IS 15540 (2004): Recommendaed practice for eddy current testing of installed non-ferromagnetic heat exchanger tubing using dual frequency method [MTD 21: Non-Destructive Testing]

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*भारतीय मानक*

# दोहरी आवृति प्रणाली के प्रयोग से स्थापित गैरफैरोमैगनेटिक ऊष्मा एवं चेन्जर नलीय के भँवर धारा परीक्षण हेतु अनुशंसित रीति

*Indian Standard*

# RECOMMENDED PRACTICE FOR EDDY CURRENT TESTING OF INSTALLED NON-FERROMAGNETIC HEAT EXCHANGER TUBING USING DUAL FREQUENCY METHOD

ICS 77.040.20



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NEW DELHI 110002

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**Price Group 3**

Non-destructive Testing Sectional Committee, MTD 21

FOREWORD

This Indian Standard was adopted by the Bureau of Indian Standards, after the draft finalized by the Non-destructive Testing Sectional Committee had been approved by the Metallurgical Engineering Division Council.

This standard is intended to be a guide for eddy current testing of installed non-ferromagnetic heat exchanger tubing using dual frequency method. The purpose of this standard is the detection and evaluation of particular types of degradation of tube which could result in tube failure during service.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 1960 'Rules for rounding off numerical value (*revised*)'. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

*Indian Standard*

# RECOMMENDED PRACTICE FOR EDDY CURRENT TESTING OF INSTALLED NON-FERROMAGNETIC HEAT EXCHANGER TUBING USING DUAL FREQUENCY METHOD

## 1 SCOPE

This standard describes procedures to be followed during dual frequency eddy current testing (using an internal bobbin type differential coil assembly) of non-ferromagnetic tubes that have been installed in a heat exchanger. The procedure recognizes the inadequacy of inspection of the installed tubes for defects and other forms of deterioration, specially those that occur under the support of baffle plates, by a single frequency eddy current test method. The document addresses the requirements of scheduled maintenance inspection of heat exchangers, either to examine the condition of the tubes after installation, or to establish the baseline data for evaluating subsequent performance of the product after exposure to various environmental conditions. The purpose is detection and evaluation of particular types of degradation of tube integrity which could result in tube failure during service.

## 2 TERMINOLOGY

For the purpose of this standard, the following definitions shall apply.

**2.1 Analysis, Impedance** — An analytical method of correlating changes in the amplitude; phase or quardrature components, or all these, of a test signal voltage to the electromagnetic conditions within the test specimen.

**2.2 Analysis, Phase** — An instrumentation technique which discriminates among signals from discontinuity in the test part by the changes in the phase angle produced.

**2.3 Coil** — Turns of conductor wound to produce a magnetic field when current passes through the conductor.

**2.4 Coil, Bobbin** — A coil or coil assembly used for eddy current testing by insertion into the tubes.

**2.5 Coils, Differential** — Two or more coils electrically connected in series and in opposition such that any electromagnetic condition which is not common to the areas of the tube being tested will produce an unbalance in the system and thus be detected.

**2.6 Depth of Penetration** — The depth at which the induced magnetic field strength or intensity has decreased to 37 percent of its surface value. The depth of penetration is an exponential function of the test frequency, conductivity and permeability of the material. Synonymous terms are standard depth of penetration and skin depth.

**2.7 Fill Factor** — The ratio of the square of the diameter of a bobbin coil to the square of the inside diameter of the tubular test specimen.

**2.8 Frequency, Test** — The number of cycles per second of alternating electric current passing in the coil. Eddy current of the same frequency is induced in the material.

**2.9 Reference Standard** — A tube with artificial discontinuities used for establishing the test sensitivity setting and for periodically checking and adjusting sensitivity setting as and when required. The discontinuities are either:

a) Flat bottomed or through wall holes of different diameter and depth, and

b) Longitudinal and transverse notches on the inner and outer surfaces of the tube.

**2.10 Basis Frequency** — The basis frequency is that test frequency selected for the examination which provides responses from known artificial defects in the calibration or reference standard tube.

**2.11 Auxiliary Frequency** — The test frequency which is additionally chosen in dual frequency testing for suppression of signal from an unwanted source.

## 3 SUMMARY OF PRACTICE

The examination is to be performed by passing a differential bobbin type probe through each tube of the heat exchanger. These probes are energized with alternating currents at two different frequencies. The electrical impedance of the probe is modified by the proximity of the tube. The important factors for the modification are the tube dimensions, electrical conductivity, and metallurgical conditions or physical discontinuities in the tube material. During passage through the tube, changes in electromagnetic response caused by these variables in the tube produce electrical signals which are processed so as to produce an appropriate combination of visual displays, audio alarms, temporary or permanent records, or a combination thereof. The specific requirements shall depend on the user's needs.

