Designation: E 243 – 97

Standard Practice for Electromagnetic (Eddy-Current) Examination of Copper and Copper-Alloy Tubes [1]

This standard is issued under the fixed designation E 243; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This practice[2] covers the procedures that shall be followed in eddy-current examination of copper and copper-alloy tubes for detecting discontinuities of a severity likely to cause failure of the tube. These procedures are applicable for tubes with outside diameters to 3⅛ in. (79.4 mm), inclusive, and wall thicknesses from 0.017 in. (0.432 mm) to 0.120 in. (3.04 mm), inclusive, or as otherwise stated in ASTM product specifications; or by other users of this practice. These procedures may be used for tubes beyond the size range recommended, upon contractual agreement between the purchaser and the manufacturer.

1.2 The procedures described in this practice are based on methods making use of encircling annular test coil systems.

1.3 The values stated in inch-pound units are to be regarded as the standard.

NOTE 1—This practice may be used as a guideline for the examination, by means of internal probe test coil systems, of installations using tubular products where the outer surface of the tube is not accessible. For such applications, the technical differences associated with the use of internal probe coils should be recognized and accommodated. The effect of foreign materials on the tube surface and signals due to tube supports are typical of the factors that must be considered.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

B 111 Specification for Copper and Copper-Alloy Seamless Condenser Tubes and Ferrule Stock[3]

B 395 Specification for U-Bend Seamless Copper and Copper Alloy Heat Exchanger and Condenser Tubes[3]

B 543 Specification for Welded Copper and Copper-Alloy Heat Exchanger Tube[3]

E 543 Practice for Evaluating Agencies that Perform Nondestructive Testing[4]

E 1316 Terminology for Nondestructive Examinations[4]

2.2 *Other Documents:*

SNT-TC-1A Recommended Practice for Nondestructive Testing Personnel Qualification and Certification[5]

ANSI/ASNT CP-189 ASNT Standard for Qualification and Certification of Nondestructive Testing Personnel[5]

MIL-STD-410 Nondestructive Testing Personnel Qualification and Certification[6]

3. Terminology

3.1 *Definitions of Terms Specific to this Standard*

3.1.1 The following terms are defined in relation to this standard.

3.1.1.1 *artificial discontinuity calibration standard*—a standard consisting of a selected tube with defined artificial discontinuities, used when adjusting the system controls to obtain some predetermined system output signal level. This standard may be used for periodic checking of the instrument during a test.

3.1.1.2 *percent maximum unbalance calibration standard*—a method of calibration that can be used with speed-insensitive instruments (see 3.1.1.4). The acceptance level of the test is established at the operating test frequency as an accurately calibrated fraction of the maximum unbalance signal resulting from the end effect of a tube. Any low-noise tube from the production run having a squared end may be used

[1] This practice is under the jurisdiction of ASTM Committee E-7 on Nondestructive Testing and is the direct responsibility of Subcommittee E07.07 on Electromagnetic Methods.

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[2] For ASME Boiler and Pressure Vessel Code applications see related Practice SE-243 in the Code.

[3] *Annual Book of ASTM Standards*, Vol 02.01.

[4] *Annual Book of ASTM Standards*, Vol 03.03.

[5] Available from American Society for Nondestructive Testing, 1711 Arlingate Plaza, PO Box 28518, Columbus, Ohio 43228-0518.

[6] Available from Standardization Documents Order Desk, Building 4 Section D, 700 Robbins Avenue, Philadelphia, PA 19111-5904, Attn: NPODS

as this standard. This standard may be used for periodic checking of the instrument during a test.

3.1.1.3 *electrical center*—the center established by the electromagnetic field distribution within the test coil. A constant-intensity signal, irrespective of the circumferential position of a discontinuity, is indicative of electrical centering. The electrical center may be different from the physical center of the test coil.

3.1.1.4 *speed-sensitive equipment*—test equipment that produces a variation in signal response with variations in the test speed. Speed-insensitive equipment provides a constant signal response with changing test speeds.

3.1.1.5 *off-line testing*—eddy-current tests conducted on equipment that includes the test coil and means to propel individual tubes under test through the coil at appropriate speeds and conditions.

