Eddy Current Testing: A Predictive Maintenance Tool

Eddy Current Testing of chiller tubes

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Introduction

Chiller is the heart of an air conditioning and refrigeration system. The critical functions that chiller systems perform require predictive maintenance schedules which, if neglected, may result in catastrophic failures necessitating emergency repair, downtime, unplanned costs and extreme inconvenience to the operating personnel.

Due to the various chemical, mechanical, pressure and temperature-related conditions occurring within chillers, the tubes are the most susceptible parts of shell-and-tube type heat exchangers.

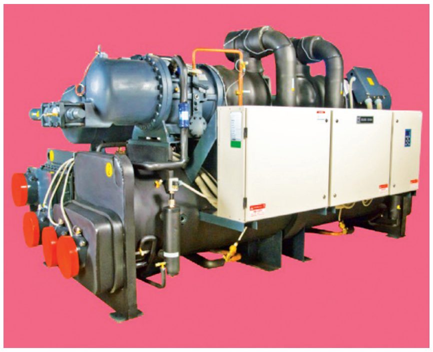


Figure 1: Chiller package

Causes of Tube Failure

Metal erosion

Fluid velocity in excess of the manufacturer's recommendation is likely to cause erosion damage as metal wears from the tubing surfaces. If any corrosion is already present on the exchanger, the erosion is accelerated. A metal erosion problem, most often, occurs inside the tubes, along the U bends and near the tube entrances.

Water Hammer

Pressure spikes, surges or shock waves, as a result of a sudden and rapid acceleration or deceleration of fluid, may result in water hammer. Control valves that open or close suddenly to control fluid flow can also produce water hammer.

Vibration

Excess vibration can cause tube failure as a result of fatigue stress cracks and/ or erosion where the tubes make contact with baffles. Fluid velocities that exceed 6 FPS could cause vibration-induced damage in the tubes, often causing baffle supports to cut into the tubes. Velocity-induced vibrations may also cause fatigue failures by hardening the tubes at the contact points between baffles or in U-Bend segments, resulting in cracks and splits.

Thermal fatigue

Tubes, predominantly in the U-bend sections, can fail as a result of fatigue from accumulated stresses related to constant thermal cycling. This problem is significantly aggravated as the temperature difference across U-bends increases.

About the Author

Sanjeev Rastogi is a mechanical engineer and a post graduate in management from BITS Pilani. After working in Grasim for 12 years, he has been with Blue Star for 6 years in Service Specialists Group. He is a certified TAB professional from NEBB (National Environmental Balancing Bureau, USA), the premier International Certification Association of firms that deliver high performance building systems.

Freeze-up

Freeze failure is most commonly found in evaporators. This failure is due to temperature drop below the freezing point of circulating fluid. Typical freeze-ups are a result of malfunction of a thermal protection system or inadequate antifreeze solutions (brine).

Result of Tube Failure

When a tube fails in a chiller, water enters the refrigerant side of the chiller. Water mixes with the refrigerant and forms an acid, which attacks the internal metal surfaces of the machine. The resulting damage can be catastrophic, rendering a unit beyond repair. *Figure 2* shows the cooler of a centrifugal chiller where, due to tube leakage, water entered the shell and full corrosion on shell side took place. This breakdown required the replacement of the cooler at a cost of Rs.30 lacs.

Figure 2: Corrosion of cooler shell due to water

Types of Tube Failure

Figure 3 to *8* depict different types of tube failures in heat exchangers.

