~~Designation:E376–06~~ Designation: E376 – 11

Standard Practice for Measuring Coating Thickness by Magnetic-Field or Eddy-Current (Electromagnetic) ~~Examination~~Testing Methods[1]

This standard is issued under the fixed designation E376; 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

~~1.1This practice covers the use of magnetic- and eddy-current-type thickness instruments (gages) for nondestructive thickness measurement of a coating on a metal substrate. *~~

1.1 This practice covers the use of magnetic- and eddy-current-type thickness instruments (gauges) for nondestructive thickness measurement of a coating on a metal substrate.

1.2 More specific uses of these instruments are covered by Practice D7091 and the following test methods issued by ASTM: Test Methods B244, B499, B530, and G12.

~~1.3The values stated in SI units are to be regarded as standard. The inch-pound units in parentheses are for information only and may be approximate.~~

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

1.4 Measurements made in accordance with this practice will be in compliance with the requirements of ISO 2178 as printed in 1982.

1.5 *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]

B244 Test Method for Measurement of Thickness of Anodic Coatings on Aluminum and of Other Nonconductive Coatings on Nonmagnetic Basis Metals with Eddy-Current Instruments

B499 Test Method for Measurement of Coating Thicknesses by the Magnetic Method: Nonmagnetic Coatings on Magnetic Basis Metals

B530 Test Method for Measurement of Coating Thicknesses by the Magnetic Method: Electrodeposited Nickel Coatings on Magnetic and Nonmagnetic Substrates

D7091 Practice for Nondestructive Measurement of Dry Film Thickness of Nonmagnetic Coatings Applied to Ferrous Metals and Nonmagnetic, Nonconductive Coatings Applied to Non-Ferrous Metals

E543 Specification for Agencies Performing Nondestructive Testing

E1316 Terminology for Nondestructive Examinations

G12 Test Method for Nondestructive Measurement of Film Thickness of Pipeline Coatings on Steel

2.2 *ASNT Standards:*[3]

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

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

2.3 *AIA Standard:*

NAS-410 Certification and Qualification of Nondestructive Testing Personnel[4]

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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 ~~The~~ 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., 1250 Eye St., NW, Washington, DC 20005. (Replacement standard for MIL-STD-410.)~~

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

2.4 *International Standard:*

ISO 2178 Nonmagnetic Coatings on Magnetic Substrate—Measurement of Coating Thickness—Magnetic Method[5]

NOTE 1—See Appendix X1.

3. Terminology

~~3.1 *Definitions*—Definitions of terms relating to electromagnetic examination are given in Terminology~~

3.1 *Definitions*—For definitions of terms relating to this practice, refer to Terminology E1316.

4. Significance and Use

4.1 *General*—No presently available thickness gauge is applicable to all combinations of coating-substrate thicknesses and materials. The limitations of a particular instrument are generally delineated by its manufacturer.

4.2 *Magnetic*—Magnetic-type gauges measure either magnetic attraction between a magnet and a coating or its substrate, or reluctance of a magnetic flux path passing through the coating and substrate. These gauges are designed to measure thickness of a nonmagnetic coating on a magnetic substrate. Some of them will also measure thickness of nickel coatings on a magnetic or nonmagnetic substrate.[6]

4.3 *Eddy Current*—~~Eddy-current-type thickness gages are electronic instruments that measure variations in impedance of an eddy-current inducing coil caused by coating thickness variations. They can only be used if the electrical conductivity of the coating differs significantly from that of the substrate.~~ —Eddy-current-type thickness gauges are electronic instruments that measure variations in impedance of an eddy-current inducing coil caused by coating thickness variations. They can only be used if the electrical conductivity of the coating differs significantly from that of the substrate.

4.4 *Accuracy*—The accuracy of a measurement depends on the instrument, its calibration and standardization, and its operating conditions. The accuracy is also affected by the interferences listed in Section 5, such as part geometry (curvature), magnetic permeability, and surface roughness.

NOTE 2—This practice allows the coating thickness to be determined within ±10 % of its true thickness or to within ±2.5 µm (or ±0.0001-in.), whichever is the greater. (See exceptions in Appendix X2.)

5. Interferences

5.1 *Thickness of Coating*—The precision of a measurement changes with coating thickness depending on method used and instrument design. Generally, the precision is a percentage of the coating thickness except at the lower end of the ranges where it is a fixed thickness.

5.2 *Magnetic Properties of Basis Metal*—Magnetic thickness gauges are affected by variations of the magnetic properties of the basis metal. For practical purposes, magnetic variations in low-carbon AISI 1005-1020 steels may be considered to be insignificant. To avoid the influences of severe or localized heat treatments and cold working, the instrument should be standardized using a reference standard having a base metal with the same magnetic properties as that of the test specimen or, preferably and if available, with a sample of the part to be examined before application of the coating.

5.3 *Thickness of Substrate*—For each method there is an effective depth of penetration of field created by the instrument probe. This is the critical depth or thickness beyond which the instrument will no longer be affected by increase of substrate thickness. Since it depends on the instrument probe and substrate, it should be determined experimentally.

5.4 *Structure and Composition of Coating and Substrate*—Eddy-current instruments are sensitive to variations of structure, composition, and other factors affecting electrical conductivity and magnetic permeability of the coating and substrate. For example, such instruments are sensitive to differences between: (*1*) aluminum alloys, (*2*) chromium coatings deposited at different temperatures, and (*3*) organic coatings containing variable amounts of metallic pigments.