## 4 SIGNIFICANCE

**4.1** Eddy current testing is a non-destructive method of locating discontinuities in tubing made of electrically conducting material. Signals can be produced by discontinuities located either on the inner or the outer surfaces of the tube, or by discontinuities within the tube wall. When using an internal bobbin probe, the density of eddy currents decreases very rapidly and exponentially as the distance from the internal surface increases. Therefore the amplitude and detection sensitivity for outer surface discontinuities decreases correspondingly.

**4.2** Single frequency techniques for testing have the disadvantage of interference from extraneous sources, the most predominant being the support or baffle plates in an installed heat exchanger. The use of dual frequency helps to eliminate the contribution of the extraneous source and improves the detectability of defects especially those under the support plates.

**4.3** The purpose of dual frequency examination is to facilitate the evaluation of the condition of each heat exchanger tube, and in assessing the likelihood of failure during service even in the proximity of baffle or support plate.

## 5 EQUIPMENT

### 5.1 Electronic Equipment

**5.1.1** The electronic equipment shall be capable of energizing the differential probe coils with alternating currents of the suitable frequencies simultaneously, and shall be capable of sensing changes in the electromagnetic response of the probe. The equipment shall provide phase and amplitude information.

**5.1.2** The equipment shall be capable of mixing the output from the two channels, that is to subtract the Channel 2; signals from Channel 1. This is done by weighting and phase rotating the signals from Channel 2. Channel 1 signals are unmodified before mixing. The mixer shall subtract Channel 2 from Channel 1 and the output amplified and phase rotated to form the mixer output.

### 5.2 Test Coils

Test coil shall be so designed, that it will have impedance matching with the equipment will be capable of inducing current the tune and sensing changes in the electrical characteristics of the tube. The test coil diameter shall be selected to yield the largest practical fill factor. In the differential coil probe system, the reference coil is identical to, and on the same longitudinal axis as the test coil. In this configuration, both coils function simultaneously as test and reference coils, and the instrument responds only to unbalance voltage between the two coils.

### 5.3 Read Out Devices

A X-Y storage display oscilloscope is used as a readout device to enable phase discrimination and improve the ability to detect all types of defects. The oscilloscope normally displays the locus of the impedance values due to the discontinuities.

### 5.4 Recording Devices

Magnetic tape recorder and strip chart recorder are the two commonly used recording devices during any inspection. The magnetic tape recorder can be used to store the inspection data and to playback the same on the oscilloscope at a future data for analysis. The strip chart recorder can be used to generate a hard copy of the variations of the components of the complex impedance as a function of time. Both the devices serve as a source of permanent documentation of the inspection.

### 5.5 Driving Mechanism

A means of mechanically traversing the probe coil through the tubes may be used to improve on the rate of inspection and precise location of the defect. Whether the probe is traversed through the tube manually or mechanically, care should be taken to maintain as uniform a probe speed as possible to produce repeatable indications of discontinuities when using speed sensitive equipment.

### 5.6 Phase Selective System

An instrumentation system that includes built in circuitry to indicate phase differences in the response signals relative to the excitation signal. This ability aids in better characterization of defect signals. Phase may also provide information on defect position relative to the tube wall surfaces, and this information may be used to estimate the relative severity of defects.

## 6 CALIBRATION PROCEDURE

**6.1** The reference tube with artificial defects shall be manufactured from a length of tubing of the same nominal size and chemical composition as those to be examined in the heat exchanger. The intent of this reference standard is to verify the sensitivity of defect detection by the procedure and equipment adopted. The standard shall contain calibration discontinuities as follows:

