnetic or conductive tube deposits (such as iron oxide) can reduce data quality or create false call indications. These error sources may be reduced or eliminated by removing conductive deposits prior to testing, or by selecting using an alternative NDE methods (e.g. ultrasonics).

12.0 Reporting

The following items may be included in the examination report and archived for future reference:

1. Owner, location, type, and serial number of component examined.
2. Size, material type and grade, and configuration of tubes examined.
3. Tube numbering system.
4. Extent of examination, for example, areas of interest, complete or partial coverage, which tubes, and to what length.
5. Personnel performing the examination and their qualifications.
6. Models, types, and serial numbers of the components of the tubing inspection system used, including probe and extension length if applicable.
7. For the initial data acquisition from the tubing inspection system reference standard, a complete list of all relevant instrument settings and parameters used, such as operating frequencies, probe drive voltages, gains, types of mixed or processed channels, and probe speed. The list shall enable settings to be referenced to each individual tube examined.
8. Serial numbers of all of the tube standards used.
9. Brief outline of all techniques used during the examination.
10. A list of all heat-exchanger regions or specific tubes where limited sensitivity was obtained. Indicate which flaws on the system reference standard would not have been detectable in those regions. Where possible, indicate factors that may have limited sensitivity.

11. Specific information about techniques and depth reference curves used for sizing each indication.

12. Indication evaluation and reporting criteria

13. A list of flaws as specified in the purchasing agreement.

14. A detailed tube map with coded individual tube results

15. Informational screen shots of relevant degradation examples

16. Complementary examination results that influenced interpretation and evaluation.

17. NDE procedure numbers and revisions.

Note: Tubing NDE reports should not include inspection company history, NDE theory, or statements of conjecture.

12.1 Base line NDE Data. The raw NDE data from heat exchanger inspections is the property of the owner/user. The owner/user should collect and maintain prior NDE inspection data for future inspection data comparisons or incident investigations.
A1.0 **Multi-Frequency Eddy Current Testing**

Eddy current testing uses circular AC current coils in close proximity to the inside surface of the tube. The ECT coils produces an electromagnetic field which induces eddy currents in the test material. The eddy current system is calibrated by a tube with machined flaws and made of the same or similar conductivity of the tubing under inspection. Tube flaw responses are then detected and compared to those of the calibration for flaw interpretation. Typical examination methods employ bobbin type probes that contain two coils. Each coil induces a localized 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 utilized 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 localized or gradual wall loss. An example of a MFEC coil can be seen in figure A1.1.

**EDDY CURRENT TESTING**

Two coils are excited with an AC current; producing a magnetic field around them.
The magnetic field penetrates the tube material and generates opposite AC current in the material. These currents are called « eddy currents ».
Any defects that change the eddy current flow circulation will change the impedance of the coils in the probe.
These changes in the impedance of the coils are measured and use to detect the defects in the tube.
A1.1 An example of MEET ECT data can be seen in Figure 1.2. The coil design is composed of two coils wound around a plastic bobbin. The first coil is the absolute coil. The second or differential coil that produces an opposite phase angle flaw response due to its opposite coil winding direction. The volume of the flaw tends to produce the amplitude of the eddy current response. The depth of the flaw is approximated by the change in the phase angle of the signal.

Figure A1.1 MEET ECT Coil Design

A1.2 MEET ECT Capabilities

1. Inspection speed up to approximately 24 inches per second
2. Distinguishes between ID and OD flaws
3. Good reliability and accuracy of test results
4. Can detect gradual wall thinning and localised flaws
5. Can detect metallurgical material changes
6. Provides both phase and amplitude information
7. U-bend tubes can be inspected with some radius limitation
8. Permanent records can be obtained on test results
8. By using MFECT techniques, flaws under the support plates (baffles) can be found and evaluated accurately.
9. Can detect axial cracks

A1.3 **MFECT ECT Limitations**

1. Limited to only non-magnetic tube material.
   
   Requires a frequency mix to inspect tubing beneath a tube sheet or baffle.
2. Does not detect circumferential cracks
3. Application is limited to 3-inch tube sizes and 0.125 wall thickness. Larger diameter and thicker wall materials could be inspected with specialized equipment.
4. Test instrumentation, systems and software packages could be very expensive.
5. Test performance can depend on the level of investment in Tubing NDE equipment.
6. Requires high inspection skills for data analysis and evaluation.
7. Discontinuities adjacent to end sheets are difficult to detect.
8. Tubes must be cleaned.

