Tech Sheet #129

Heat Exchange Institute

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Common NDE Tube Test Methods

Scope

It is the intent of this HEI Bulletin to identify the various common and accepted non-destructive tests (NDT) available to the end user for surface condenser, feedwater heater and power plant heat exchanger tubing.

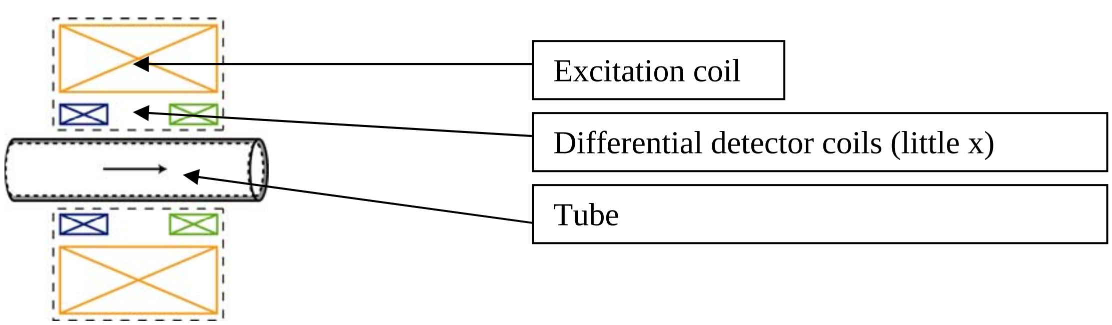
The guideline will identify basic fundamentals of each of the various procedures including advantages of both mandated and optional test methods based upon the applicable ASTM (or other) governing specification. Since the manufacture of a perfect tube is not possible, the inherent limitations of all testing procedures will also be addressed. The HEI strongly recommends that each test be evaluated and implemented not only on its own and singular merits but considered complementary with other tests and practices in order to insure the best possible results are achieved.

The successful implementation of any test method is largely operator-dependent. Therefore, the stringent training and qualifications required of the individuals associated with each of the testing methods is also of paramount importance in achieving acceptable and repeatable results. Most testing practices identified in this guideline typically follow the accepted NDE testing practices of the ASTM.

1. Eddy Current Test (ECT)

1.1. Overview

The ECT method employed by tube manufacturers uses a differential method where two cross sections of a tube are compared against each other. These two cross sections are typically separated approximately 0.1”. Eddy currents are induced using an encircling driver coil that alternates a magnetic field into the tube. For condenser, feedwater heater and balance of plant heat exchanger tubing, the test frequency is typically between 2.5 KHz and 100 KHz. Two differential coils are encircled by the driver coil and are close to the tube surface as shown in Figure 1. The differential coils are electronically coupled so that they produce no signal when identical tube material is in both coils at the same time. A tube discontinuity in one coil creates different eddy currents than in the other. This imbalance between the two detection coils produces an electrical signal used to identify a defect. The strength of the signal is normally related to the volume of the imperfection.



1.2. ASTM references

1.2.1. E309, E243 or E426, A450, B111, B338, B751, A 1016

1.3. Reference standard and calibration

1.3.1. A reference standard is used to calibrate the instrument and set the reject signal threshold. It consists of a length of tube identical to the material being tested, of the same geometry, and machined with standard artificial defects (offline test) or standard artificial defects made on material running in a tube mill (inline test).

1.3.2. Standard machined discontinuities include a 12.5 percent of wall transverse notch, or a 0.031" or smaller thru-wall drilled hole. Unless specified on the purchase order, the choice is made by the manufacturer. Slightly smaller machined longitudinal and transverse OD and ID artificial defects might be specified. These are described in ASTM A 688 and A 803 supplements S1 and S2 for stainless steels, B751 for copper and copper alloys and in the supplementary requirements of A 556 for carbon steels.

1.4. Advantages

1.4.1. Good sensitivity to short abrupt discontinuities

1.4.2. Best sensitivity to short discontinuities that breach the OD surface

1.4.3. Good sensitivity to short mid-wall or partial wall discontinuities.

1.4.4. Best effectiveness on small diameter tubes (diameters under 2" OD and wall thicknesses under 0.200").

1.4.5. More than five decades of proven effectiveness.

1.4.6. Equipment is relatively inexpensive.

1.4.7. Testing can be automated and performed at high process speed.

1.4.8. For all above attributes, this test has become the baseline standard of the industry.

1.5. Disadvantages

1.5.1. Because the method compares signals from two adjacent volumes, or in certain cases signals from single coils, it is less sensitive to continuous discontinuities aligned with the longitudinal axis of the tube that bridge both coils. Signals from longitudinal defects are commonly generated from the end of the defect.

