



Designation: E376 – 19

Standard Practice for Measuring Coating Thickness by Magnetic-Field or Eddy Current (Electromagnetic) Testing Methods¹

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 U.S. Department of Defense.

1. Scope*

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 (that is, electrically conducting) substrate. The substrate may be ferrous or nonferrous. The coating or plating being measured may be electrically conducting or insulating as well as ferrous or non-ferrous.

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](#), and [B530](#).

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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.6 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

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. 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

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:⁴

[NAS-410](#) Certification and Qualification of Nondestructive Testing Personnel

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>. (Replacement standard for MIL-STD-410.)

2.4 ISO Standards:⁵

ISO 2178 Nonmagnetic Coatings on Magnetic Substrate—Measurement of Coating Thickness—Magnetic Method
ISO 9712 Non-destructive Testing—Qualification and Certification of NDT Personnel

NOTE 1—See **Appendix X1**.

3. Terminology

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

4. Significance and Use

4.1 *General*—Most thickness gauges are not applicable to all combinations of coating-substrate thicknesses and materials. The limitations of a particular instrument are generally delineated by its manufacturer. The substrate material and coating combination to be measured as well as the inherent variations in the substrate and coating shall be reviewed prior to selecting the instrument to be used and the measurement accuracy required.

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 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, the foils, 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, electrical conductivity, and surface roughness.

NOTE 2—This practice under ideal conditions may allow the coating thickness to be determined within $\pm 10\%$ of its true thickness or to within $\pm 2.5\ \mu\text{m}$ (or $\pm 0.0001\ \text{in.}$), 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 proper-

ties 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 ($\frac{1}{8}$ to $\frac{1}{2}$ 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.

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 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.

5.13 *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, 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.

NOTE 3—Note that NAS-410 does not require personnel certification when using direct read instruments.

6.2.2 Qualification and certification for personnel may be reduced when the following conditions are met:

6.2.2.1 The examination will be limited to operating equipment that displays the results in thickness units.

6.2.2.2 A specific procedure is used that is approved by a certified Level III in accordance with 6.2.1.

6.2.2.3 Documentation of training and examination is performed to ensure that personnel are qualified. Qualified personnel are those who have demonstrated, by passing written and practical proficiency tests, that they possess the skills and job knowledge necessary to ensure acceptable workmanship.

6.3 *Qualification of Nondestructive Testing Agencies*—If specified in the contractual agreement, NDT agencies shall be qualified and evaluated as specified in 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).

7.8 In some cases, standardization of instruments with two-pole probes should be checked with the poles rotated 0, 90, 180, and 270° (see 5.8 and 5.9).

7.9 The substrate thickness for examination/measurement and standardization should be the same if the depth of penetration referred to in 5.3 is not exceeded. Very often it is possible to back up the substrates of standard and examination

specimens with sufficient thickness of the same material (to exceed the critical thickness) and make readings independent of substrate thickness.⁷

7.10 If the curvature of the coating to be measured is so arched as to preclude standardization on a flat surface, then the curvature of the coated standard or of the substrate on which the foil is placed should have the same contour.

7.11 The surface roughness and surface texture of the substrate standard should be similar to the surface of the test specimen or correction factors that account for the measurement offset created by the rough surface may be used.

8. Procedure

8.1 Operate each instrument in accordance with the manufacturer's instructions giving appropriate attention to factors listed in Section 5.

8.2 Check the instrument calibration at the site each time the instrument is put into service and at frequent intervals during use to assure proper performance.

8.3 Observe the following precautions:

8.3.1 *Thickness of Substrate*—When thickness of the substrate is less than the critical thickness (see 5.3), and cannot be backed up by the same metal, measurements with eddy current gauges should not be made over metal surfaces, or other electrically conducting materials.

8.3.1.1 With magnetic gauges the effective thickness of a flat substrate can be increased by placing it on a flat layer of material of the same magnetic properties.

8.3.2 *Edge Effects*—Readings should not be made closer than 13 mm (½ in.) from edges, holes, inside corners, etc., of a specimen unless validity of calibration for such a measurement has been demonstrated (see 7.5).

8.3.3 *Curvature Effects*—If the instrument has been standardized with a specimen of similar curvature, measurement and standardization should normally be made with the same probe orientation.

8.3.4 *Number of Readings*:

8.3.4.1 Because of normal instrument variability, it is necessary to make several readings at each position. Local variations in coating thickness may also require that a number of measurements be made in any given area; this applies particularly to a rough surface.