A2.0 **Segmented Eddy Current Array (ECA) probes for use with non-magnetic material:**

ECA tubing probes are designed to inspect non-ferromagnetic tubing. Instead of coils wound around a bobbin, the ECA uses a series of smaller **pancake-shaped** coils that are set in various array configurations according to design. Array coils can detect, characterize and size ID and OD defects in any orientation as well as provide the approximate clock position of the flaw by use of a C-scan image. Common defect types include pitting, cracking, wear and erosion. Stress corrosion cracking (SCC) can be detected but not sized. A typical calibration standard for ECA inspections include ASME type pitting defects, wear defects and cracking defects. These types of multi-defect calibration standards are used to generate separate calibration curves for each of the defect types. Current ECA instrumentation for tubing inspections can support up to 128 channels of data. In addition to typical strip chart and impedance plane displays, ECA data can be presented in a 2D and 3D C-Scan format. (See figure A2).
An example of ECA data can be seen in figure A2.1.
A2.2 ECA Capabilities

1. Inspection speed up to approximately 24 inches per second
2. Distinguishes between ID and OD flaws
3. Can detect tube flaws beneath tube sheets or baffles without a frequency mix
4. Reliability and accuracy of test results
5. Can detect gradual wall thinning and localized flaws
6. C-scan plot with flaw clock position and circumferential extent of defects
7. Provides both phase and amplitude information
8. U-bend tubes can be inspected with some radius limitation
9. Permanent records can be obtained on test results

A2.3 ECA Limitations

1. Limited to only non-magnetic tube material.
2. Application is limited to 3 inch tube sizes and 0.125 wall thickness. Larger diameter and thicker wall materials could be inspected with specialized equipment. Test instrumentation, systems and software packages could be very expensive.
3. Requires high inspection skills for data analysis and evaluation.
4. Tubes must be cleaned.
A3.0 Near Field Eddy Current (NFT) for use with magnetic materials (ID inspection only):

NFT probes are primarily used to inspect carbon steel tubes with aluminum fins (ACHE coolers). This probe type is limited to detecting, characterizing and sizing ID defects without interference from the tube fins.

A3.1 Defect types include ID pitting, ID wear and ID cracking. Typical inspection speeds are limited to 12 inches per second. NFT probes have up to 30 multiplexed array coils in addition to an absolute bobbin coil. The array coils are used to detect and size ID pitting and cracking defects while the absolute bobbin coil is used to detect and size ID wear defects. NFT probes do not contain magnets which make them easy to push and pull through ferromagnetic tubing. NFT probe data can be displayed as 2D/3D C-scans, standard strip chart and impedance plane displays. (See figure A3)

![Near Field Test Coil](image)

**Figure A3: Near Field Test Coil**

Data example with labels and explanations

A3.2 NFT Capabilities

1. cover a typical range of tube sizes including, but not limited to from .750” (19.05 mm) to 2” (50.8 mm) diameter
2. Inspecting ferrous tubing (SA-214, SA-179, SA-201),
3. Detecting I.D. inlet erosion, corrosion, pitting and axial cracks
4. Inspecting tubes from .750” (19.05 mm) to 2” (50.8 mm),
5. Archiving and collecting data for historical trending,
6. Inspecting up to 12” per second (400 tubes per 8-hour shift), to accurately size inlet erosion/corrosion, and
7. NFT is not affected by external support structures or tube sheets or fins

