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Comparison of OD and ID Eddy-Current Inspection of Tubing

Scope

The Eddy Current test (ECT) test is the primary nondestructive test (NDT) used in tube mill certification testing for condenser, feedwater heater, and balance of plant (BOP) power generation tubing. When tested at the tube mill, the procedure is performed using encircling differential outside diameter (OD) coils. Such OD testing techniques are well accepted by industry and consumers alike. This technique has, in fact, been the standard tubing NDT practice for several decades and is incorporated into the ASME Boiler & Pressure Vessel Code. Details of this type of test and its advantages and limitations are defined in the HEI Tech Sheet #129. Although ultrasonic testing (UT), remote field testing (RFT) and flux leakage testing may be acceptable alternatives, they are only used when specified by the customer, or by a small number of product specifications such as ASTM B338. As a result, this document will only discuss the EC test. Once the tubing is manufactured, the owner or end user may specify an additional EC test using an ID probe. The purpose of this document is to describe the major differences between the two tests and what each is intended to accomplish.

Inspection from the Tube OD

Most ASTM and ASME tubular product specifications require a nondestructive electric test NDE. The NDE tests may include eddy current testing, ultrasonic testing, or flux leakage testing. The product specifications do not necessarily designate which of these three must be used, and unless agreed upon in the purchase order, the test choice is at the option of the tube producer. The test that is the quickest, with the highest reliability and provides good sensitivity for finding sharp, abrupt defects is the OD eddy current test. It is the overwhelming choice of both tube manufacturers and end users. The ASTM has developed recommended practices on how those tests may be performed. These include as follows:

ASTM E309 / SE309 –Standard Practice for Eddy-Current Examination of Steel Tubular Products Using Magnetic Saturation

ASTM E426 / SE426 –Standard Practice for Electromagnetic (Eddy-Current) Examination of Seamless and Welded Tubular Products, Austenitic Stainless Steel and Similar Alloys

ASTM E571 / SE571 –Standard Practice for Electromagnetic (Eddy-Current) Examination of Nickel and Nickel Alloy Tubular Products

ASTM E2096 - Standard Practice for In Situ Examination of Ferromagnetic Heat-Exchanger Tubes Using Remote Field Testing

ASTM E-690 / ASTM E690 - Standard Practice for In Situ Electromagnetic (Eddy-Current) Examination of Nonmagnetic Heat Exchanger Tubes

Approximately 25 years ago, the ASTM A01.09/A01.10 NDE task group recognized that the "E" practices identified above did not have sufficient detail to ensure that tube mills were incorporating all of the necessary ASTM requirements. In addition, there was no validation that the procedures used at one manufacturing plant would provide similar test results as those at another mill. As a result, the ASTM developed a number of additional requirements which were then added into the general tubular product specifications. These additional requirements specified items such as calibration size & location (artificial defect size & type, i.e., drilled hole or notch), and calibration procedures to ensure consistent & repeatable results. These requirements also included training and certification of operators, signal to noise ratio recommendations, and required equipment calibration standards. The general specifications that include the additional requirements are as follows:

ASTM A450 / A450M – Standard Specification for General Requirements for Carbon and Low Alloy Steel Tubes

ASTM A1016/A1016M - Standard Specification for General Requirements for Ferritic Alloy Steel, Austenitic Alloy Steel, and Stainless Steel Tubes

The ASTM/ASME OD EC testing of tubes is usually accomplished using only one frequency, typically within a range of 25 KHz to 100 KHz. As the magnetic field penetrates the metal, the ability to receive a signal lessens or attenuates. This phenomenon is called standard depth of penetration or alternatively, the "skin effect". The depth of penetration decreases with increasing frequency, conductivity and magnetic permeability. As a result, the signal returning from an imperfection near the OD will be stronger than an identically sized imperfection away from the OD surface. The specifications do not address the imperfection's location. Rejection is typically decided on a go/no-go signal amplitude criteria from an artificial defect described in the general specification or in the supplementary requirements of the product specifications. Magnetic properties or anomalies can be created in non-magnetic materials through minor parent metal alloy excursions, manufacturing, welding, strain-induced cold work and other processes and may not be detected using conventional OD saturation. These signals are defined as anomalies or discontinuities and are not considered a manufacturing defect. This magnetic coupling is achieved by using encircling coils to create a saturating magnetic field. This magnetic saturation does not necessarily improve the testing sensitivity or repeatability but does allow penetration of eddy currents in magnetic materials.

One additional advantage of OD ECT inspection is that the tubing can be fully magnetically saturated during testing to ensure the maximum level of sensitivity and repeatability, vastly reducing the occurrence of false indications on those materials which have ferromagnetic domains. As noted earlier, carbon and alloy steels, stainless steels and some nickel alloys may contain small magnetic domains that must be magnetically coupled during testing to minimize "noise" providing for "quiet" or higher signal to noise inspection with eddy currents. Even austenitic stainless steels which are considered to be non-magnetic, may have small magnetic regions from residual delta ferrite formed during the welding process or strain induced martensite from cold working.

Special tube configurations such as integral ID and/or OD fins will require unique technologies that are not covered in this document but should be reviewed with the manufacturer prior to the onset of testing.