5.5 *Edge Effect*—All examination methods are sensitive to abrupt surface changes of test specimens; therefore, measurements made too near an edge or inside corner will not be valid unless the instrument is specifically standardized for such a measurement. The effect usually extends 3 to 13 mm (⅛ to ½ in.) from the discontinuity, depending on method probe configuration, and instrument. Edge effect is usually a function of coil diameter.

5.6 *Curvature of Examination Surface*—Thickness measurements are sensitive to curvature of the specimen. This sensitivity varies considerably between instruments and becomes more pronounced with increasing curvature.

5.7 *Smoothness of Surface, Including That of Base Metal*—Since a rough surface may make single measurements inaccurate, a greater number of measurements will provide an average value that is more truly representative of the overall coating thickness. Roughness also may cause certain instruments to read high since their probes may rest on peaks.

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[4] Available from Aerospace Industries Association of America, Inc. (AIA), 1000 Wilson Blvd., Suite 1700, Arlington, VA 22209-3928, http://www.aia-aerospace.org. (Replacement standard for MIL-STD-410.)

[5] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

[6] Autocatalytically deposited nickel-phosphorus alloys containing more than 8 % phosphorus are sufficiently nonmagnetic to be measured by this method, as long as the measurement is made prior to any heat treatment.

5.8 *Direction of Rolling of Base Metal*—Instruments with two pole pieces may be sensitive to direction of rolling of the base metal; that is, gauge readings may change depending on alignment of pole pieces with surface of specimen or part under examination.

5.9 *Residual Magnetism in Base Metal*—Residual magnetism in base metal may affect readings of magnetic- and eddy-current-type instruments.

5.10 *Stray Magnetic Fields*—Strong magnetic fields, as from arc welding, can seriously interfere with operations of certain thickness gauges.

5.11 *Cleanness of Probe and Test Surface*—Measurements are sensitive to foreign material that prevents intimate contact between probe and coating surface.

5.12 *Pressure of Probe*—Instrument readings can be sensitive to pressure with which probe is applied to test surface.

5.13 *Probe Position*—Some magnetic-type gauges are sensitive to position of probe relative to the earth. For example, operation of gauge in a horizontal or upside-down position may require a new standardization or may be impossible.

5.14 *Temperature*—Eddy-current instruments may be affected by temperature variations.

6. Basis of Application

6.1 The following items are subject to contractual agreement between the parties using or referencing this standard.

6.2 *Personnel Qualification*

6.2.1 If specified in the contractual agreement, personnel performing examinations to this standard shall be qualified in accordance with a nationally or internationally recognized NDT personnel qualification practice or standard such as ANSI/ASNT-CP-189, SNT-TC-1A, NAS-410, 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.

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

6.4 *Procedures and Techniques*—The procedures and techniques to be utilized shall be as specified in the contractual agreement.

6.5 *Surface Preparation*—The pre-examination surface preparation criteria shall be in accordance with 5.11 and requirements specified in the contractual agreement.

6.6 *Timing of Examination*—The timing of examination shall be in accordance with the applicable contractual agreement.

6.7 *Extent of Examination*—The extent of examination shall be in accordance with the applicable contractual agreement.

6.8 *Reporting Criteria/Acceptance Criteria*—Reporting criteria for the examination results shall be in accordance with Section 9 unless otherwise specified. Since acceptance criteria are not specified in this standard, they shall be specified in the contractual agreement.

6.9 *Reexamination of Repaired/Reworked Items*—Reexamination of repaired/reworked items is not addressed in this standard and if required shall be specified in the contractual agreement.

7. Calibration and Standardization

7.1 Each instrument should be calibrated in accordance with the manufacturer's instructions and standardized before use by employing suitable thickness standards. Standardization should be checked at frequent intervals during use. Attention should be given to Section 5 and Section 8.

7.2 Reference standards of uniform thickness are available in either of two types, foil or coated substrate, as supplied or recommended by the manufacturer of the instrument. There are instances, however, where reference standards are made by other than instrument manufacturers.

7.2.1 *Standardization Foils (Shims)*—Standardization foil is placed on the surface of uncoated base metal when standardizing the instrument. Foils are advantageous for standardizing on curved surfaces and are often more readily available than a coated standard. To prevent measurement errors due to poor contact between foil and substrate, make sure of intimate contact between them. Foils are subject to indentation and should, therefore, be replaced when damaged.

7.2.1.1 Nonmagnetic foils may be used to standardize magnetic thickness gauges for measurement of nonmagnetic coatings. Nonconductive plastic foils can be used to standardize eddy-current instruments for measurement of nonconductive coatings.

7.2.1.2 Resilient foils should not be used if there is possibility that the instrument probe will cause a change in thickness reading. Use of two or more foils on top of each other should be avoided unless flexibility of thin foils is required for a curved surface.

7.2.2 Coated reference standards consist of coatings of known thickness permanently bonded to the substrate material.

7.3 Thicknesses of reference standards should bracket and be as close as possible to the coating thickness being measured.

7.4 For magnetic instruments, reference standards should have the same magnetic properties as the coated specimen.

7.5 For eddy-current instruments, the reference standard should have the same electrical and magnetic properties as those of coated specimen being measured (see 5.4).

7.6 To determine standardization validity, a reading on a bare specimen identical in magnetic and electrical properties to that of the test specimen substrate is recommended.

7.7 If the coating process is changed, the standardization may no longer be valid, especially for magnetic coatings and eddy-current gauges (see 5.4).