

OPTIMIZING CONDENSER TUBE LIFE WITH NONDESTRUCTIVE TESTING

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Nondestructive testing is an effective way to determine the lifespan of your condenser and heat exchanger tubes. The results are analyzed and discontinuities or anomalies can be categorized and reported by defect type and depth. This provides management with an accurate assessment of unit condition and remaining useful life. Additionally, precautionary steps can be taken to plug damaged tubes or avoid any potential failures reducing costly condenser tube leaks and preventing forced outages.



Caption: A qualified data acquisition technician inserts an eddy current probe into a tube for examination.

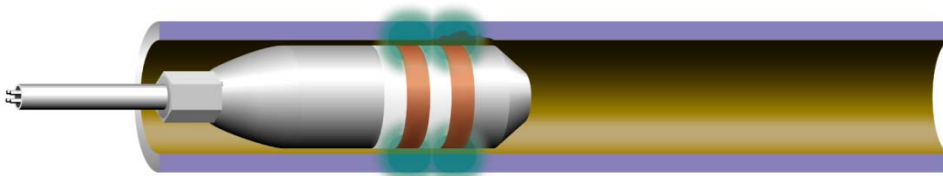
EDDY CURRENT TESTING

Eddy current testing is a well-established form of nondestructive testing used to examine non-ferritic tubing in condensers and heat exchangers. Tubing such as austenitic stainless steel, titanium, brass and copper nickel are often tested with eddy current methodology.

The eddy current method is a volumetric testing process that uses an electromagnetic field to identify defects in the tubing. An electron flow (eddy current) is induced in electrically conductive material and an electromagnetic field is generated by a probe. The probe is first placed in a standard and calibrated to known defects producing representative signals. The probe is then placed inside the tubing to be tested and pulled. Variations in the eddy currents are recorded and compared to those produced by the standard. Variations are caused by the frequencies applied, the characteristics of the material and any flaws or defects. An analysis on the results is performed

following the tests; successful and accurate analysis is based on analyst experience, proper calibration to standard, and selection of frequencies.

Any defect or anomaly in the tubing that disrupts the flow of the eddy currents can be detected. Depending on the number of frequencies and channels used, defects with unique characteristics can be found. Small defects such as pitting and cracking can be detected in the differential mode. Wall-thinning defects such as steam erosion or inlet end erosion are detected in the absolute mode. Additionally, higher frequencies are more sensitive to near-surface flaws, and lower frequencies are more sensitive to subsurface flaws and conditions on the outer diameter (OD) tube surface. The complex and varied nature of anomalies and defects necessitate the use of multiple frequencies for accurate identification.



Caption: As a standard bobbin coil eddy current probe passes through the tube, the electromagnetic field (in green) is disrupted by a defect in the tube wall. Illustration courtesy of Zetec.

MULTIPLE FREQUENCIES

An essential element in the eddy current testing process is the use of multiple testing frequencies. A true volumetric inspection requires complete penetration of the tube wall from various perspectives; as prime frequency is set affording full wall penetration; additional frequencies are required to gain an accurate and detailed perspective of the defect. Multiple frequencies offer the ability to better detect, measure, and confirm flaws in all areas of a tube wall and allow for a more thorough evaluation with higher confidence. In fact, additional frequencies are vital to confirm certain defects, such as under-deposit corrosion and microbiologically influenced corrosion.

A minimum of three frequencies is highly recommended to perform optimum testing. While present day eddy current testing instruments have the capacity to carry up to eight frequencies, at least three are utilized, or more commonly four, to gain a full perspective on the defect. From the chosen optimum frequency, the alternate frequencies are usually $\frac{1}{2}$ and $\frac{1}{4}$ of the prime frequency for mixing out support plates and other unwanted signals from structures or noise. The optimum frequencies will vary from low, to midrange, to high depending on the material under test.

Evaluation of inner diameter (ID) and outer diameter (OD) defects or varying size may also require different frequencies. Each frequency may be carried on two channels to further evaluate variations and in order to confirm the reading.

Utilizing multiple frequencies in the testing process provides the analyst with sufficient information to call the defects with greater accuracy and reliability. Utilizing a multi-frequency test instrument and standard probes

commonly used for testing condenser tubes, tube samples with various defects will be examined utilizing one, two, three and four frequencies. Defect acquisition rates will also be varied and the results reported.

The experience of the analyst is another important factor in the testing process. ECT technicians should be certified to (ASNT) SNT-TC-1A guidelines. Additionally, level IIIA and senior level IIA analyst should have passed both Electric Power Research Institute's (EPRI) Data review and evaluation of balance-of-plant (BOP) Heat Exchangers class. All analysts should have passed an industry approved data-analysis level IIA class.