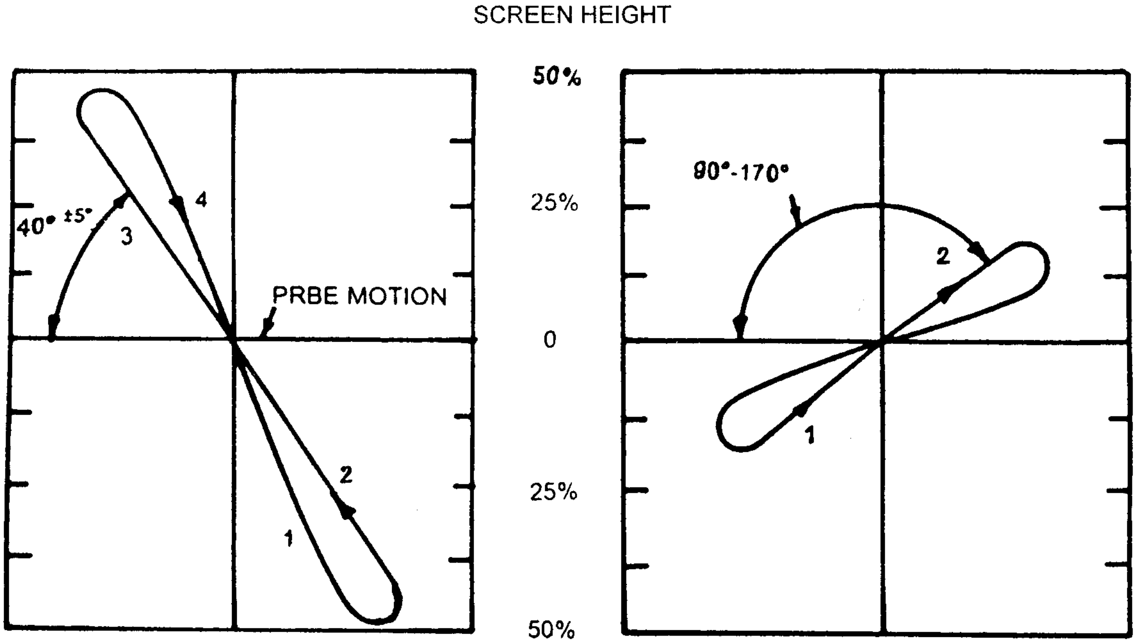
a) A single hole drilled 100 percent through the wall of 1.3 mm diameter for 20 mm OD tubing and smaller and of 1.7 mm for larger diameter tubing.
b) Four flat bottomed holes 4.75 mm diameter, spaced 90° apart in a single plane around the tube circumference, 20 percent through the tube wall from the OD.
c) A 360° circumferential groove, 3.20 mm wide and 10 percent through from the inner surface of the tube.
d) All calibration discontinuities shall be spaced not less than twice the length of the sensing unit of the inspection equipment so that they can be identified from each other and from the end of the tube.
e) Each calibration discontinuity or defect shall be identified by a serial number. Their locations in the standard tube should be marked in an appropriate but unambiguous manner.
f) The dimensions of the calibration discontinuities and the response of the eddy current test system to these discontinuities should be recorded for the continued and repeated use.

**6.2** A ring made of a material similar to the tube supports of the heat exchanger being examined shall be used to simulate the signals expected from tube supports. The width of the ring (the dimension parallel to the longitudinal axis of the tube, when the ring is slipped over the tube) should be same as the normal thickness of the tube support in the heat exchanger to be tested. The inside diameter of the ring should be equal to the nominal inside diameter of the holes in the tube support, and the minimum outside diameter of the ring should equal the inside diameter plus twice the width of the ring in the axial direction.

**6.3 Basis Frequency ($F_1$) Calibration Procedure**

The eddy current test system shall be calibrated using the reference standard described in **6.1**. The following procedure shall be adopted:

a) Adjust the ET instrument for a chosen so that the phase angle of signal from the 20 percent flat bottomed holes is between 50° and 130° rotated clockwise from the signals of the through wall hole (*see* Fig. 1).
b) The trace display for the four 20 percent flat bottomed holes shall be generated. When pulling the probe, in the directions illustrated in Fig. 1 down and to the left first, followed by an upward motion to the right, followed by a downward motion to return to the point of origin.
c) The sensitivity shall be adjusted to produce a response through the wall hole with an




1A 100 Percent Through Wall Signal

1B 20 Percent Through Wall Signal

FIG. 1 EXAMPLES OF TYPICAL SIGNALS FROM A PROPERLY CALIBERATED DIFFERENTIAL COIL PROBE SYSTEM amplitude of minimum 50 percent of the full CRT screen height. At this setting, the phase and amplitude of signals from each applicable calibration discontinuity shall be clearly distinguishable.

d) Adjust the phase control so that the signal response due to probe wobble is positioned along the horizontal axis of the display within ± 5°. The responses from the calibration holes shall be maintained as described above.

**6.4 Auxiliary Frequency ($F_2$) Calibration**

The auxiliary frequency for purposes of support plate elimination shall generally be around half the basis frequency, but may be any suitable value determined by experiment. It should show a strong support plate signals, which is larger relative to a defect signal than in the case of basis frequency.

NOTE — Any ratio of basis frequency to auxiliary frequency may be used with the precaution that simple multiples and sub-multiples may cause interference between the two channels. This will be seen as increased spot size or even as circles, but may be simply remedied by a small change in auxiliary frequency setting. Once the auxiliary frequency is fixed, small alterations either side of this value should be made to ensure that it is not close to an interference condition.

## 7 EQUIPMENT STANDARDIZATION AND SETUP PROCEDURE

**7.1** Set the basis and auxiliary frequencies in Channel 1 and Channel 2 respectively on the equipment.

**7.2** Move the probe to and fro over a calibration defect in the reference tube and set Channel 1 gain for required amplitude.

