



Standard Test Methods for Nondestructive Measurement of Dry Film Thickness of Nonmagnetic Coatings Applied to a Ferrous Base¹

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This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 These test methods cover the nondestructive measurement of the dry film thickness of nonmagnetic coatings applied over a ferrous base material using commercially available test instruments. The test methods cover the use of instruments based on magnetic measuring principles only. Test Method A provides for the measurement of films using magnetic pull-off gages and Test Method B provides for the measurement of films using magnetic flux gages.

1.2 These test methods are not applicable to coatings that will be readily deformable under the load of the measuring instruments, as the instrument probe must be placed directly on the coating surface to take a reading.

1.3 *This standard does not purport to address all of the safety problems, 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:

D 609 Practice for Preparation of Cold-Rolled Steel Panels for Testing Paint, Varnish, Conversion Coatings, and Related Coating Products²

D 823 Practices for Producing Films of Uniform Thickness of Paint, Varnish, and Related Products on Test Panels²

D 1005 Test Method for Measurement of Dry-Film Thickness of Organic Coatings Using Micrometers²

D 3980 Practice for Interlaboratory Testing of Paint and Related Materials²

2.2 Steel Structures Painting Council Standard:

SSPC-PA2 Measurement of Dry Paint Thickness with Magnetic Gages³

TEST METHOD A—MAGNETIC PULL-OFF GAGES

3. Summary of Test Method

3.1 Instruments complying with this test method measure thickness by using a spring calibrated to determine the force required to pull a permanent magnet from a ferrous base coated with a nonmagnetic film. The instrument must be placed directly on the coating surface to take a reading.

3.2 The attractive force of the magnet to the substrate varies inversely with the thickness of the applied film. The spring tension required to overcome the attraction of the magnet to the substrate is shown on the instrument scale as the distance (in mils or micrometres) between the magnet and the substrate.

3.3 It should be recognized that the accuracy of the measurements can be influenced when measurements are made closer than 1 in. (25 mm) to an edge.

4. Significance and Use

4.1 After calibrating the instrument using shims of known thickness and either a bare part of the metal object or metal of the same kind, the instrument magnet (or metal foot) is placed in contact with the coated metal in the manner described in 12.1. The results of many test methods applicable to coatings are markedly affected by the film thickness of the dry film, some examples being adhesion, flexibility, and hardness to name a few. To be able to compare results obtained by different operators, it is essential to measure film thickness closely.

4.2 Most protective and high performance coatings are applied to meet a requirement or a specification for the dry-film thickness of each coat, or for the complete system, or both. Coatings must be applied within certain minimum and maximum thickness tolerances in order that they can fulfill their intended function. In addition to potential performance deficiencies, it is uneconomical to apply more material than

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² *Annual Book of ASTM Standards*, Vol 06.01.

³ Available from Steel Structures Painting Council, 4516 Henry St., Pittsburgh, PA 15213.

necessary when coating large areas such as metal structures and coils. This test method is used to measure film thickness of coatings on ferrous metals.

5. Apparatus

5.1 *Permanent Magnet*, small, either attached directly to a coil spring (“pencil” gage)⁴ or to a horizontal lever arm which is attached to a helical spring (“banana” gage).⁵ Increasing force is applied to the magnet by extending the coil spring in the first case or turning a graduated dial that coils the helical spring in the second. The readings obtained are shown directly on the instrument scale or converted by reference to a calibration curve.

5.2 *Nonmagnetic Thickness Shims or Polished Metal Certification Calibration Standards*⁶—Shims with assigned values traceable to National Standards are available, but when shims are used that are not traceable to National Standards, the thickness must be measured to the nearest 0.1 mil (2.5 μm) using a micrometer as described in Procedure D in Test Method D 1005.

6. Test Specimens

6.1 When this test method is used in the field, the specimen is the coated structure or article on which the thickness is to be evaluated.