A3.3 NFT Disadvantages

1. Does not detect O.D. defects
2. Does not detect circumferential cracks
3. Signal amplitude is the only quantifiable parameter
4. Does not differentiate between pitting and cracks
5. Limited sizing capabilities for pit-type indications,
6. Probe must maintain a good fill-factor (75% - 80%) to have good sensitivity to small pits
7. Data can be complex and requires a high degree of operator experience

A4.0 Near Field Eddy Current Array

Near Field Eddy Current Array (NFA) technology functions in transmit-receive mode. A single bobbin coil acts as the transmitter to generate the near field, an absolute bobbin receiver coil detects and sizes the general internal wall loss, and up to two rows of multiplexed receiver coils cover the entire inner surface of aluminium-finned tubes (full 360). With up to 30 optimized coils and thanks to channel multiplexing, NFTA is capable of generating high-quality signals yielding a very good signal-to-noise ratio (SNR) that allow detecting circumferential and axial cracking. The coil configuration of NFTA also enables C-scan imaging despite a scan speed equivalent to NFT 12 in/second.
A4.1 NFA Capabilities

1. Inspect air cooler tube with a high-resolution array, providing intuitive C-scans
2. Detecting and sizing internal defects in one pass
3. Detecting axial and circumferential cracks
4. Easy to use (no magnet = easy to push and pull)

A4.2 NFA Limitations

1. Cannot see outside diameter defects less than 20% wall loss
2. Cannot differentiate between ID and OD flaws

A4.3 NFA Guidance on use

Near field array eddy current should be used on all-carbon steel tubes with aluminum fins in order to avoid electromagnetic noise from the fins. A NFT array consists of multiple, segmented circumferential and axial sensor NDE sensors arrays. Each sensor contributes an independent localized response that is recorded into a mosaic C-scan image. NFT Arrays have improved flaw detection sensitivity and sizing capabilities over conventional NFT and provide more detailed information on defect morphology.

A5.0 Partial Saturation Eddy Current

The Partial partial saturation eddy current (using with rare earth magnets) 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.
A5.1 PS-ECT Capabilities

1. Inspection speed up to approximately 720 inches per minute 7 inches per second
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

A5.2 PS-ECT Limitations

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

A5.3 PS-ECT Guidance on Use

For use on non-ferrous welded tubes or non-ferrous tubes with permeability

A 6.0 Full Saturation Eddy Current

Full saturation eddy current (FS-ECT) uses a 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 signal to noise ratio. The application of a full saturation eddy current technique depends on the permeability of the material, tube thickness and diameter.

A6.1 FS-ECT Capabilities

1. Inspection speed up to approximately 24 inches per second
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

A6.2 FS-ECT Limitations

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

A7.0 Remote Field Eddy Current Testing

Remote Field Eddy Current (often abbreviated RFT or Remote Field Testing) is quite distinct from standard eddy current testing in three of its main characteristics:

1. RFT operates at frequencies typically below 1KHz; whereas, eddy current operates above 1KHz
2. RFT can penetrate through thin-wall carbon steel heat exchanger and boiler tubes because of its low frequency operation
3. RFT is a pitch-catch method; whereas a sending coil transmits an electromagnetic field to a nearby receiving coil. The resulting impedance measurement indirectly measures wall thickness. See Figure A7.

![Image of RFT probe design](image)

**Figure A7: RFT probe design**

A7.1 The RFT field passes right through the heat exchanger or boiler tube wall and far side defects are equally well detected. Two pick up coils wound in opposite directions are available to receive the driver electromagnetic field. Typically, two pick up coils receive the electromagnetic field which has passed through the wall from the driver coil. The flaw response from both receiver coils are shown as figure 8 differential channel view as well as an absolute coil response from a single coil from the coil pair. See figure A7.1 below.
RFT is also much less sensitive to fill factor (lift-off, or proximity) of the probe’s coils to the inside of the tube. Fill factors as low as 50% can still be used with success, which allows the inspection of tubes that are restricted with internal scale or inlet protectors.