Not only is it important to use multiple frequencies, it is essential to select the correct range or values. For an example of lower range frequencies consider 30 kilohertz (KHz), a typical prime frequency when testing admiralty brass tubes with .049" wall thickness, reducing to ½ of prime or 15 KHz and even to ¼ of prime on the lower end of the range. For higher range frequencies consider testing of 304 stainless steel tubing with .028" wall thickness, the typical prime frequency may be 800-900 KHz, reducing to ½ prime or 400 KHz and then to 200 KHz. The number and value of frequencies also affects the rate at which defects can be detected. Though lower frequencies are preferred for copper alloys and subsurface flaws, they take longer to propagate reducing the speed at which acquisition can be performed.

Uses of Multiple Frequencies

	High Frequencies	Low Frequencies
Use	<ul style="list-style-type: none"> Stainless Steels (.028) Near surface flaws ID Pitting 	<ul style="list-style-type: none"> Brass / Copper Alloys (.049) Subsurface Flaws Severe Pitting
Range	<ul style="list-style-type: none"> 800 to 900 KHz (High) 400 KHz (Mid) 200 KHz (Low) 	<ul style="list-style-type: none"> 30 KHz (High) 15 KHz (Mid) 7 to 8 KHz (Low)

The use of fewer frequencies may expedite testing, but may result in less accurate results. The purpose of testing is to achieve accurate identification of defects and their causes, and a significant economic or remedial decision is usually dependent on the outcome. The speed and cost of testing should be secondary concerns. Consider the following:

Depth of Penetration: Depth of penetration is the depth at which the magnetic field strength or intensity of induced eddy currents has decreased to 37% of its surface value. The depth of penetration is an exponential function of the frequency of the signal, and the conductivity and permeability of the material. The effective depth of penetration is the depth beyond which a test system can no longer detect changes in specimen thickness or the presence of discontinuities; the eddy current density at that point is simply too weak.

Misleading OD Signals: Any individual frequency has limitations on its depth of penetration and its ability to determine the continuation of the tube wall to the OD. The presence of other conductive materials, such as tube support plates and metallic deposit elements, can lead to ambiguous signals. In many cases, magnetite deposits on the tube OD have been mistaken for erosion. Another case of misleading OD signals is from Microbiologically Influenced Corrosion (MIC). Due to the nature of these corrosion phenomena, as microorganisms hollow out the tube wall and leave only a small defect in the near surface, the eddy currents can be misleading and indicate the

defect as being OD-initiated. Without the aid of additional frequencies, the analyst can mischaracterize the condition of the tubes.

Mixing Out Tube Support Plates: Controlled probe speed and the use of multiple frequencies are essential to identifying defects near tube support plates. The tube support plate may hide or distort a defect as the support plate material is conductive. Common defects include axial cracking, tube support plate fretting wear and condensate grooving. Absence of a lower frequency to differentiate the tube support plate will leave the analyst with insufficient data and poor test results. The reduced frequencies can also aid in determining the condition of the tube support itself.

The Shape of Pits: The geometric shape of a pit is not a perfect circle, nor does it typically have a flat bottom, as machined into a calibration standard. The signal response to a natural flaw may differ from that of an artificial or reference flaw. Pits of a given depth, elongated in the direction of water flow, have a different effect on the signal phase than do round pits of the same depth.

OTHER VARIABLES IN EDDY CURRENT TESTING

While multiple frequencies are significant variables in the Eddy Current Testing process there are other variables to consider. Some of the other variables which affect results are:

- the calibration standard
- fill factor
- tube cleanliness
- probe speed

Calibration Standard: A standard is used to calibrate the testing instrumentation and is necessary to determine applicable frequencies. The standard is manufactured from a length of tubing of the same size and material of the tubing to be tested and contains calibration discontinuities and defects machined into the tube, including ID and OD pitting and incremental degrees of wall loss.

Fill Factor: Fill factor is the volume at which the probe occupies the ID of the tube. Fill factor is such a significant variable that many quality assurance guidelines call for a minimum of 80%, though ideally, the probe would occupy as much of the diameter of the tested tube as possible. High fill factor provides better magnetic coupling with the tube and decreases the effects of centering variables. A low fill factor reduces the sensitivity of the exam and may result in the probe traveling closer to one portion of the tube wall.

Probe Speed: Probes may be inserted into the tubes manually or by an automated probe pusher. Probe traveling speeds range from 30" to 48" per second; some high frequency applications can run up to 60" per second. Common probe speeds for copper, a very low frequency, may be restricted to 24" per second. The amount of data collected by the probe, the sample rate, is limited by the inspection frequency and the number of channels activated. Based on the sample rate, a probe traveling too quickly using a low frequency and slow sample rate can miss flaws and give erroneous signals. Additionally the presence of deposits and obstructions will cause inconsistent probe speeds potentially increasing signal to noise ratio and distorted signals.