Figure 3: ID Corrosion

Figure 4: ID Pitting

Figure 5: OD Corrosion

Figure 6: Radial Crack

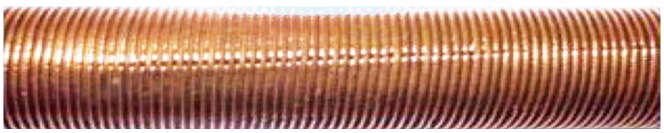


Figure 7: Longitudinal Crack

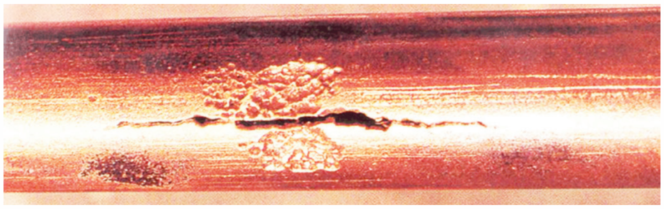


Figure 8: Stress Corrosion Crack

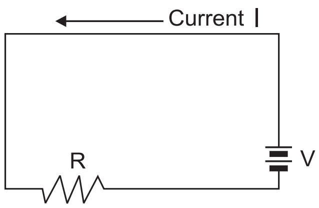
Solution: Predictive Maintenance Through ECT

Eddy Current Testing (ECT) can detect potential failures, allowing repairs to be made prior to a failure. ECT is one of the several methods that use the principle of electromagnetism as the basis for conducting non-destructive examinations. It is a means of checking the condition of the tubes in a heat exchanger. ECT is based on the induction of electromagnetic field in the component being examined and can detect various forms of internal and external damage. It uses an internal probe specifically designed for the tube ID. If the probe encounters ID or OD defects as it is pulled through the tube, the eddy currents are interrupted, causing an impedance change in the coils which is measured by the ECT equipment.

Generation of Eddy Currents

In 1824, Oersted discovered that current passing though a coil creates a magnetic field capable of shifting a compass needle. Seven years later, Faraday and Henry noticed that a moving magnetic field would induce current in an electrical conductor. This process of generating electrical current in a conductor by placing the conductor in a changing magnetic field is called electromagnetic induction or just induction.

- It is called induction because the current is said to be induced in the conductor by the magnetic field.
- The rate at which the magnetic field changes also has an effect on the amount of current or voltage that was induced.



$$I = \frac{V}{R}$$

$$V_L = \frac{d\o}{dt}$$

Where:

V_L = induced voltage in volts

dø/dt = rate of change in magnetic flux in webers/second

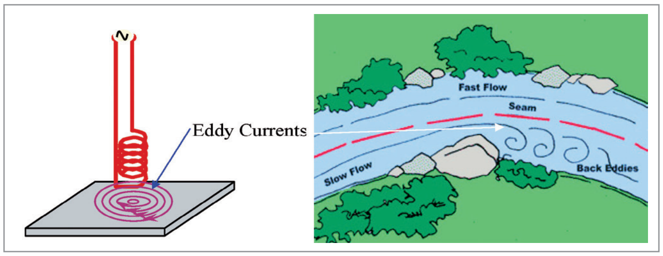


Figure 9: Eddy currents are like eddies formed when a fluid flows in a circular path around obstacles

Eddy currents are induced electrical currents that flow in a circular path. They get their name from "eddies" that are formed when a liquid or gas flows in a circular path around obstacles.

In order to generate eddy currents for an inspection, a probe is used. Inside the probe is a length of electrical conductor which is formed into a coil. Alternating current is allowed to flow in the coil at a frequency based on the type of test specimen involved. There are three characteristics of the specimen that affect the strength of the induced eddy currents:

1. Electrical conductivity of the material
2. Magnetic permeability of the material
3. Amount of solid material in the vicinity of the test coil

Eddy Current Testing of Tubes

The flow pattern of the induced eddy currents in the tubes is circumferential, which is disturbed by the presence of cracks or other discontinuities.

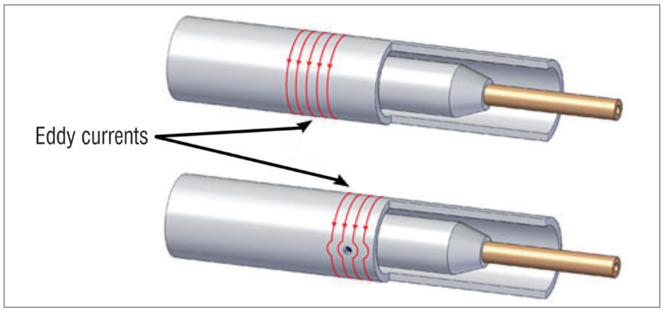


Figure 10: Eddy currents are disturbed by cracks and discontinuities

The presence of a defect in the material affects the flow pattern of the eddy current, which in turn affects its associated magnetic field, and the change is detected by the equipment.