1.5.2. Poor sensitivity to long, slow changing discontinuities aligned with the longitudinal axis of the tube. As an example, an imperfection in a tube of 0.100" wall thickness that starts with no depth, then gradually increases to thru wall and back to no depth, all within 2.5" of tube length, may go undetected.

1.5.3. Attenuation produces a drop in signal as the imperfection is further away from the surface of the tube where the signal is generated. Testing at the tube factory is done with the signal generation on the OD surface. This results in OD oriented defects having a stronger signal than those on the ID.

1.5.4. Marginal capability to detect ID discontinuities in wall thicknesses greater than .200 inches.

1.5.5. Less effective when applied to large diameters.

1.5.6. Rejections can be the result of non-injurious imperfections.

1.6. Cautions

1.6.1 Baseline testing performed on installed tubes is normally performed with eddy current signals generated near the ID surface. This emphasizes signals close to the ID surface. Therefore, the results from the OD testing performed at the tube factory may be significantly different than ID baseline testing. Because of this, ID baseline testing should not be used for acceptance or rejection for the supplied tube.

2. Ultrasonic Test (UT)

2.1. Overview

The Ultrasonic Test requires the transfer of pulsed high frequency sound energy into the tube wall thickness, and searches for an echo or reflected sound energy coming off the surface of a discontinuity. Transducers that produce the sound, and detect the reflected sound, must be coupled to the tube by a sound transferring fluid, usually water. The sound energy is focused and angled to create a shear wave that reflects between the OD and ID surfaces of the tube wall. If a discontinuity is angled to reflect the sound wave back to the transducer, the transducer detects this and generates an electronic signal. Imperfections that can reflect the sound include cracks, holes, laps, coarse grain size and other micro structure differences. . While eddy current signal strength is a function of the volume of the imperfection, ultrasonic signal strength is a function of the surface area of the imperfection. Additionally, defect orientation has a very significant impact on signal strength as the sound may be reflected in a direction away from the transducer.

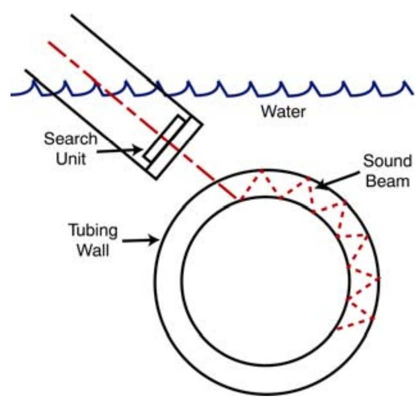


Figure 2. Graphic of shear wave ultrasonic testing.

2.2. ASTM references

2.2.1. E213, E273, A450, A1016, E243, B543, B111

2.3. Reference standard and calibration

2.3.1. A reference standard is used to calibrate the instrument and set the reject signal threshold. It consists of a length of tube identical to the material being tested, of the same geometry, and machined with standard artificial defects. The machined discontinuities must be oriented in the plane of desired inspection. For smaller tubes (under 2” OD) the orientation is to find discontinuities that have their major axis more or less parallel to the tube longitudinal axis.

2.3.2. Standard machined discontinuities, most commonly notches, are 12.5 percent of wall depth, both on the OD and ID. Slightly shallower notches might be used.

2.3.3. Notch length is typically .75” or 1” long.

2.3.4. As natural imperfections may be oriented in a direction that is not optimum for signal reflection to the transducers, they may produce an electrical signal with lower amplitude than that produced by the reference standard discontinuities, and could pass the test.