3.1.1.6 *on-line testing*—eddy-current tests conducted on equipment that includes the test coil and means to propel tubes under test through the coil at appropriate speeds and conditions as an integral part of a continuous tube manufacturing sequence.

3.2 *Definitions of Terms*—Refer to Terminology E 1316 for definitions of terms that are applicable to nondestructive examinations in general.

4. Summary of Practice

4.1 Testing is usually performed by passing the tube lengthwise through a coil energized with alternating current at one or more frequencies. The electrical impedance of the coil is modified by the proximity of the tube, the tube dimensions, electrical conductivity and magnetic permeability of the tube material, and metallurgical or mechanical discontinuities in the tube. During passage of the tube, the changes in electromagnetic response caused by these variables in the tube produce electrical signals which are processed so as to actuate an audio or visual signaling device or mechanical marker which produces a record.

5. Significance and Use

5.1 Eddy-current testing is a nondestructive method of locating discontinuities in a product. Signals can be produced by discontinuities located either on the external or internal surface of the tube or by discontinuities totally contained within the walls. Since the density of eddy currents decreases nearly exponentially as the distance from the external surface increases, the response to deep-seated defects decreases.

5.2 Some indications obtained by this method may not be relevant to product quality; for example, a reject signal may be caused by minute dents or tool chatter marks that are not detrimental to the end use of the product. Irrelevant indications can mask unacceptable discontinuities. Relevant indications are those which result from nonacceptable discontinuities. Any indication above the reject level that is believed to be irrelevant shall be regarded as unacceptable until it is demonstrated by re-examination or other means to be irrelevant (see 10.3.2).

5.3 Eddy-current testing systems are generally not sensitive to discontinuities adjacent to the ends of the tube (end effect). On-line eddy-current testing would not be subject to end effect.

5.4 Discontinuities such as scratches or seams that are continuous and uniform for the full length of the tube may not always be detected.

6. Basis of Application

6.1 *Personnel Qualification*—Nondestructive testing (NDT) personnel shall be qualified in accordance with a nationally recognized NDT personnel qualification practice or standard such as ANSI/ASNT CP-189, SNT-TC-1A, MIL-STD-410 or a similar document. The practice or standard used and its applicable revision shall be specified in the purchase specification or contractual agreement between the using parties.

6.2 *Qualification of Nondestructive Testing Agencies*—If specified in the purchase specification or contractual agreement, NDT agencies shall be evaluated and qualified as described in Practice E 543. The applicable edition of Practice E 543 shall be identified in the purchase specification or contractual agreement between the using parties.

7. Apparatus

7.1 *Electronic Apparatus*—The electronic apparatus shall be capable of energizing the test coil with alternating currents of suitable frequencies (for example, 1 kHz to 125 kHz), and shall be capable of sensing the changes in the electromagnetic response of the coils. Electrical signals produced in this manner are processed so as to actuate an audio or visual signaling device or mechanical marker which produces a record.

7.2 *Test Coils*—Test coils shall be capable of inducing current in the tube and sensing changes in the electrical characteristics of the tube. The test coil diameter should be selected to yield the largest practical fill-factor.

7.3 *Driving Mechanism*—A mechanical means of passing the tube through the test coil with minimum vibration of the test coil or the tube. The device shall maintain the tube substantially concentric with the electrical center of the test coil. A uniform speed (±5.0 % speed variation maximum) shall be maintained.

7.4 *End Effect Suppression Device*—A means capable of suppressing the signals produced at the ends of the tube. Individual ASTM product specifications shall specify when an end effect suppression device is mandatory.

NOTE 2—Signals close to the ends of the tube may carry on beyond the limits of end suppression. Refer to 9.5.

8. Reference Standards

8.1 *Artificial Discontinuity Reference Standard*:

8.1.1 The tube used when adjusting the sensitivity setting of the apparatus shall be selected from a typical production run and shall be representative of the purchaser's order. The tubes shall be passed through the test coil with the instrument sensitivity high enough to determine the nominal background noise inherent in the tubes. The reference standard shall be selected from tubes exhibiting low background noise. For on-line eddy-current testing, the reference standard is created in a tube portion existent in the continuous manufacturing sequence or in other forms as allowed by the product specification.

