Designation: E1606 – 15

Standard Practice for Electromagnetic (Eddy Current) Examination of Copper and Aluminum Redraw Rod for Electrical Purposes[1]

This standard is issued under the fixed designation E1606; 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.

1. Scope*

1.1 This practice covers the procedures that shall be followed in electromagnetic (eddy current) examination of copper and aluminum redraw rods for detecting discontinuities or imperfections of a severity likely to cause failure or markedly impair surface quality of the rod. These procedures are applicable for continuous lengths of redraw rod in diameters from ¼ to 1⅜ in. (6.4 to 35 mm) suitable for further fabrication into electrical conductors.

1.2 This practice covers redraw rod made from tough-pitch or oxygen-free coppers. It can also be used for other types of copper such as fire-refined high conductivity rod. It is also appropriate for aluminum and other nonferrous alloys used for electrical purposes.

1.3 The procedures described in this practice are based on methods for making use of differential or absolute stationary encircling annular test coil systems.

1.4 This practice does not establish acceptance criteria. Acceptance criteria must be established by the using parties.

1.5 *Units*—The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.6 *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:*[2]

E543 Specification for Agencies Performing Nondestructive Testing

E1316 Terminology for Nondestructive Examinations

E1033 Practice for Electromagnetic (Eddy Current) Examination of Type F-Continuously Welded (CW) Ferromagnetic Pipe and Tubing Above the Curie Temperature

E2884 Guide for Eddy Current Testing of Electrically Conducting Materials Using Conformable Sensor Arrays

2.2 *ASNT Documents:*[3]

SNT-TC-1A Recommended Practice for Personnel Qualification and Certification in Nondestructive Testing

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

2.3 *AIA Standard:*[4]

NAS 410 Certification and Qualification of Nondestructive Testing Personnel

2.4 *ISO Standard:*[5]

ISO 9712 Non-Destructive Testing—Qualification and Certification of NDT Personnel

3. Terminology

3.1 Standard terminology relating to electromagnetic testing may be found in Terminology E1316, Section C: Electromagnetic Testing.

4. Summary of Practice

4.1 The examination is performed by passing the rod lengthwise through a differential or absolute coil, or both, energized with alternating current at a fixed frequency. The electrical impedance of the test coil is affected by rod vibrations, rod dimensions, electrical conductivity of the rod material, and metallurgical or mechanical discontinuities in the rod surface. During passage of the rod, the changes in impedance caused by these variables in the rod produce electrical signals that are processed so as to actuate an audio,

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

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from American Society for Nondestructive Testing (ASNT), P.O. Box 28518, 1711 Arlingate Ln., Columbus, OH 43228-0518, http://www.asnt.org.

[4] Available from Aerospace Industries Association of America, Inc. (AIA), 1000 Wilson Blvd., Suite 1700, Arlington, VA 22209-3928, http://www.aia-aerospace.org.

[5] Available from International Organization for Standardization (ISO), ISO Central Secretariat, BIBC II, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, http://www.iso.org.

***A Summary of Changes section appears at the end of this standard**

visual, or electrical signaling device. These electrical signals can also be displayed and stored digitally or used to actuate mechanical markers to produce a record of indications.

4.2 The relative severity and type of imperfections may be indicated by eddy current signal amplitude, phase, or both with automatic display and recording. Alarm levels can be set to provide data for counting and recording of event totals in various categories, as well as for providing outputs for actuating other devices. Because the responses from natural discontinuities may vary significantly from those of artificial discontinuities, care must be exercised in establishing sensitivity and acceptance criteria for the examination.

5. Significance and Use

5.1 Eddy current instrumentation provides timely and useful information regarding the acceptability of copper and aluminum rod for quality control purposes as well as providing for early warning that unacceptable rod is being produced. Eddy current testing is a nondestructive method of locating surface discontinuities in a product. Signals can be produced by discontinuities located on the surface of the rod. Since the density of eddy currents decreases nearly exponentially as the distance from the surface increases, deep-seated defects may be undetected.

5.1.1 An exception is the detection of subsurface ferromagnetic inclusions with an additional, or shared, winding enveloped in a DC magnetic field and the addition of appropriate instrumentation. The coil winding, acting as a transducer, generates a voltage as the magnetized inclusion passes through, providing an electrical signal separate from the eddy current response to surface imperfections. The rod is transparent to the DC effect allowing high sensitivity to ferromagnetic inclusions, in the absence of eddy current noise. The method is inherently speed sensitive but is enhanced by high throughput speeds enabling the detection of small subsurface ferromagnetic inclusions which are particularly detrimental to rod quality.