**7.3** Move the probe to be near the support plate (ensure that the support plate is in a defect free region); then with the probe passing to and fro in this area, set Channel 2 gain and phase so that the support plate signal is approximately at the time phase as Channel 1 but is slightly larger in amplitude (approximately 20 percent larger).

**7.4** Adjust mixer input controls (vertical and horizontal attenuations, phase) until the support plate signal as seen on Channel 2 matches the support plate signals of Channel 1. The mixer output signal will reduce in amplitude as the two support plate signals are better matched.

**7.5** Adjust till mixer output becomes minimum.

**7.6** Move the probe to a defect under a support plate. The defect should now show up clearly on the mixer output. The controls of the mixer module may now be adjusted in phase and amplitude for visual inspection and recording.

NOTE — The power supply to the equipment, should be free from voltage fluctuations and spikes. This can be achieved by using a voltage stabilizer with line filter. A good electrical earth should also be provided.

## 8 CORRELATION OF SIGNALS TO ESTIMATE DEPTH OF DISCONTINUITIES

The depth of discontinuities is primarily shown by the phase angle of the output signal. A relationship of reference depths *versus* signals phase angle shall be developed prior to the actual examination at site. The following procedure may be followed:

a) A standard tube length shall be taken from the same nominal size (diameter and wall thickness) and material (chemical composition and product form) as the tubes to be examined.

b) Artificial defects in the form of flat bottomed holes drilled to varying depths shall be generated.

c) Drilled holes in the calibration standard (*see* **6.1**) may be used where additional depths are required.

d) When drilled holes are used, the dimensions shall be as follows:

   1) Four flat bottomed drill holes 4.75 mm diameter, 20 percent through the wall [same as in calibration tube standard (*see* **6.1**)].

   2) One flat bottomed drill hole 4.75 mm diameter × 40 percent through the wall from the outside surface.

   3) One flat bottomed drill hole 2.75 mm diameter × 60 percent through the wall from the outside surface.

   4) One flat bottomed drill hole 2.0 mm diameter × 80 percent through the wall from the outside surface.

   5) One through the wall drilled hole [same as in calibration standard (*see* **6.1**)].

e) The change in phase angle of the signal may be used to estimate depth of the defects which exhibit a known regularity in their growth history. Standards representative of the defect shall be used to generate phase angle *versus* depth calibration curve.

## 9 PROCEDURE OF INSPECTION

**9.1** The tubes in the heat exchanger should be as clean and dry as practical before eddy current examination is attempted.

**9.2** Calibrate the eddy current test system at the start of each examination and check at appropriate intervals or whenever improper functioning of the system is observed. If improper functioning occurs, resulting in a loss of equipment sensitivity, recalibrate the system in accordance with **6.1** and re-examine all tubes examined since the last calibration. The time interval between calibration shall be decided by the customer or user.

**9.3** Note particularly the tubes which produce signals that exceed a specified maximum with respect to a pre-specified artificial defect.

**9.4** Data shall be recorded as the probe traverses the tube.

**9.5** Since there may be a need to compare the results of this test procedure, as applied to a particular tube or heat exchanger, with the results of prior or subsequent examination, it is important that a record be kept of each examination. Tubes with indications in excess of a predetermined level should be recorded to identify the affected tube, its location, and when necessary to describe the level of response.

NOTE — The maximum traversing speed is determined by the frequency response of the electronic system employed. For the currently available commercial equipment, the traverse speed during examination is recommended not to exceed 0.3 m/s. Higher traverse speeds may be used, if adequate frequency response and sensitivity to the applicable calibration discontinuities can be demonstrated.

## 10 REPORT

**10.1** A report documenting the results of each examination should contain the following information.

**10.1.1** *General*

a) The dates on which the examination was conducted.
b) The owner of the heat exchanger and its exact location.
c) The manufacturer of the heat exchanger, its serial number and the location of the tubes examined in the bundle.
d) The name of the individual responsible for conducting the examination and the name of a representative of the heat exchanger owner responsible for approving the procedure.
e) Tube material, diameter and wall thickness.

**10.1.2** *Details of Eddy Current Equipment Calibration*

a) Manufacturer of the equipment and its type,
b) Equipment calibration procedure,
c) Size of the probe and its type,
d) A description of the calibration discontinuities used,
e) A description of the response from calibration discontinuities in the reference tube and the procedure,
f) Equipment settings for frequency and signal mixing and the frequencies used,
g) Scanning speed during examination, and
h) Details of recording equipment and procedure.

**10.1.3** *Results*

**10.1.3.1** The location of significant discontinuities in the tubes, their amplitude, phase and other relevant characteristics to be noted down.

**10.1.3.2** An interpretation of the results with recommendations.

**10.2** Additional information, if necessary.

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