2.4. Advantages

2.4.1. Good sensitivity to long, continuous, or slow changing discontinuities of the appropriate orientation.

2.4.2. Similar sensitivity to OD, ID, or mid-wall discontinuities.

2.4.3. Will detect non-thru-wall discontinuities.

2.5. Disadvantages

2.5.1. Minimum sensitivity to short discontinuities or discontinuities oriented in line with the transducer beam wave.

2.5.2. Equipment is more expensive than eddy current.

2.5.3. Test speeds are typically slower than Eddy Current.

2.5.4. Set up time can be longer than Eddy Current.

2.5.5. For the above reasons, this test is more costly than Eddy Current.

2.5.6. Rejections can be the result of non-injurious imperfections.

2.5.7. UT testing has a higher rate of false positives compared to Eddy Current

3. Flux Leakage Test (FLT)

3.1. Overview

The Flux Leakage Test uses the principle that ferromagnetic materials (carbon and alloy steels, ferritic stainless steels) has the capacity to capture magnetic flux and increase the flux density a hundred fold compared to the flux density in air or non-magnetic materials (copper alloys, aluminum alloys, titanium, and many nickel alloys).

Magnetic flux is increased in the tube cross section to the saturation point. Any discontinuity is a reduction in cross section, thus causing the flux to escape and bridge the OD around the discontinuity. The second principle is that an electric current is produced in conductors moving through a magnetic field Magnetic poles and the electric sensors either rotate around the tube or the tube rotates within the poles and sensor coils. Sensor coils moving through escaping flux indicate a discontinuity and the section marked or the tube rejected.

3.2. ASTM reference

3.2.1. E570, A450, A1016

3.3. Reference Standard

3.3.1. For tubes under 4" OD, detection is limited to discontinuities approximately parallel to the tube's longitudinal axis. A reference standard is used to calibrate the instrument and set the reject signal threshold. It consists of a length of tube taken from the material to be tested, with machined notches added. The notches must be in a radial plane with length parallel to the longitudinal axis of the tube.

3.3.2. Standard notches are 12.5 percent of wall depth, both on the OD and ID. Slightly shallower notches might be used.

3.3.3. Notch length shall not exceed 1".

3.3.4. It should be understood that tubes with natural discontinuities that produce an electrical signal with lower amplitude than that produced by the reference standard discontinuities, will pass the test.

3.4. Advantages

3.4.1. Good sensitivity to long, continuous, or slow changing discontinuities with major axis more or less parallel to the tube longitudinal axis.

3.4.2. Best sensitivity to discontinuities that breach the OD surface.

3.4.3. Will detect non-thru-wall discontinuities.

3.4.4. Test is conducted in the dry condition.

3.4.5. Test can be automated and performed at relatively high speeds.

3.5. Disadvantages

3.5.1. Commercial equipment is not available for tubes smaller than 1.5" OD.

3.5.2. Inspection for discontinuities oriented transversely to the tube longitudinal axis is not available for tubes smaller than 4" OD.

3.5.3. Less sensitive to short, transversely oriented, mid-wall or ID discontinuities.

3.5.4. Setting the saturation density flux is problematic but critical to the success of the test.

3.5.5. The test is only applicable to plain carbon steels, not austenitic stainless steels or other non-magnetic materials.

3.5.6. Equipment is expensive.

3.5.7. For all above reasons this test has not been applied in the heat exchanger or boiler tube industry.

4. Pneumatic Leak Testing (PLT)

4.1. Air Underwater (AUW)(add AUW material from down below)

4.2. Pressure Change Method
The Pressure Change Method(s) involve measuring the change in pressure, over time, using a sensitive pressure transducer. There are three methods, all of which are intended to be equivalent.

4.2.1 Pressure Differential, measures the drop in pressure over time as a result of air escaping from inside one tube when compared to another tube at an identical pressure, or one tube against a control volume at identical pressure

4.2.2 Pressure Decay, where one tube is pressurized and pressure decay is measured over time

4.2.3 Vacuum Decay, where one tube is evacuated and vacuum decay is measured over time.

4.2.4 For either pneumatic leak test, the pressure must be greater than 33 psi, and for the vacuum decay test, the pressure must be less than 6 psi. Test time is dependent upon the resolution of the pressure transducer and the volume of the tube being tested; however, test times in the range of 5 to 15 seconds are normal. The test is automated and not subject to human inconsistencies.

4.3. ASTM reference

4.3.1. A1016, A1047

4.4. Reference standard and calibration

4.4.1. A reference standard with a hole as small as .003" may be used.

4.5. Advantages

4.5.1. Thru-wall discontinuities as small as .003" may be detected. However, these small discontinuities are subject to fouling, resulting in false positive results. Larger discontinuities are less subject to error.