Figure A7.2: RFT data presentation

A7.2 RFT probes may contain single or dual exciter (see figure A7.2) for tube sizes from 0.250" to 3.5" diameter. Heat exchanger and boiler tube defects detectable (sizable) with RFT probes are:

1. Internal and external corrosion pits and under-deposit corrosion (sizable)
2. Internal and external erosion (sizable)
3. General wall loss
4. Creep damage such as thermal fatigue cracking (if orientated perpendicular to the resultant field)
5. Baffle wear and tube-tube fretting (sizable)
6. Hydrogen damage and water treatment chemical-induced damage
7. Steam impingement erosion (sizable)
8. Cracking in tube wall (if orientated perpendicular to the resultant field) and sometimes in membranes (with special probes)
A7.3 RFT Limitations:

1. Scanning speed is typically about half that of eddy current technique (6-12 inches per second, but could be slower based on the operating frequency.
2. Threshold of detection is typically 20% for local wall loss and 10% for general thinning
3. Accuracy is usually quoted at +/- 15% of actual wall-loss
4. Repeatability is excellent, but includes un-wanted characteristics of the steel, such as relative magnetic permeability. Repeatability is technician dependent.
5. RFT has limited sensitivity and accuracy at baffle plates because the plates prevent the field from traveling on the outside of the tube. (See ASTM E2096)
6. Although RFT is easier to understand than ECT, there has been a lack of formal training and certification until recently. This has led to the technique being quite operator-dependent. ASNT has recently added RFT to its family of electromagnetic test techniques and there are now codes and standards governing its use in both ASNT and ASME.

A7.4 RFT Application Guidance:

The RFT technique can be used with less tube cleanliness than other electromagnetic and ultrasonic techniques, however, dirty tubes can create noisy data due to “travel or acoustic” noise. High-pressure water jet blasting or grit blasting should be used in the case of hard deposits.

Flexible RFT probes can be used to inspect boiler tubes or u-tube return-bends; however, they will be smaller than the ideal-sized probes for straight tube, because of the tendency for the tubes to flatten when bent. Proper centering is required for the inspection of the straight runs of the tubes when using probes designed for bend inspections.
A8.0 Magnetic Flux Leakage

A magnetic flux leakage (MFL) probe utilizes a powerful magnet to magnetize the material under examination (i.e. Carbon Steel). If defects are present (corrosion or material loss), the magnetic field “leaks” from the material. MFL probes incorporate magnetic detector(s) where it can detect the leakage field. During the examination, a magnetic circuit forms between the probe and tube under inspection. The magnetic field induced in the tube saturates it until it can no longer contain any more flux. The flux overflows and leaks out of the tube wall, and strategically located sensors can accurately measure the flux leakage caused by a defect. Because the magnetic flux leakage is a vector, only the amplitude (voltage) of the leakage field can be measured.

Typically three sensors are used to measure the flux leakage received. The “Lead Differential Coil” is used to detect ID/OD sharp indications. The “Absolute Coil” is part of the “Lead Coil” and is used to detect ID/OD gradual defects. The “Trail Differential Coil” is placed outside the magnetic field to detect the “residual” flux leakage left behind by ID sharp indications. By comparing the information between all three coils, a defect orientation (ID or OD) can be established. (see figure A8).
A8.1 MFL Capabilities

1. Distinguishes ID from OD flaws.
2. Can inspect ferromagnetic tubes from 0.75 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. Inspection speeds of up to 24 inches/second.
6. Can detect flaws under support plates as well as flaws adjacent to end sheets.
7. Aluminum fins do not affect the test results.
8. Circumferential cracking may be detected with array-type MFL coils.

A8.2 MFL Limitations

1. Detectability is limited to flaws 20% and greater.
2. Large magnets that are difficult to move.
3. Very sensitive to inspection speed. Accuracy of test results can fluctuate with probe speed.
4. Poor sensitivity to tubing flaws beneath tube sheets.
5. Instrumentation and probes could be very expensive.
6. Tubes must be cleaned. Scale or deposit can fill a flaw which will make it difficult to qualify its depth.
7. Requires high inspection skills for data analysis and evaluation.
8. Longitudinal or axial flaws cannot be detected.
9. Difficult to accurately size discontinuities.
11. MFL has largely been replaced by the NFT or NFA test methods.