6.2 For laboratory use, apply the materials to be tested to panels of the composition and surface conditions on which it is desired to determine the thickness.

NOTE 1—Applicable test panel description and surface preparation methods are given in Practice D 609.

NOTE 2—Coatings should be applied in accordance with Practices D 823 or as agreed upon between the purchaser and the seller.

7. Calibration of Apparatus

7.1 Calibrate the instrument in an area free of stray magnetic fields, such as power lines, generators, or welding equipment. There shall be no vibration apparent on the test piece when the instrument is being calibrated.

7.2 Use a bare section of the substrate after the specified surface preparation has been accomplished. If an uncoated section of the substrate is not available, uncoated test panels similar to the type on which the specified surface preparation has been performed may be used.

7.3 Select calibration shims in the expected thickness range to be measured. For example, if a coating is approximately 3 mils (75 μm) in thickness, calibrate the instrument at 3 mils. Then check the calibration, using shims of both a lesser and greater thickness, to determine the thickness range over which the instrument is calibrated. The limits of this range are set at the points where the gage no longer registers the shim thickness within the manufacturer’s stated accuracy (for example, $\pm 15\%$).

⁴ Apparatus of the “pencil” (coil spring) type found to be typical are shown in Table 1.

⁵ Apparatus of the “banana” (helical spring) type found to be typical are shown in Table 1.

⁶ Polished metal standards for this purpose are available from U.S. Department of Commerce, National Institute of Standards and Technology, Standard Reference Material Program, Building 202, Room 204, Gaithersburg, MD 20899.

7.4 Lay a calibration shim on the bare, uncoated substrate and bring the instrument magnet in direct contact with the shim. Remove the magnet from the shim by slowly rotating the dial scale ring clockwise (for helical spring-type instruments) or lifting the entire instrument housing (for coil spring-type instruments). Hold the shim so that it will not flex during calibration, causing the magnet to lift prematurely. Observe the thickness shown on the instrument scale at the moment when the magnet breaks contact with the surface.

7.5 If the instrument scale reading does not agree with the shim thickness, calibration is required. This can be accomplished by physical calibration or by drafting a calibration curve. A calibration curve involves plotting a graph with the actual gage reading on one axis and the shim reading on the other. For physical calibration, consult the manufacturer’s instructions.

NOTE 3—Instruments based on the scale dial ring/helical spring can be calibrated and used in any position, while those based on the coil spring must be calibrated and used in the vertical position only.

8. Calibration of Apparatus—Polished Metal Calibration Standards

8.1 Follow 7.1, 7.2, and 7.3.

8.2 Place the gage directly on the calibration standard. If the instrument scale reading does not agree with the shim thickness, calibration is required as in 7.5.

8.3 After the gage is calibrated, take ten readings on the bare, prepared substrate. Record the mean of these readings. This is a correction for variations of magnetic attraction due to the roughness of the substrate.

8.4 Subtract the value obtained in 8.3 when measuring the coating thickness to obtain the corrected thickness of the paint.

NOTE 4—More information on this calibration test method is described in SSPC-PA 2.

9. Procedure

9.1 Use the instrument only after it has been calibrated in accordance with Section 7 or 8.

9.2 Assure that the coating is dry prior to use of the instrument.

9.3 Inspect the magnet tip and surface to be measured to assure that they are clean. Adherent magnetic filings or other surface contaminants will affect gage readings.

9.4 Take readings in locations free of vibration, electrical, or magnetic fields.

9.5 If thickness readings are found to be outside the calibration range established in 7.3, repeat the calibration procedure in the appropriate range. Check the calibration before, during, and after each use to ensure that the instrument continues to read properly. If the instrument is found to be out of adjustment, remeasure the thicknesses taken since the last satisfactory calibration check was made.

9.6 Take a sufficient number of readings to characterize the surface.

9.6.1 For laboratory measurements, a recommended minimum is three for a 3 by 6-in. (75 by 150-mm) panel and more in proportion to size.

