Designation: E 376 – 03

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

This standard is issued under the fixed designation E 376; 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 covers the use of magnetic- and eddy-current-type thickness instruments (gages) for nondestructive thickness measurement of a coating on a metal substrate.

1.2 More specific uses of these instruments are covered by the following test methods issued by ASTM: Test Methods B 244, B 499, B 530, D 1186, D 1400, and G 12.

1.3 The 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.

1.4 Measurements made in accordance with this practice will be in compliance with the requirements of ISO International Standard 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:*

B 244 Test Method for Measurement of Thickness of Anodic Coatings on Aluminum and of Other Nonconductive Coatings on Nonmagnetic Basis Metals with Eddy-Current Instruments[2]

B 499 Test Method for Measurement of Coating Thicknesses by the Magnetic Method: Nonmagnetic Coatings on Magnetic Basis Metals[2]

B 530 Test Method for Measurement of Coating Thicknesses by the Magnetic Method: Electrodeposited Nickel Coatings on Magnetic and Nonmagnetic Substrates[2]

D 1186 Test Methods for Nondestructive Measurement of Dry Film Thickness of Nonmagnetic Coatings Applied to a Ferrous Base[3]

D 1400 Test Method for Nondestructive Measurement of Dry Film Thickness of Nonconductive Coatings Applied to a Nonferrous Metal Base[3]

E 1316 Terminology for Nondestructive Examinations[4]

E 543 Practice for Agencies Performing Nondestructive Testing[4]

G 12 Test Method for Nondestructive Measurement of Film Thickness of Pipeline Coatings on Steel[5]

2.2 *ASNT Standards:*[6]

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[7]

2.4 *International Standard:*

ISO 2178 Nonmagnetic Coatings on Magnetic Substrate—Measurement of Coating Thickness—Magnetic Method[8]

NOTE 1—See Appendix X1.

3. Terminology

3.1 *Definitions*—Definitions of terms relating to electromagnetic examination are given in Terminology E 1316.

4. Significance and Use

4.1 *General*—No presently available thickness gage 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 gages measure either magnetic attraction between a magnet and a coating or its substrate,

[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] *Annual Book of ASTM Standards*, Vol 02.05.

[3] *Annual Book of ASTM Standards*, Vol 06.01.

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

[5] *Annual Book of ASTM Standards*, Vol 06.02.

[6] Available from The American Society for Nondestructive Testing (ASNT), P.O. Box 28518, 1711 Arlingate Ln., Columbus, OH 43228-0518.

[7] Available from Aerospace Industries Association of America, Inc., 1250 Eye St., NW, Washington, DC 20005. (Replacement standard for MIL-STD-410.)

[8] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036.

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or reluctance of a magnetic flux path passing through the coating and substrate. These gages 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.[9]

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.

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 gages 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.

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, gage 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 gages.

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 gages are sensitive to position of probe relative to the earth. For example, operation of gage 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 in Practice E 543. The applicable edition of E 543 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

[9] 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.

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 gages 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 gages (see 5.4).

7.8 In some cases, calibration 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.[10]

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.

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 gages should not be made over metal surfaces, or other electrically conducting materials.

8.3.1.1 With magnetic gages 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 calibrated with a specimen of similar curvature, measurement and calibration 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 calibration. 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 stationalry 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

[10] Coated standards suitable for many applications for the practice may be purchased from the Office of Standard reference materials, National Institute for Standards and Technology (NIST), Gaithersburg, MD 20899.

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, 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. Precision and Bias

10.1 The instrument, its calibration, and its operation shall be such that the coating thickness can be determined within ±10 % of its true thickness or to within ±2.5 µm, or ±0.0001, whichever is the greater. (See exceptions in Appendix X2.)

11. Keywords

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

APPENDIXES

(Nonmandatory Information)

X1. ASTM STANDARDS COVERING MAGNETIC AND EDDY CURRENT THICKNESS GAGES

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 ±15 % can be obtained with magnetic gages.

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.

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