Calculating Fill Factor:

Fill factor is the ratio of the square of the probe outer diameter to the square of the tube ID.

For example, a 1" OD x 22 BWG tube (where 22 BWG = .028" wall) and a .900" OD probe calculates to a 90.8% fill factor.

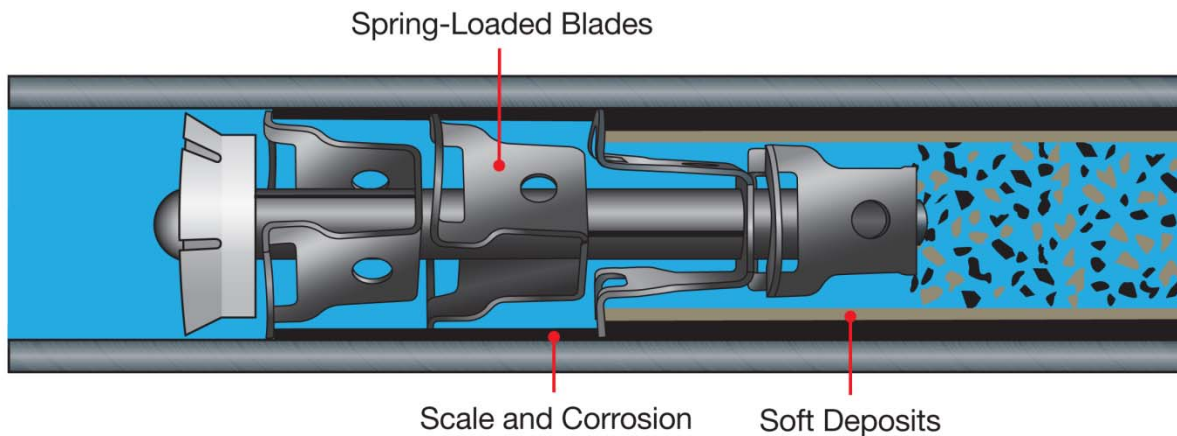
$$1 - (2 \times .028) = .944 \text{ tube ID}$$

$$0.900^2 / .944^2 = .81 / .8911 = .908 \text{ or } \mathbf{90.8\% \text{ fill factor}}$$

TUBE CLEANLINESS

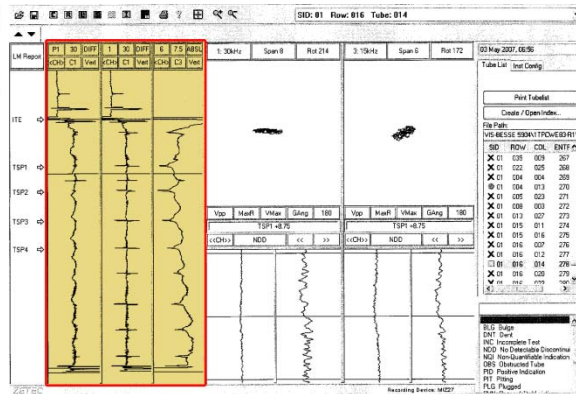
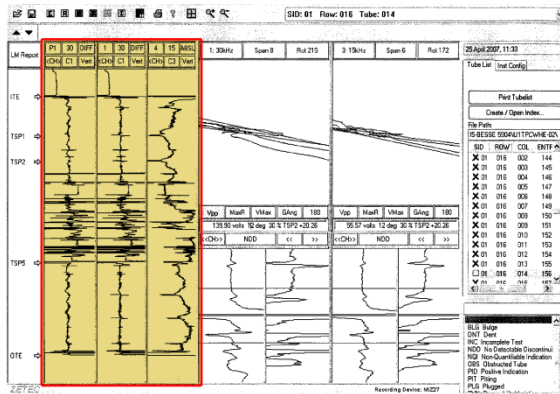
The cleanliness of the tubes is another important factor in successful eddy current testing. Fouled tubes compromise the integrity and completeness of the testing process, generating unreliable data and incomplete analysis. A thorough inspection of the tube is necessary to produce successful test results. Fouling can prevent the probes from examining the full-length of the tube and any metallic deposits can generate misleading signals. Deposits and obstructions can compromise fill factor, or worse, can cause damage to the probes. Overall noise-to-signal ratio is also improved by clean tubes.

Cleaning the tubes, preferably with mechanical tube cleaners, is preferred prior to an inspection and the most effective deposit removal techniques should be applied.



Caption: A mechanical tube cleaner, such as the Conco C4S, can remove deposits and fouling that would otherwise distort the probe signal or obstruct its passage through the tube.

Side-by-Side Comparison of Fouling Impact on Data Quality



Ineffective Cleaning

Effective Cleaning

Caption: Analysis of the sample data on the left is distorted and difficult for the analyst to read. The data on the right is the same tube after being adequately cleaned.