9.6.2 For field measurements, a recommended minimum is five determinations at random for every 100 ft² (10 m²) of

surface area. Each of the five determinations should be the mean of three separate gage readings within the area of a ½-in. (12-mm) diameter circle.

9.7 Make measurements at least 1 in. (25 mm) away from any edge or corner of the specimen. If it is necessary to measure closer than 1 in., recheck the calibration in the specific area to determine the extent of the effect (if any) the edge has on the measurement.

10. Report

10.1 Report the following information: the instrument used, serial number, range, and mean of the thickness readings

found. Depending upon the application, it may be useful to record the individual readings as well.

11. Precision and Bias

11.1 On the basis of an interlaboratory study of this test method, conducted to determine the precision of several types of instrument in measuring a wide range of coating thicknesses, the intralaboratory and interlaboratory coefficients of variation, calculated using procedures described in Practice D 3980 were found to be those shown in Table 1 for the instrument evaluated. Based upon these coefficients, the following criteria should be used for judging, at the 95 %

TABLE 1 Precision of Film Thickness Measurements

Intralaboratory							
Coating Thickness		0.5 to 1.5 mils			5 to 17 mils		
Test Method	Instrument ^A	Degrees of Freedom (DF)	Coefficient of Variation (v_w), %	Maximum Allowable Difference (MAD), %	Degrees of Freedom (DF)	Coefficient of Variation (v_w), %	Maximum Allowable Difference (MAD), %
A	Coil Spring						
	Elcometer 157	12	9		12	5	
	Tinsley	12	6		12	4	
	Pooled	24	7.65	22.4	24	4.53	13.3
A	Helical spring						
	Elcometer 111	12	6		12	3	
	Microtest FIM	28	5		28	2	
	Magne Gage	4	6		8	2	
	Pooled	44	5.4	15.4	48	2.3	6.6
B	Mechanical						
	Elcometer 101	22	7	20.6	22	3	8.8
B	Probe						
	Elcometer 150	12	5		12	1	
	Minitest FN 250	6	5		6	2	
	GE Type B Gage	32	4		32	3	
	Permascope ES	12	4		12	2	
	Verimeter ML 301	2	6		3	2	
	Accuderm M	4	1		6	2	
	Pooled	68	4.25	12.1	71	2.4	6.8
Interlaboratory							
Coating Thickness		0.5 to 1.5 mils			5 to 17 mils		
Test Method	Instrument ^A	Degrees of Freedom (DF)	Coefficient of Variation (v_b), %	Maximum Allowable Difference (MAD), %	Degrees of Freedom (DF)	Coefficient of Variation (v_b), %	Maximum Allowable Difference (MAD), %
A	Coil Spring						
	Elcometer 157	2	22		2	12	
	Tinsley	2	10		2	7	
	Pooled	4	17.1	67.2	4	9.8	38.6
A	Helical Spring						
	Elcometer 111	2	5	30.5 ^C	2	2	12.2 ^C
	Microtest FIM	8	15	49	8	10	32.6
	Magne Gage	^B	^B		^B	^B	
B	Mechanical						
	Elcometer 101	4	11	43.5	4	2	8 ^D
B	Probe						
	Elcometer 150	4	7		4	4	
	Minitest FN 250	...	...		2	3	
	GE Type B	12	6		...	...	
	Permascope ES	6	6		6	3	
	Pooled	22	6.2	18.3 ^C	12	3.4	10.4
	Minitest FN 250	2	22	...	...	...	...
	GE Type B	...	...	...	12	6	18.5
	Verimeter ML 301	^B	^B		^B	^B	
	Accuderm M	^B	^B		^B	^B	

^A Results obtained using the models shown. Some instruments are available as newer models, which are not included.

^B No interlaboratory results provided.

^C Insufficient results for reliable estimate.