5.2 Some indications obtained by this practice may not be relevant to product quality. For example, a signal may be caused by minute flaws or irregularities, by anomalies in the material, or a combination thereof, that are not detrimental to the end use of the product. Nonrelevant indications, referred to as "noise," can mask unacceptable discontinuities. On the other hand, relevant indications are those that may result from unacceptable discontinuities and should be determined by agreement between the user and the supplier. Any indication that is believed to be irrelevant shall be regarded as unacceptable until it is demonstrated by reexamination or other means to be nonrelevant.

6. Basis of Application

6.1 *Personnel Qualification*—If specified in the contractual agreement, personnel performing examinations to this practice shall be qualified in accordance with a nationally recognized nondestructive testing (NDT) personnel qualification practice or standard, such as ANSI/ASNT-CP-189, SNT-TC-1A, NAS-410, ISO 9712, or a similar document and certified by the employer or certifying agency, as applicable. The practice or standard used and its applicable revision shall be identified in the contractual agreement between the using parties.

6.2 *Qualification of Nondestructive Testing Agencies*—If specified in the contractual agreement, NDT agencies shall be qualified and evaluated as described in Practice E543. The applicable edition of Practice E543 shall be specified in the contractual agreement.

7. Apparatus

7.1 *Electronic Apparatus,* differential or absolute systems (or both) capable of energizing the test coil with alternating currents of suitable frequencies (for example, in the range from 1 kHz to 1 MHz), and capable of sensing the changes in the electrical impedance of the coils. Electrical signals that are processed so as to actuate an audio, visual, or electrical signaling device. These electrical signals can also be displayed and stored digitally or used to actuate mechanical markers to produce a record of indications.

7.1.1 The electronic apparatus should also be able to provide an electrical signal, either internally or externally, that can be used to test the apparatus without having a test coil connected. This electrical signal is used to verify sensitivity levels and alarm threshold for the apparatus.

7.1.2 The electronic apparatus should have an adjustable filter that includes in its bandwidth the anticipated flaw signal frequencies.

7.1.3 The electronic apparatus may have a "filter out" configuration that allows the adjustable filter to be bypassed during system standardization.

7.2 *Test Coils,* capable of inducing currents in the rod and sensing changes in the electrical characteristics of the rod. The test coil diameter should be selected to yield the largest practical fill factor. The coil assembly, whether differential or absolute coils, consists of one or more electrical coils, cooling apparatus that is adequate to maintain the proper coil-operating temperature and prevent thermal damage, if needed, and positioning mechanisms for adjusting and maintaining a constant spacing between the coil and the rod surface. Some assemblies may include mechanical guides to prevent physical damage to the coils by contact with the product.

7.3 *Driving Mechanism*—An optional mechanical means may be used for passing the reference standard through the test coil with minimum vibration of the test coil or rod. If used, the mechanical device shall maintain the rod substantially concentric with the electrical center of the test coil. When using an apparatus that is sensitive to speed variations a constant speed (up to ±5.0 % of the actual rod speed) shall be maintained. When using an apparatus that can be configured to be insensitive to speed variations for the purposes of calibration or standardization, the reference standard can be moved through the test coil manually with the mechanical centering maintained by removable, closely fitted bushings. This technique should be utilized by the apparatus supplier as well as the user.

8. Reference Standards

8.1 Reference standards containing one or more artificial discontinuity may be used to establish sensitivity and alarm threshold settings to be used during eddy current examination.

Sensitivity and alarm thresholds can be established using a reference standard with a single artificial discontinuity if the instrument is configured to respond only to signal amplitude, without regard to phase differences. If phase differences are detected and processed, additional artificial notches can be included in the reference standard to create and display phase responses.

8.2 Artificial discontinuities 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 consistent 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 the excitation frequency.

8.3 A suggested material reference standard is shown in Fig. 1. Artificial discontinuities of any other dimension or contour may be used in a reference standard by mutual agreement between the supplier and purchaser.

8.4 When using a reference standard with multiple artificial discontinuities, they shall be spaced to provide signal resolution adequate for interpretation. A sample of this type might be prepared with a hole drilled radially into the rod in each of three successive transverse planes at 0, 120, and 240°, and one round bottom transverse notch on the rod surface at 120° (Fig. 1).

8.4.1 *Drilled Holes*—The holes shall be drilled radially with No. 72 drill into the rod using a suitable drill jig that has a bushing to guide the drill, with care being taken to avoid distortion or mechanical damage of the rod while drilling. The diameter of the drilled hole shall be 0.025 in. (0.635 mm) and shall not vary by more than ±0.001 in. (±0.025 mm). The depth shall be 0.075 in. (1.90 mm) and shall not vary more than ±0.003 in. (±0.076 mm).