8.1.2 The artificial discontinuities shall be spaced to provide signal resolution adequate for interpretation. The artificial discontinuities shall be prepared in accordance with one of the following options:

(a) A round bottom transverse notch on the outside of the tube in each of three successive transverse planes at 0, 120, and 240° (Fig. 1).

(b) A hole drilled radially through the tube wall in each of three successive transverse planes at 0, 120, and 240° (Fig. 2).

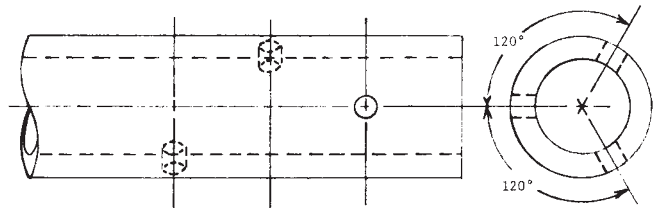
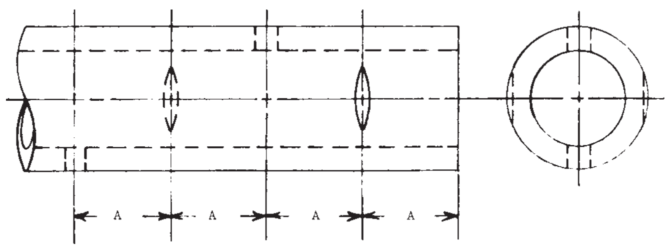


FIG. 2 Reference Standard with Three Holes

(c) One round bottom transverse notch on the outside of the tube at 0° and another at 180°, and one hole drilled radially through the wall at 90° and another at 270°. Only one notch or hole shall be made in each transverse plane (Fig. 3).



NOTE 1—A = Space to provide signal resolution adequate for interpretation.

FIG. 3 Reference Standard with Two Notches and Two Holes

(d) Four round bottom transverse notches on the outside of the tube, all on the same element of the tube (Fig. 4).

(e) Four holes drilled radially through the tube wall, all the same element of the tube (Fig. 5).

8.1.2.1 *Round Bottom Transverse Notch*—The notch shall be made using a suitable jig with a 0.250-in. (6.35-mm) diameter No. 4 cut, straight, round file. The outside surface of the tube shall be stroked in a substantially straight line perpendicular to the axis of the tube. The notch depth shall be in accordance with the ASTM product specification or Appendix X1 if the product specification does not specify and shall

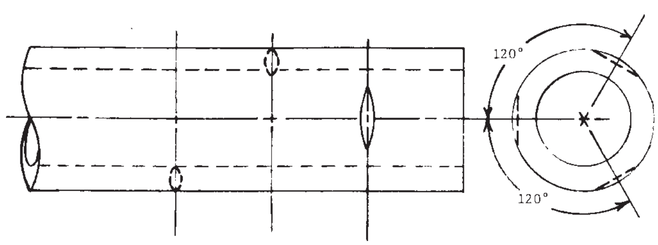
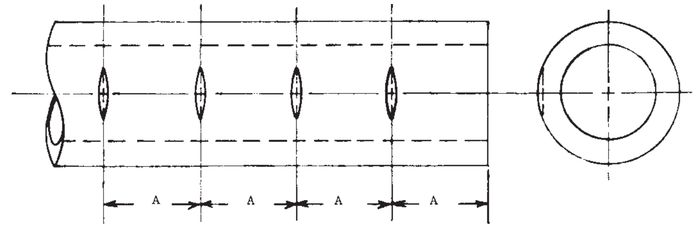
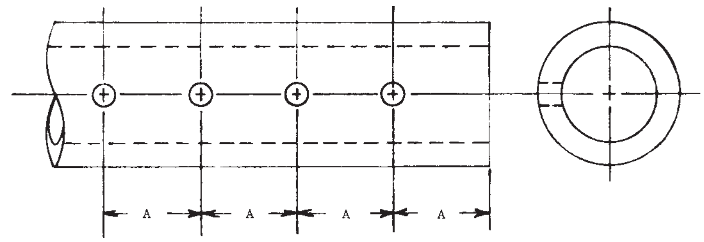


FIG. 1 Reference Standard with Three Notches



NOTE 1—A = Space to provide signal resolution adequate for interpretation.