Inspection from the tube ID

ID eddy current testing employing internal probe coils was developed as an in-service or baseline inspection tool to identify tube damage, discontinuities or operational wear. This damage may include pitting, cracking, wear from vibration or abrasion and other environmentally induced mechanisms. The indications are identified using ID probes that are passed down the length of the tube on a tethered cable that is connected to specially designed equipment containing an alternating current power source and electronics for recording and analyzing the output. The probes can be designed with differential encircling coils highly sensitive in identifying sharp, abrupt or axial damage (similar to OD testing), or can use pancake coils to identify longitudinally oriented damage. Internal probe coils can be operated in both the differential and absolute modes simultaneously for identifying both abrupt and gradually occurring discontinuities.

The ID test is not only sensitive to tube damage and wear but may also identify other discontinuities including scratches and dents caused by transport and handling, installation, and OD and ID debris that can come from a variety of sources. Therefore, if a one-time test is performed on an existing heat exchanger, it may be difficult to determine which indications are the results of service vs. those that are a result of the manufacturing and installation process.

The baseline eddy current test was developed to separate service related damage vs. manufacturing/installation process defects. The baseline test is most effective when performed immediately after the installation of the tubing and is typically done in the fabricator's shop. It should be noted however that even with specialized electronics, the use of a bobbin coil will have considerable difficulty determining the precise discontinuity shape. Depth can be determined with a single frequency but multiple frequencies will improve the analysis. Signal length and a comparison of the absolute and differential signals from the same discontinuity can also help. The ability & knowledge of the signal analyst to correctly & accurately interpret potential failure mechanisms for the tubes serviced and the signals' location in the heat exchanger becomes of paramount importance. A baseline test can be performed for the following reasons:

- To determine if the tube was damaged during installation in the heat exchanger
- To develop a database of discontinuities and anomalies, including their locations in the heat exchanger for comparison with future examinations

An initial ID baseline map facilitates in-service evaluations by comparing the initial readings to a second test after a given service exposure. Tracking indication changes becomes a useful tool to understand the effect of pits, cracks and other wall loss damage in the tubing over the service timeline. This information can then facilitate predictive maintenance programs.

During ID testing, indications are normally identified as a percentage of wall loss which is determined by a combination of phase angle shift and different responses to multiple frequencies. Because natural damage may not provide identical size data to the artificial defects used to calibrate the equipment, accurate sizing of the damage needs to be verified by removing samples with indications and comparing them to the calculation made during the analysis. However, removal of actual samples may not always be practical; in that case, the analysis must rely on past experience.

There is no standard accept/reject criteria for ID electric testing of feedwater heater, condenser or balance of plant heat exchangers. Steam generator tubing has several criteria for rejection and many are associated to the artificial defects machined into the reference standard per ASME, Section V, Article 8, Appendix II. This reference standard does not simulate the feedwater heater, condenser and BOP heat exchanger indications and may result in excessive reject rates from non-injurious indications.

ID testing to develop a baseline condition map is a mature technology and can be a very useful tool to help track tube damage and wear and future heat exchanger tube problems. Testing should be performed after the tubing is installed, rolled, seal welded and other surrounding manufacturing processes are completed. Detailed test information such as frequencies, probe speeds, phase angles and other parameters need to be carefully documented as well as probe descriptions and model numbers. When the test is duplicated, it can be compared easily to the baseline map to identify any changes to the tubes.

Conclusion

Investigative efforts in producing this HEI Tech Sheet have not identified any known research or studies that have been performed comparing the results of OD EC testing vs. ID EC testing of new commercial grade tubes. As such, this Tech Sheet is compelled to identify concerns relative to this issue as follows:

- The impact of attenuation needs to be better understood and addressed. Testing performed from the OD will accentuate OD imperfections while ID testing will accentuate those on the ID.
- The use of different frequencies will also have a significant impact on the signal vs. depth of the discontinuity.
- With any eddy current testing, fill factor, or the distance between the coil and the tube, is critical for determining discontinuity sizing. A high fill factor and precise coil centering improves sensitivity while a low fill factor results in a less precise response. When OD testing is performed the tubing is rigidly held and centering within the coil is ensured through the use of stationary rolls in both in-line and offline testing. Depending on the calibration process, OD-tested tubes can either be held stationary or rotated during testing. ID probes rarely have effective centering devices and no requirement or specification currently exists to prove centering. In the case of ID probe coils, a high fill factor results in better centering. Poor centering results in less sensitivity in the hemisphere of the tube that has a larger gap between the probe coil and tube wall. In a baseline test, a good fill factor is usually achievable because the tubes are clean. Testing tubes that have been in service may result in lower fill factors because of ID fouling.
- Most ID eddy current probes do not have a method for saturation to ensure that small magnetic domains do not produce false indications. Those probes with saturation only have sufficient energy to saturate thin walls and the testing is significantly slower.
- If the ID testing is performed before installation in the bundle, imperfections developed during the installation process are typically ignored.

The OD ECT is the current industry norm for NDE certification of new tubing. Considering all of the issues above and in the absence of detailed comparative studies, the use of ID testing as an acceptance criterion for new tubing is not only controversial but highly subjective. In light of these concerns, it is therefore recommended that users discuss these issues in detail with the proposed tube manufacturers before specifying an ID test.