^D Interlaboratory MAD is usually larger than intralaboratory MAD.

confidence level, the acceptability of results:

11.1.1 *Repeatability*—Two results, each the mean of four measurements, obtained by the same operator using the same instrument should be considered suspect if they differ by more than the maximum allowable difference values given in Table 1 for the appropriate film thickness.

11.1.2 *Reproducibility*—Two results, each the mean of four measurements, obtained by operators in different laboratories, each obtained using instruments from the same category, should be suspect if they differ by more than the maximum allowable difference values shown in Table 1.

11.2 *Bias*—The bias for Test Method A of this standard for measuring dry film thickness cannot be determined because each instrument has its own bias.

TEST METHOD B—MAGNETIC FLUX GAGES

12. Summary of Test Method

12.1 After calibrating the instrument using shims of known thickness and either a bare part of the metal object or metal of the same kind, the instrument probe is placed in contact with the coated metal. Instruments of this type determine, within the probe of the instrument itself, changes in the magnetic flux caused by variations in the distance between the magnet and the substrate.

12.2 It should be recognized that the accuracy of the measurements may be influenced when made closer than 1 in. (25 mm) to an edge or 3 in. (75 mm) to another mass of metal. The edge or mass of the steel may cause flux leakage from the instrument, thus distorting the readings.

13. Apparatus

13.1 The testing apparatus shall be mechanically or electrically operated. Mechanically operated instruments house an internal horseshoe magnet, the contacts of which are placed directly on the coated substrate.⁷ Electrically operated instruments utilize a separate instrument probe that houses the magnet or coil energized by alternating current and is placed directly on the surface.⁸ In both types, the coating thickness is shown on the instrument scale or meter.

14. Test Specimens

14.1 The test specimens described in Section 6 are also applicable to Test Method B. Refer to the manufacturer's instructions when measuring paint thicknesses on substrates less than 1/8 in. thickness.

15. Calibration of Apparatus

15.1 Follow the steps outlined in 7.1-7.3.

⁷ Apparatus of the mechanical type found to be typical for this purpose are shown in Table 1.

⁸ Apparatus of the probe type found to be typical for this purpose are shown in Table 1.

15.2 Hold the instrument contact or probe handle firmly on the surface and perpendicular to the measuring plane during calibration and use. Follow the manufacturer's instructions for the specific adjustment of the instrument.

NOTE 5—The probe-type instruments can be calibrated and used in any position, but the integral-magnet type must be recalibrated or calibration verified for each position of use.

16. Procedure

16.1 Follow the steps outlined in 9.1-9.3.

16.2 Take measurements no closer than 1 in. (25 mm) to an edge or 3 in. (75 mm) to another mass of steel. If such measurements are necessary, recheck the calibration in the specific area to determine the effect the edge or mass of steel has on the instrument reading.

17. Report

17.1 Report the following information: the instrument used, serial number, range, and mean of the thickness readings found. Depending upon the application, it may be useful to record the individual readings as well.

18. Precision and Bias

18.1 *Precision*—On the basis of an interlaboratory study of this test method in which several types of instruments were used in various laboratories to measure a wide range of dry-film thickness on the same set of panels, the intra- and interlaboratory coefficients of variation, calculated using procedures described in Practice D 3980, were found to be as shown in Table 1. Based upon these coefficients the following criteria should be used for judging, at the 95 % confidence level, the acceptability of results:

18.1.1 *Repeatability*—Two results, each the mean of four measurements, obtained by the same operator using instruments from the same category should be considered suspect if they differ by more than the maximum allowable difference values given in Table 1 for the appropriate film thickness.

18.1.2 *Reproducibility*—Two results, each the mean of four measurements, obtained by operators in different laboratories using instruments from the same category should be considered suspect if they differ by more than the maximum allowable difference values given in Table 1 for the appropriate film thickness.

18.2 *Bias*—The bias for Test Method A of this standard for measuring dry film thickness cannot be determined because each instrument has its own bias.

19. Keywords

19.1 coating thickness; dry film thickness; magnetic gages; nondestructive thickness; paint thickness

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