8.4.2 *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 rod surface shall be stroked in a substantially straight line perpendicular to its longitudinal axis. The notch depth shall be 0.010 in. (0.25 mm) and shall not vary from the prescribed depth by more than ±0.001 in. (±0.025 mm) when measured at the center of the notch.

8.4.3 The straightness of the rod should not vary more than ±0.015 in. (±0.38 mm) over a 12-in. (305-mm) length.

8.4.4 Diameter variations between the reference standard and any other replacements should not vary more than ±0.015 in. (±0.38 mm) of the diameter of the rod being replaced, that is, between 1.1 and 6 % variation.

8.4.5 Electrical discharge machinery (EDM) can be used as an alternative to drilling holes or filing the notch, but the same dimension tolerances must be adapted.

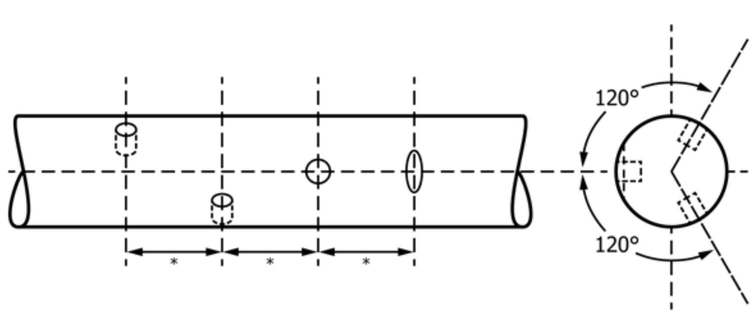
8.5 As an alternative to using a reference standard with multiple discontinuities, a single artificial discontinuity in the reference standard can suffice as a basis for compensating for differences between the electrical and mechanical center of the test coil, if they exist. A single discontinuity can be rotated at 120° intervals, making three trials. With either method employed, the sensitivity and alarm levels should be adequate to compensate for the worst case signals, alarming on the smallest signals.

8.6 The reference standard 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. Furthermore, it may be processed subsequently into a mechanically shaved or machined condition. The rods shall be passed through the test coil with the instrument sensitivity set high enough to determine the nominal background noise inherent in the rods. Any reference standard used shall be selected from rods exhibiting a typical background noise.

NOTE 1—Any copper-zinc-lead alloy (leaded brasses) may also be used as a reference standard. These materials have significantly lower electrical conductivity values compared with tough-pitch or oxygen-free copper and therefore, have a conductivity value at room temperature that is comparable to that of copper rod at elevated temperature.

9. Adjustment and Standardization of Apparatus Settings

9.1 The rod manufacturer shall select equipment, reference standards, and test parameters consistent for the product, unless otherwise agreed upon between the manufacturer and the purchaser. The method of manufacture of continuous cast copper and aluminum rod limits the use of a physical reference standard for in-line system standardization as is the norm for most eddy current examinations. The continuity of product



NOTE 1—A suggested length between discontinuities is 2 in. (51 mm). However, this space should be sufficient to provide signal resolution adequate for interpretation. The speed of the reference standard through the test coil is not critical, but a range from 5 to 150 ft/min (1.5 to 45.72 m/min) is recommended.

FIG. 1 Reference Standards With Three Holes and One Notch

runs into long coils and the high line speeds (up to 8000 ft/min or 37.8 m/s) requires the use of alternative calibration and standardization methods.

9.2 When using the reference standard, described in Fig. 1, or a reference standard having a single artificial discontinuity, adjust the apparatus to the lowest sensitivity required to detect all discontinuities. The rod speed maintained during standardization should be any value up to approximately 500 ft/min (152 m/min), ± 5 % of the selected speed.[6] An approximately constant rod speed shall be maintained during the adjustment process.

9.3 An alternate industry-accepted method for system standardization and sensitivity adjustment includes either electronically generated signals to simulate responses to reference notches or historical test coil response values. This is similar to the standardization procedure used in Practice E1033 for Type F-Continuously welded ferromagnetic tubing above the Curie temperature.

9.3.1 Apparatus should be tested or verified to meet the manufacturer's specification at the manufacturer's recommended interval or at an interval set by the rod manufacturer based on historical data. The purpose is to demonstrate consistency over time in order to facilitate comparative results of historical product quality.