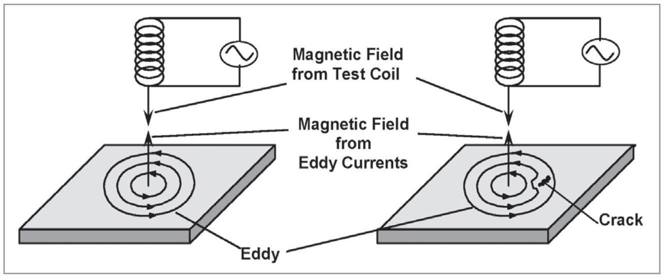


Figure 11: Disturbance in eddy currents is detected by the equipment

Reference Tube

In eddy current testing, signals generated from the test specimen must be compared with known values. Reference standards are typically manufactured from the same or very similar material as the test specimen. This is called a Reference Tube, and is manufactured according to ASME specifications as mentioned below.

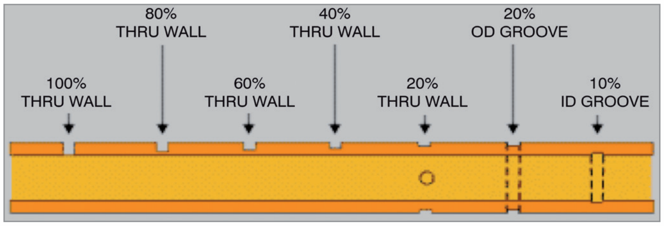


Figure 12: Reference tube as per ASME code

As per the ASME code, the following artificial defects are made on the reference calibration standard:

- A 100% through-wall hole 0.052 in diameter
- Flat – bottomed drilled hole 5/64 in diameter, 80% though the tube wall from the OD
- Flat – bottomed drilled hole 7/64 in diameter, 60% though the tube wall from the OD
- Flat – bottomed drilled hole 3/16 in diameter 40% though the tube wall from the OD
- Four flat – bottomed drilled holes 3/16 in diameter spaced 90° apart in a single plane around the tube circumferential, 20% through the tube wall from the OD
- A 360° circumferential groove, 20% through the tube wall from the OD 1/8 in width
- A 360° circumferential groove, 10% to 20% through the tube wall from the ID, 1/16 in width

Figure 13: ECT probe or Bobbin

ECT Procedure at a Glance

- Tube ID, tube thickness, tube MOC is required to select the reference tube and probe (Bobbin). The operating frequency is determined by the tube material and wall thickness.
- Number and position of baffle plates is required before start up.
- Remove shell end cover and see the physical condition of tubes.
- Tube cleaning by brushing is required to get good results.
- Tube needs to be dry and free from oil to safeguard the probe.
- Before inserting the probe in tubes, check tubes are through, i.e. there are no obstructions for the probe to pass. Obstructions may damage the probe.
- Insert suitable probe in each tube and, while pulling back, record the readings.

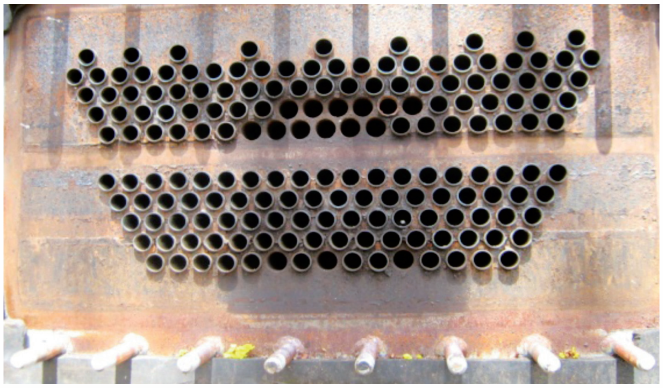


Figure 14: Visual inspection of chiller tubes

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Figure 15: Comparing test results with specimen tube data

- With the help of associated software, compare the results with specimen tube data.
- Print the summary report.
- As per standard practice, tubes having more than 80% defects need to be plugged for safer working of the chiller. Also, as per standard practice, manufacturers recommend plugging of a maximum 10% tubes. This may vary depending on the loading pattern at site for cooler and ambient condition for condenser.