A9.0 Internal Rotating Inspection System

Internal rotating ultrasonic inspection (IRIS) method. 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 onto 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. (See figure A9 and A9.1).

Figure A9: IRIS probe design

Figure A9.1: IRIS data set for a calibration tube

A9.1 IRIS 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 4.0 inches (or larger with specialized equipment) with wall thickness up to 0.25 inches.
6. Final reports with applicable software can be generated instantly.
7. Permanent records can be obtained on test results.

A9.2 IRIS Limitations

1. Coupling medium (water) is always needed.
2. Tubes must typically be plugged to maintain water fill.
3. Tubes must be thoroughly cleaned.
4. ID surface corrosion and deposits can significantly reduce test sensitivity due to the absorption and scattering of sound waves.
5. Test speed is approximately 3-4 inches/second. 12 inches per second high-performance equipment. Some systems cannot record the entire tube length due to computer processing and file buffer size limitations. Instrumentation and probes could be very expensive.
6. Requires high inspection skills for data analysis and evaluation.
7. Cannot detect cracking, small diameter pitting or through wall holes.

A9.3 IRIS Guidance on Use

IRIS should be utilized on tubing that is extremely clean and with the increase of rotation speed of the sensor and data storage, whole tube files can be collected for later analysis.

A10 Remote Visual Inspection

The inside of the tubes can be partially checked at the ends by use of flashlight extensions, fiber optic scopes, borescopes and special probes. The special probes are slender 18-inch (3.2 cm) rods with pointed tips bent at 90 degrees to the axis of the rod. With these tools, it is possible to locate pitting and corrosion near the tube ends. See figures A10 and A10.1.
A10.1 Several tools are available for the assessment of tube conditions. Long mechanical callipers such as an Elliot gauge can be used to detect general or localized corrosion within 12 in. (30.5 cm) of the tube ends.

A10.2 Removal of one or more tubes at random will permit sectioning and more thorough inspection for determining the probable service life of the remainder of the bundle. Tube removal is also employed when special examinations, such as metallurgical and chemical ones, are needed to check for dezincification of brass tubes, the depth of etching or new cracks, or high-temperature metallurgical changes.

A11.0 Acoustic Pulse Reflectometry
Acoustic Pulse Reflectometry (APR) is a non-ultrasonic NDE method that uses an airborne acoustic wave to detect blockages or through wall holes in heat exchanger tubing. An acoustic pulse is injected into a tube and is measured by a small microphone. The inner tube walls create a guided wave with frequencies that remain unchanged until an increase or decrease in tube diameter occurs or if a through wall feature is encountered. APR is limited to detecting tube deposits and blockages greater than 15% of the tube inside diameter. It does not detect pitting and has a low commercial availability. See figures A11 and 11.1.

Figure A11: APR Instrument

Figure A11.1: APR Principle

A11. APR capabilities include:
1. High inspection rates. Average test time of 3 seconds per tube.
2. Instantaneous results.
3. Capable of testing far distances
4. May detect blockages and holes in U-bend tubes.
5. May be used to verify tube cleaning or de-fouling
A11.2 APR limitations include:
   Does not detect ID pitting
   Does not detect OD flaws
   May have difficulty detecting gradual ID wall loss
   Tubes should be dry

A12.0 Tube end callipers

Many tubing NDE methods have difficulty inspecting tube ends within the tube sheets due
to end-effects and tube sheet interference. Mechanical gauging of the tube ends is
performed to detect ID tube end erosion. A common gauge for this purpose is an internal
three point expanding dial calliper. See Figure A12.

Elliott’s Tube Hole Gauges make it easy to accurately measure tube IDs and tube sheet holes found in vessels.