FIG. 4 Reference Standard with Four Notches in Line



NOTE 1—A = Space to provide signal resolution adequate for interpretation.

FIG. 5 Reference Standard with Four Holes in Line

not vary from the notch depth by more than ±0.0005 in. (±0.013 mm) when measured at the center of the notch (see Table X1.1).[7]

NOTE 3—Tables X1.1 and X1.2 should not be used for acceptance or rejection of materials.

8.1.2.2 *Drilled Holes*—The hole shall be drilled radially through the wall using a suitable drill jig that has a bushing to guide the drill, care being taken to avoid distortion of the tube while drilling. The drilled hole diameter shall be in accordance with the ASTM product specification or Appendix X1 if the product specification does not specify and shall not vary by more than +0.001, −0.000 in. (+0.026 mm) of the hole diameter specified (see Table X1.2) (Note 3).[7]

8.1.2.3 *Other Artificial Discontinuities*—Discontinuities of other contours may be used in the reference standard by mutual agreement between supplier and purchaser.

8.2 *Percent Maximum Unbalance Reference Standard*—This method of standardization shall be used only with speed-insensitive equipment, and equipment specifically designed or adapted to accommodate the use of this calibration method. Maximum unbalance of differential coils is obtained by placing the squared end of a tube in only one of the differential coils and using an accurately calibrated attenuator to obtain the (100 %) maximum unbalance signal. A percentage of the maximum unbalance signal shall define the test acceptance level at a specific operating frequency and this percentage shall be obtained from the ASTM product specification.

8.3 *Other Reference Standards*—Other reference standards may be used by mutual agreement between supplier and purchaser.

[7] Tables X1.1 and X1.2 are extracted from Specifications B 111, B 395, and B 543.

NOTE 4—Artificial discontinuities and the percent of maximum unbalance are not intended to be representative of natural discontinuities or produce a direct relationship between instrument response and discontinuity severity; they are intended only for establishing sensitivity levels as outlined in Section 9. The relationship between instrument response and discontinuity size, shape, and location is important and should be established separately, particularly as related to test frequency.

9. Adjustment and Standardization of Apparatus Sensitivity

9.1 The tube manufacturer shall select equipment, reference standard, and test parameters consistent for the product, unless otherwise agreed upon between manufacturer and purchaser.

9.2 When using the artificial discontinuity reference standard, prepared in accordance with one of the five options, adjust the apparatus to the lowest sensitivity required to detect the following:

9.2.1 For Figs. 1-3: all artificial discontinuities in the standard. The tube speed maintained during standardization shall be the same as the speed used in production testing.

9.2.2 For Figs. 4 and 5: a minimum of two of the four artificial discontinuities as the tube is rotated by 120°- intervals through 0, 120, and 240°, or by 90°- intervals through 0, 90, 180, and 270° on successive passes. The tube speed maintained during standardization shall be the same as the speed used in production testing.

9.3 When using the percent maximum unbalance reference standard, adjust the apparatus to the percent unbalance called for in the ASTM product specification.

NOTE 5—Sensitivity control settings are usually indicated by arbitrary numbers on the control panel of the testing instruments. These numerical settings differ among instruments of different types. It is, therefore, not proper to transfer numerical settings on one instrument to those of another instrument, unless the percent maximum unbalance reference standard is used. Even among instruments of the same design and from the same manufacturer, sensitivity control settings may vary. Undue emphasis on the numerical value of sensitivity control settings is not justified and shall not be used unless referenced accurately to the maximum unbalance signal.

9.4 Discard and replace the tube used as the reference standard when erroneous signals are produced from mechanical, metallurgical, or other damage to the standard.