Advantages of Eddy Current Testing

- Sensitive to small cracks and other defects
- Detects surface and near surface defects
- Inspection gives immediate results with portable equipment
- Minimum part preparation is required

Limitations of Eddy Current Testing

- Only conductive materials can be inspected
- Surface must be accessible to the probe
- Skill and training required is more extensive than other techniques
- Surface finish and roughness may interfere with test results
- Reference standards are needed for setup
- Flaws that lie parallel to the probe coil winding and probe scan direction are undetectable
- For bundle tube heat exchangers, flexible probe is required

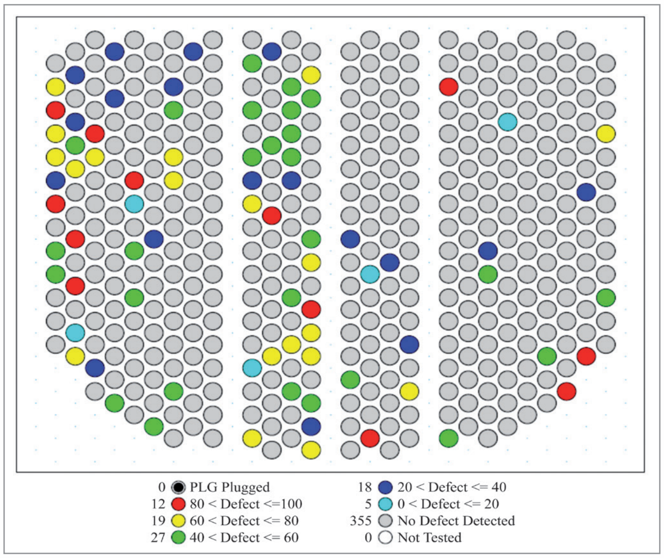

Figure 16: Plugging tubes based on test results

Conclusion

Eddy Current Testing is a tool which can be effectively used to inspect and monitor tube health in a heat exchanger. Since the first ever use of ECT for industrial purpose in 1933, probe technology and data processing have now advanced to the point where ECT is recognized as being fast, simple, and accurate.The technology is now used in the HVAC industry for the detection of surface or near-surface defects in tubes. Regular inspection can help keep track of defect development in the tubes. ❖

ABC of Eddy Current Testing

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Eddy Current Testing (ECT) is an important non-destructive testing (NDT) method being used widely in copper based product manufacturing/ user industry under *ASTM E-243*. Typical applications include; electrical conductivity measurement, determination of material homogeneity, as also surface and sub-surface flaw detection in semis like tubes.

In simple terms, the principle of ECT is based on generation of a magnetic field by passing an alternate current. In order to generate eddy currents for an inspection, a probe or coil is used. Inside the probe is a length of electrical conductor which is formed into a coil. Alternating current is allowed to flow in the coil at a particular frequency.

A magnetic field forms in and around the coil as the alternating current flows through the coil. When an electrically conductive material (e.g. copper tube) is placed in the coil's dynamic magnetic field, eddy currents are induced in the material because of electromagnetic induction.

When an electrically conductive material is placed within or brought near a test coil carrying alternating current and thus into a magnetic field, eddy currents are induced within the material. The induced eddy currents flowing in the material are dependent on the electrical conductivity and magnet permeability of the material and the surface defects. The defects or the variation in the conductivity and permeability cause distortions in the eddy current flow, which in turn results in impedance change. The signal due to change in impedance is amplified, filtered, displayed and processed.

Several defects can be detected by ECT, which include;

- Cracks
- Folds
- Laminations
- Pin holes
- Porosity

Today, eddy current testing has become an integral part of copper tube manufacturing and utilization in AC&R industry. It is now possible to go for 100% eddy current inspection of copper tubes prior to dispatch – thus ensuring the required quality in each lot. *ASTM E-243* procedures are applicable for tubes with outside diameter up to 3-1/8" (79.4 mm).