THE EFFECTS OF UTILIZING MULTIPLE FREQUENCIES ON SPECIFIC TUBES

Tests have been conducted that clearly demonstrate that the proper selection and use of multiple frequencies provide a better perspective for the analyst and more accurate eddy current testing results. While speed may be compromised, the proper identification of defects will be achieved with a higher level of confidence.

Test and Test Procedure

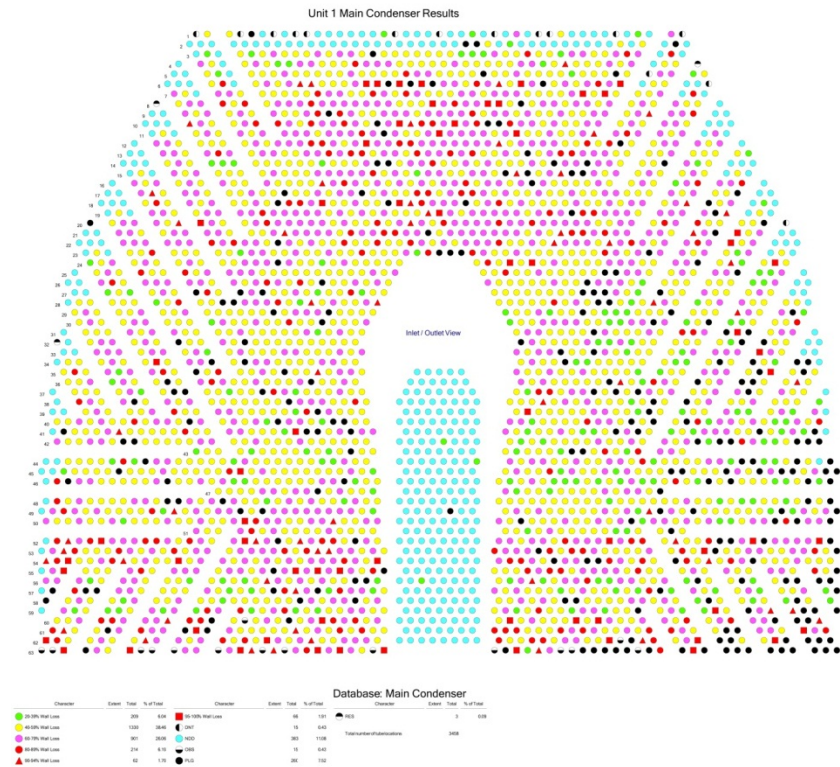
Eddy current testing was performed on a number of tubes at the Conco test facility in Verona, Pennsylvania. Testing was performed with one, two and four frequencies or high, midrange and low frequency on two, four and eight channels respectively, with and without a tube support ring simulating a tube support plate. The tubes had known defects, both ID and OD, and in some cases in excess of 40 percent wall loss. The standard bobbin coil probes had a fill factor of greater than 85%. And the probe speed was controlled by the use of a Zetec 3D high speed probe pusher. The results were consistent.

Each indication was captured for review by an analyst. Overall, distortion of the signal was present at higher speeds, making it difficult to read. The single frequency test could not accurately measure or identify defects when placed under a tube support ring or tube support standard due to the absence of a subtractor frequency. Testing with at least three frequencies was needed to inspect parts with known defects of greater than 40% through wall indications when these indications are under a tube support. The best and most accurate results were achieved using low, midrange and high frequencies at a moderate to low probe speed.

DELIVERABLES

A thorough eddy current examination will yield a considerable amount of data for analysis. Upon completion, testing companies should provide a detailed final report, summarizing the condition and integrity of the condenser, as well as:

- A brief summary on the condition of the individual tubes tested
- Any other relative information or recommendations
- Graphics of specific tubes that may be of interest for further review
- Quick reference Data-Matrix chart
- A color-coded tube sheet map that will graphically display the individual tube condition and very quickly identify any problem areas



Caption: A graphic representation of the condenser is displayed with individual tubes color-coded for quick analysis.

CONCLUSION

The successful application of the Eddy Current method for nondestructive testing of condenser and heat exchanger tubes is dependent on a number of variables. Other than analyst experience, the use of multiple frequencies has the most significant impact on results. With proper cleaning of the tubes, the use of multiple low, midrange and high frequencies simultaneously assures the best and most accurate results. Better quality data is collected allowing the analyst to assess accurate identification and quantification of tube defects such as pitting on the ID or OD defects under support plates. The accurate identification of these defects is paramount to the process.

Successful remedial action, proper future operation, suggested maintenance practices, or useful life estimation are dependent on this assessment.

This article acknowledges prior work and contributions from colleagues at Conco Systems.