9.5 Determine the length of tubing requiring suppression of end effect signals by selecting a tube of low background noise and making a series of reference holes or notches at 0.5-in. (12.7-mm) intervals near the end of this special tube. Pass the tube through the test coil at the production test speed with the artificial discontinuities end first, and then with the artificial discontinuities end last. Determine the distance from the tube end at which the signal response from successive discontinuities is uniform with a recording device such as a pen recorder or memory oscilloscope. Use a signal suppression method (photo relay, mechanical switches, or proximity devices are commonly used) to permit testing only when the length of tubing exhibiting uniform signals is within the test coil. The section of tube passing through the test coil during end effect suppression is not tested in accordance with 9.2 or 9.3.

9.5.1 As an option to 9.5, when a recording device is not available, the length of tubing requiring end suppression may be determined by selecting a tube of low background noise and making a reference hole or notch at 6 to 8 in. (152 to 203 mm) from the tube end. Pass the tube through the test coil at the production test speed with the artificial discontinuity end first and then with the artificial discontinuity end last. If the artificial discontinuity is not detected, another artificial discontinuity should be made further from the end. If it is detected, cut off 0.5-in. (12.7-mm) increments from the end of the tube until the artificial discontinuity is no longer detected. The shortest distance from the end that the artificial discontinuity can be detected is that length of tube which shall require end effect signal suppression.

10. Procedure

10.1 Electrically center the tubing in the test coil at the start of the test run. The tube manufacturer may use the artificial discontinuity reference standard or prepare a separate tube for this purpose in accordance with 8.1 and 8.2. Pass the tube through the test system and mechanically adjust its position in the test coil such that the requirements of 9.2 are satisfied.

10.2 Standardize the test system at the start of the test run and at periodic intervals (for example, every 2 h) of continuous operation or whenever improper functioning of the system is suspected.

10.3 Pass the tubes through the test system standardized as described in Section 9.

10.3.1 Accept those tubes that produce output signals conforming to the limits in the applicable ASTM product specification.

10.3.2 Tubes that produce output signals not conforming to the limits in the applicable ASTM product specification may, at the option of the manufacturer, be set aside for re-examination (see 5.2). Upon re-examination, accept the tubes if the output signals are within acceptable limits (10.3.1) or demonstrated by other re-examination to be irrelevant.

10.4 Tubes may be examined at the finish size after the final anneal or heat treatment, or at the finish size prior to the final anneal or heat treatment unless otherwise agreed upon between the supplier and the purchaser.

11. Keywords

11.1 electromagnetic (eddy current) testing; NDT; nondestructive testing; copper; tubing

APPENDIX

(Nonmandatory Information)

X1. TABLES

TABLE X1.1 Notch Depth

Tube Wall Thickness, in.	Tube Outside Diameter, in.		
	Over ¼ to ¾, incl	Over ¾ to 1¼, incl	Over 1¼ to 3⅛, incl
Over 0.017–0.032	0.005	0.006	0.007
Incl 0.032–0.049	0.006	0.006	0.0075
Incl 0.049–0.083	0.007	0.0075	0.008
Incl 0.083–0.109	0.0075	0.0085	0.0095
Incl 0.109–0.120	0.009	0.009	0.011

Tube Wall Thickness, mm	Tube Outside Diameter, mm		
	Over 6 to 19, incl	Over 19 to 32, incl	Over 32 to 79, incl
Over 0.43–0.61	0.13	0.15	0.18
Incl 0.81–1.3	0.15	0.15	0.19
Incl. 1.3–2.1	0.18	0.19	0.20
Incl. 2.1–2.8	0.19	0.22	0.24
Incl. 2.8–3.0	0.23	0.23	0.28

TABLE X1.2 Diameter of Drilled Holes

Tube Outside Diameter	Diameter of Drilled Holes	Drill No.
in.	in.	
¼ to ¾, incl	0.025	72
Over ¾ –1, incl	0.031	68
Over 1–1¼, incl	0.036	64
Over 1¼ –1½, incl	0.042	58
Over 1½ –1¾, incl	0.046	56
Over 1¾ –2, incl	0.052	55

Tube Outside Diameter	Diameter of Drilled Holes	Drill No.
mm	mm	
6.0–19.0, incl	0.635	72
Over 19.0–25, incl	0.785	68
Over 25–32, incl	0.915	64
Over 32–38, incl	1.07	58
Over 38–45, incl	1.17	56
Over 45–50, incl	1.32	55