4.5.2. Very small thru-wall holes can be detected, smaller than other electrical NDT methods.

4.5.3. Test is conducted in the dry condition.

4.5.4. Low equipment cost.

4.5.5. Automated, operator independent.

4.6. Disadvantages

4.6.1. The discontinuity must be thru-wall. A large discontinuity, 99% thru-wall, will not be detected.

5. Air Under Water Test (AUW)

5.1. Overview

The Air Under Water test is performed by submerging a tube pressurized with compressed air in a water tank while an inspector(s) look for leaks. Test pressures shall be a minimum of 100 psi. The tube passes the test if the inspector does not see air bubbles.

5.2. ASTM references

5.2.1. A450, A498, A1016, and others.

5.3. Reference standard and calibration

There is no reference standard or calibration procedure stated, although pressure gauges require calibration.

5.4. Advantages

5.4.1. Very sensitive to small, thru-wall discontinuities.

5.4.2. More sensitive to small thru-wall discontinuities than any of the electrical NDT options.

5.4.3. Lowest equipment cost option

5.4.4. Lowest operator qualification requirement.

5.5. Disadvantages

5.5.1. The process is a visual testing method and operator diligence is necessary.

5.5.2. Only thru-wall discontinuities can be detected. A large discontinuity, 99% thru-wall, will not be detected.

5.5.3. Labor intensive. To properly perform this test, the operator should walk full length of the tube and lighting is important.

5.5.4. Because of speed and labor, cost is moderate. This can be reduced by simultaneous testing of multiple tubes.

6. Hydrostatic Test (HT)

6.1. Overview

The Hydrostatic Test is performed by pumping water into a tube to evacuate all air, increasing the pressure to a predetermined test value , and holding the pressure for at least 5 seconds. The tube passes the test if there is no visual water leakage and the test pressure is maintained.

6.2. ASTM references

6.2.1. A450, A498, A1016, and others.

6.3. Reference standard and calibration

6.3.1. There is no reference standard or calibration procedure stated, although pressure gauges require calibration.

6.4. Advantages

6.4.1. Sensitive to medium and larger thru-wall discontinuities.

6.4.2. Low equipment cost

6.4.3. Low operator qualification requirement.

6.5. Disadvantages

6.5.1. The process is operator dependent, increasing the potential for error.

6.5.2. Because of the high viscosity of the water, this is the least sensitive of the pressure testing methods. Depending on time of testing, it could be two to three orders of magnitude less sensitive than the pneumatic leak test or air-under-water test.

6.5.3. **Only thru-wall discontinuities can be detected**. A large discontinuity, 99% thru-wall, will not be detected.

6.5.4. This is a slow NDT method.

6.5.5. It is labor intensive.

6.5.6. Because of speed and labor, cost is moderate.

Summary comparison table follows on page 9.

Summary comparison table

Defect Description		Non Destructive Electric			Leak Tests		
		ECT	UT	FLT*	PLT	AUW	HT
*Abrupt	Longitudinal	**1**	**2**	**2**	N/A	N/A	N/A
	Transverse	**1**	**3**	**3**	N/A	N/A	N/A
*Gradual	Longitudinal	**3**	**1**	**1**	N/A	N/A	N/A
	Transverse	**1**	**3**	**3**	N/A	N/A	N/A
ID		**2**	**1**	**2**	N/A	N/A	N/A
OD		**1**	**1**	**1**	N/A	N/A	N/A
Thru-Wall		**1**	**1**	**1**	1	1	1

*Gradual – A defect that is more than ½" in length

*Abrupt – An example would be a thru wall hole

Legend	
1 = Excellent Detectability **2** = Good Detectability **3** = Fair Detectability N/A = Undetectable	***** = only possible on ferromagnetic materials

ECT- Eddy Current Test, typically ASTM E309, E426, or E571
UT – Ultrasonic Test, typically E213 or SE213
FLT – Flux Leakage Test, ASTM E570
PLT – Pneumatic Leak Test, typically ASTM A1047
AUW – Air Under Water,
HT - Hydrostatic Leak Test, typically ASTM A1016 or B751