8.3.4.2 Instruments of the attractive force type are sensitive to vibrations, and readings that are obviously erroneous should be rejected.

8.3.5 *Direction of Mechanical Working*—If the direction of mechanical working has a pronounced effect on the reading, make the measurement on the specimen with the probe in the same orientation as that used during standardization. If this is impossible, make four measurements in various orientations by rotating the probe in increments of 90°.

8.3.6 *Residual Magnetism*—When residual magnetism is present in the base metal, when using two-pole instruments

employing a stationary magnetic field make measurements in two orientations differing by 180°. With single-pole instruments employing a stationary magnetic field, it may be necessary to demagnetize the specimen to get valid results, and this may also be advisable with two-pole instruments.

8.3.7 *Cleaning of Surface*—Foreign materials such as dirt, grease, and corrosion products should be removed by cleaning without removing any coating material. Areas on specimens having visible contamination that are difficult to remove such as flux, acid spots, dross, and oxide, should be avoided in making measurements.

8.3.8 *Lead Coatings*—The magnet of an instrument of the attractive force type may stick to lead and lead alloy coatings. Apply a very thin film of oil to improve the reproducibility of readings and correct the measurement for the thickness of the oil film. Excess oil shall be wiped off so that the surface is virtually dry. The correction may be determined by measuring the coating thickness of a nonsticking coating of appropriate thickness with and without the oil film and taking the difference between the two measurements. Do not use this procedure with other coatings.

8.3.9 *Techniques*—The readings obtained may depend on the operator technique. For example, the pressure applied to a probe, or the rate of applying a balancing force to a magnet, will vary from one individual to another. Reduce or minimize such effects either by having the instrument calibrated by the same operator who will make the measurement or by using constant pressure probes. In appropriate cases when a constant pressure probe is not being used, the use of a measuring stand is strongly recommended.

8.3.10 *Position of Probe*—In general, gently place the instrument probe perpendicular to the specimen surface at the point of measurement. For some instruments of the attractive force type, this is essential. With some instruments, however, it is desirable to tilt the probe slightly and select the angle of inclination giving the minimum reading. If, on a smooth surface, the readings obtained vary substantially with the angle of inclination, it is probable that the probe is worn and needs to be replaced. If a magnetic instrument is to be used in a horizontal or upside-down position, calibrate it for that position.

9. Report

9.1 An examination report should contain the following information:

9.1.1 Date and name of operator.

9.1.2 Instrument and probe identification.

9.1.3 Identification of components and indication whether the examination was on a new component, component from service, or refurbished component.

9.1.4 Material(s) of the coating(s) and substrate.

9.1.5 Type of instrument calibration and/or standardization.

9.1.6 Frequency(ies) used.

9.1.7 Examination procedure identification.

9.1.8 Results of examinations.

10. Keywords

10.1 coating thickness; eddy current probes; magnetic field; nondestructive testing

⁷ Coated standards suitable for many applications for the practice may be purchased from the Office of Standard reference materials, National Institute of Standards and Technology (NIST), 100 Bureau Dr., Stop 1070, Gaithersburg, MD 20899-1070, <http://www.nist.gov>.

APPENDIXES

(Nonmandatory Information)

X1. ASTM STANDARDS COVERING MAGNETIC AND EDDY CURRENT THICKNESS GAUGES

X1.1 There are several other ASTM standards covering other methods of measuring coating thickness. Some are listed in Section 2, others are listed in the *Index to ASTM Standards*.

X2. SPECIFIC APPLICATIONS

X2.1 Some coatings are specified by weight per unit area instead of thickness. Typical examples are shown below:

Coating Metal	Customary Unit	Equivalent Thickness
Zinc	305 g/m ² (1 oz/ft ²)	0.043 mm (0.0017 in. or 1.7 mils)
Tin	11.0 g/m ² (1 lb/base box)	0.0015 mm (0.00006 in.)

X2.2 The measurement accuracy for hot-dip zinc coatings is limited by surface profile and formation of an alloy between

the zinc and the steel substrate. Usually an accuracy of better than $\pm 15\%$ can be obtained with magnetic gauges.

X2.3 National Institute for Standards and Technology (NIST) Certified Standards should not be removed from the card on which they are mounted; they should be used on a nonmagnetic work surface.

SUMMARY OF CHANGES

Committee E07 has identified the location of selected changes to this standard since the last issue (E376 – 17) that may impact the use of this standard.

(1) Modified Section 6.2 regarding the use of direct read instruments.

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