9.3.2 As recommended by the instrument manufacturer, set the operating parameters such as coil drive level, excitation frequency, coil balance level, filter frequency settings, and phase angle to provide consistent operational performance. Generally this involves a comparison to historical response values to ensure consistency.

9.3.3 If available, an internally or externally generated calibration signal should be used to check the instrumentation without a coil connected to determine if internal instrument noise, sensitivity, and thresholds are within limits. This process should be done both before and after the test coil is connected to the electronic apparatus to verify that coil balancing is within limits. If no calibration signal is available, the noise level should be checked at a specific sensitivity against historical values.

9.3.4 Check the system using a reference standard to restore expected settings for a particular run. If factory calibration is done with artificial discontinuities, the reference standard used for factory calibration by the apparatus supplier should duplicate that used by the users. For systems that can be configured to be insensitive to speed variations, the filter should be disabled and the reference standard can be moved through the test coil manually. This type of system performance verification is also described in Guide E2884.

9.3.5 Adjust the instrument gain settings and alarm thresholds so that the response (either from an electronically generated signal, an artificial discontinuity, or the historical test coil responses value) is some predetermined fraction of the full-scale response.

9.3.5.1 The eddy current noise level is a signal that is actually generated as the rod passes through the coils. Through experience, sensitivities suitable for detecting imperfections of interest can be obtained. It must be clearly established that the noise level is material-generated and not from the instrumentation.

9.3.6 Verification of the sensitivity levels obtained through either the electronic-signal or the system-noise may be established through other nondestructive or mechanical examination methods, or both.

9.3.7 Further processing of signals can be employed to establish a grading system by using multiple thresholds to capture and categorize data that reflects the relative severity and frequency of a range of possible defects of similar types. Data can be used for comparison of the eventual quality of the rod as it performs in a variety of applications, over time.

9.4 Sensitivity control settings are usually indicated by arbitrary numbers on the control panel of analog 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. Sensitivity control settings may vary even among instruments of the same design and from the same manufacturer. Undue emphasis on the numerical value of sensitivity control settings is not justified and shall not be used.

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

10. Procedure

10.1 Standardize the system or perform system performance verification in accordance with 9.2 and 9.3. If necessary, place the reference standard at the center of the test coil at the start of the run. The rod manufacturer may use the reference standard or prepare a separate rod for this purpose in accordance with 8.1 and 8.2. Pass the rod through the system and adjust its position in the test coil such that the requirements of 9.2and 9.3 are satisfied.

10.2 Standardize the system at the start of the run and whenever improper functioning of the system is suspected by repeating 10.1.

11. Keywords

11.1 aluminum redraw rod; coil spacing; continuous cast aluminum rod; continuous cast copper rod; copper redraw rod;

[6] In actual production, throughput speed of the rod oftentimes exceeds this value. However, most eddy current instruments are speed sensitive and require a filter adjustment based on rod speed. This type of equipment produces variations in signal response with variations in test speed. Speed-insensitive equipment provides a constant signal response with changing test speeds. When a filter is added after standardization in order to improve signal-to-noise, immunity to speed variations is sacrificed. However, if the instrumentation is digital, the probable frequency response associated with a flaw signal can be calculated, based upon the length and spacing of the differential windings, the length and contour of the discontinuity, and the through-put speed and the filter parameter, set accordingly. Details of the coil configurations should be available from the apparatus supplier. If it is available, instrumentation that automatically synchronizes the filter settings with the mill speed can be employed to create virtual speed insensitivity. One caution is that the sampling rate of the digital flaw detection signal should be high enough to produce repeatable results. If the sampling rate is limited by the excitation frequency, the sampling rate should take priority over the depth of penetration. This is a reasonable trade off since the main object of this NDE method is to detect surface defects. A bonus is that higher excitation frequencies usually increase the possibility of separating acceptable variables from rejectable conditions, by phase differences.

eddy current examination; eddy current testing; electromagnetic testing ; differential coils; differential systems; fill factor; filter; reference standards; signal to noise ratio

SUMMARY OF CHANGES

Committee E07 has identified the location of selected changes to this standard since the last issue (E1606-09) that may impact the use of this standard. (Approved December 1, 2015.)

(1) Replaced "examination" with "test" to be consistent with the preferred use of these terms.
(2) Minor editorial changes throughout document to improve readability.
(3) Added subsection 1.4 on acceptability criteria.
(4) In sections 4, 5, and 7, revised descriptions of allowable instrumentation.
(5) In section 8, revised the reference standards that can be used for standardization.
(6) Section 9 revised to include an alternative standardization procedure.
(7) Appendix X1 and references to it were removed as an obsolete method.