



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

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 test method 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 Instruments²

B 499 Test Method for Measurement of Coating Thicknesses by the Magnetic Method: Nonmagnetic Coatings on Magnetic Basis Metals²

B 530 Test Method for Measurement of Coating Thicknesses by the Magnetic Method: Electrodeposited Nickel Coatings on Magnetic and Nonmagnetic Substrates²

D 1186 Test Methods for Nondestructive Measurement of Dry Film Thickness of Nonmagnetic Coatings Applied to a Ferrous Base³

D 1400 Test Method for Nondestructive Measurement of Dry Film Thickness of Nonconductive Coatings Applied to a Nonferrous Metal Base³

E 1316 Terminology for Nondestructive Examinations⁴

G 12 Test Method for Nondestructive Measurement of Film Thickness of Pipeline Coatings on Steel⁵

2.2 International Standard:

ISO 2178 Nonmagnetic Coatings on Magnetic Substrate—Measurement of Coating Thickness—Magnetic Method⁶

NOTE 1—See Appendix X1.

3. Terminology

3.1 *Definitions*—Definitions of terms relating to electromagnetic testing 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, 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.⁷

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.

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 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 American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036.

⁷ 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. 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 1005-1020 steel may be considered to be insignificant. To avoid the influences of severe or localized heat treatments and cold working, the instrument should be calibrated using a calibration 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 tested 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 or 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 test 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 calibrated 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 Test 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 Basis 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 Basis Metal*—Instruments with two pole pieces may be sensitive to direction of rolling of the basis metal; that is, gage readings may change depending on alignment of pole pieces with surface of specimen under test.

5.9 *Residual Magnetism in Basis Metal*—Residual magnetism in basis 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 *Cleanliness 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 calibration or may be impossible.

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

6. Calibration and Standardization

6.1 Each instrument should be calibrated in accordance with the manufacturer's instructions before use by employing suitable thickness standards. Calibration should be checked at frequent intervals during use. Attention should be given to Section 5 and Section 7.

6.2 Calibration 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 calibration standards are made by other than instrument manufacturers.

6.2.1 *Calibration Foils (Shims)*—Calibration foil is placed on the surface of uncoated basis metal when calibrating the instrument. Foils are advantageous for calibrating 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. Calibration foils are subject to indentation and should, therefore, be replaced when damaged.

6.2.1.1 Nonmagnetic foils may be used to calibrate magnetic thickness gages for measurement of nonmagnetic coatings. Nonconductive plastic foils can be used to calibrate eddy-current instruments for measurement of nonconductive coatings.

6.2.1.2 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.

6.2.2 *Coated Substrates Standards*—Calibration standards consist of coatings of known thickness permanently bonded to the substrate material.

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

6.4 For magnetic instruments, calibration standards should have the same magnetic properties as the coated test specimen.

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

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

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

6.8 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).

6.9 The substrate thickness for test and calibration 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 test specimens with sufficient thickness of the same material (to exceed the critical thickness) and make readings independent of substrate thickness.⁸

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

7. Procedure

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

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

7.3 Observe the following precautions:

7.3.1 *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.

7.3.1.1 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.

7.3.2 *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 6.5).

7.3.3 *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.

7.3.4 *Number of Readings*:

7.3.4.1 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.

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

7.3.5 *Direction of Mechanical Working*—If the direction of mechanical working has a pronounced effect on the reading, make the measurement on the test 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°.

7.3.6 *Residual Magnetism*—When residual magnetism is present in the basis 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 test specimen to get valid results, and this may also be advisable with two-pole instruments.

7.3.7 *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 defects that are difficult to remove such as flux, acid spots, dross, and oxide, should be avoided in making measurements.

7.3.8 *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 with and without the oil film and taking the difference between the two measurements. Do not use this procedure with other coatings.

7.3.9 *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.

7.3.10 *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.

8. Precision and Bias

8.1 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, whichever is the greater. (See exceptions in Appendix X2.)

9. Keywords

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

⁸ Coated standards suitable for many applications for the test method may be purchased from the Office of Standard reference materials, National Institute for Standards and Technology (NIST), Gaithersburg, MD 20899.



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	1 oz/ft ² (305 g/m ²)	0.0017 in. or 1.7 mils (0.043 mm)
Tin	1 lb/base box (11.0 g/m ²)	0.00006 in. (0.0015 mm)

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 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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