![Elliott’s Tube Hole Gauge](image)

**Figure A12: Tube End Calliper**

A12.1 Advantages of mechanical gauging or tube ends include:
   1. Direct mechanical measurements
   2. Tube sizes from 0.375” to 2.00” (9.5 – 50.8mm) OD
   3. Easy to calibrate

A12.2 Disadvantages of mechanical gauging or tube ends include:
   1. Limited measurement distance into the tube
   2. Measurements may be affected by tube deposits
   3. Relatively slow production
Appendix B:
Tables for NDE method selection

**B1.0** Tables B1-B3 below provide general guidance on the selection of NDE inspection methods for tubing materials, designs and damage mechanism failure modes in accordance with tubing materials and designs, flaw detection and flaw sizing capabilities. All three tables should be utilized in conjunction in determining the inspection technique to be utilized. The user of the general guidance in these tables may need to seek more specific guidance from an NDE SME for specific issues and different circumstances involved with each application.

Table B-1 outlines the suitability of NDE methods for non-ferromagnetic, low ferromagnetic, and ferromagnetic heat exchanger tubes with or without integral or aluminum fins. NDE methods are ranked numerically from 1-4 as preferred, applicable, less applicable and not applicable respectively.
Table B-2 outlines the flaw detection capabilities of NDE methods for non-ferromagnetic, low ferromagnetic, and ferromagnetic heat exchanger tubing with or without integral or aluminum fins. NDE methods are alphabetically ranked from A-D as highly effective, effective, less effective and not effective respectively.

Table B-3 outlines the flaw sizing capabilities of NDE methods for non-ferromagnetic, low ferromagnetic, and ferromagnetic heat exchanger tubing with or without integral or aluminum fins. NDE methods are alphabetically ranked from A-D as highly effective, effective, less effective and not effective respectively.
## Appendix B-1: NDT Method Suitability According to Tubing Material

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<th>RFT/RFA</th>
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<td>4</td>
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### Notes:

1: E.g. Admiralty brass, 300 series stainless steels, Cu-Ni, Hastelloy, etc.
2: Eg. Monel, 2205 Duplex stainless steel, 2207 Super Duplex stainless steel, etc.
3: E.g. Carbon steels, Nickel alloys, etc.
4: Sensor array technologies use individual sensor arrays rather than a single 360 degree sensor. Individual sensor arrays provide independent flaw responses with improved sensitivity, resolution as well as circumferential location and extent with an optional C-Scan data presentation. Sensor array technologies may also provide improved circumferential crack detection and sizing (if applicable).
5: Low commercial availability

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<th>Suitability Rank</th>
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<td>1: Preferred</td>
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<td>2: Applicable</td>
<td>An commonly applied NDT method</td>
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<td>3: Less Applicable</td>
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<td>4: Not Applicable</td>
<td>Not recommended unless a proven application within ra</td>
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<table>
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<th>Abbreviations</th>
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<tr>
<td>Metallurgical Changes (Dealloying)</td>
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Notes
1. Less effective for ID wall loss in carbon steels
2. Less effective for cracking at tube supports
3. MFA preferred for subtracting carbon steel support responses
4. Sensor array technologies use individual sensor arrays rather than a single 360 degree sensor. Individual sensor arrays provide independent flaw responses with improved sensitivity, resolution as well as circumferential location and extent with an optional C-Scan data presentation. Sensor array technologies may also provide improved circumferential crack detection and sizing (if applicable)

Legend

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Abbreviations

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### Appendix B-3: NDT Method Flaw Sizing Capabilities According to Flaw Types in Tubing

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**Notes**

1. Individual sensor arrays provide independent circumferential position and extend of flaws in a C-scan data image. Greater flaw sizing of isolated flaws and circumferential cracking (if applicable)

**Legend**

- **A:** Highly Effective
- **B:** Effective
- **C:** Less Effective
- **D:** Not Effective

**Abbreviations**

<table>
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<tr>
<th>Abbreviation</th>
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