SSPC: The Society for Protective Coatings

PAINT APPLICATION SPECIFICATION NO. 2

Measurement of Dry Coating Thickness with Magnetic Gages

1. Scope

1.1 GENERAL: This standard describes the procedures to measure the thickness of a dry film of a nonmagnetic coating applied on a magnetic substrate using commercially available magnetic gages. These procedures are intended to supplement manufacturers' operating instructions for the manual operation of the gages and are not intended to replace them.

1.2 The procedures for adjustment and measurement are described for two types of gages: pull-off gages (Type 1) and electronic gages (Type 2).

1.3 The standard defines a procedure to determine if the film thickness over an extended area conforms to the minimum and the maximum levels specified. This procedure may be modified when measuring dry film thickness on overcoated surfaces (see Note 7.1).

2. Description and Use

2.1 DEFINITIONS

2.1.1 Gage Reading: A single reading at one point.

2.1.2 Spot Measurement: The average of at least three gage readings made within a 4 cm (1.5 inch) diameter circle.

2.1.3 Calibration: The controlled and documented process of measuring traceable calibration standards and verifying that the results are within the stated accuracy of the gage. Calibrations are typically performed by the gage manufacturer or by a qualified laboratory in a controlled environment using a documented process. The standards used in the calibration are such that the combined uncertainties of the resultant measurement are less than the stated accuracy of the gage.

2.1.4 Verification: An accuracy check performed by the user using known reference standards.

2.1.5 Adjustment: The act of aligning the gage's thickness readings to match those of a known sample in order to improve the accuracy of the gage on a specific surface or in a specific portion of its measurement range. Most Type 2 gages can be adjusted on a coated part or on a shim, where the thickness of the coating or of the shim is known.

2.1.6 Coating Thickness Standard (Test Block): A smooth ferromagnetic substrate with a nonmagnetic coating of known thickness that is traceable to national standards.

2.1.7 Shim (Foil): A thin strip of non-magnetic plastic, metal, or other material of known uniform thickness used to verify the accuracy of coating dry film thickness gages.

2.1.8 Dry Film Thickness Reference Standard: A sample of known thickness used to verify the accuracy of the gage, such as coated thickness standards or shims. In some instances with the owner's permission, a sample part (a particular piece of coated steel) is used as a thickness standard for a particular job.

2.1.9 Accuracy: Consistency between a measured value and the true value of the thickness standard.

2.1.10 Structure: A unit composed of one or more connected steel members comprising a bridge, tank, ship, etc. It is possible for a single steel shape (beam, angle, tee, pipe, channel, etc.) to be considered a structure, if it is painted in a shop.

2.2 DESCRIPTION OF GAGES

2.2.1 Gage Types: The gage type is determined by the specific magnetic properties employed in measuring the thickness and is not determined by the mode of data readout, i.e. digital or analog. This standard does not cover gages that measure the effect of eddy currents produced in the substrate (see Note 7.2).

2.2.2 Type 1 – Pull-Off Gages: In pull-off gages, a permanent magnet is brought into direct contact with the coated surface. The force necessary to pull the magnet from the surface is measured and interpreted as the coating thickness value on a scale or display on the gage. Less force is required to remove the magnet from a thick coating. The scale is nonlinear.

2.2.3 Type 2 – Electronic Gages: An electronic gage uses electronic circuitry to convert a reference signal into coating thickness.

2.3 USE OF PAINT APPLICATION STANDARD NO. 2: This document contains the following:

- Calibration, verification, adjustment, and measurement procedures (Section 3);
- Required number of measurements for conformance to a thickness specification (Section 4);
- Notes on gage principles and various factors affecting thickness measurement (Notes 7.2 to 7.18);
- A numerical example of thickness measurement over an extended area (Appendix 1);
- A numerical example of the calibration adjustment of Type 2 gages using plastic shims (Appendix 2);
- An example protocol for measuring DFT on beams or girders (Appendix 3);
- An example protocol for measuring DFT for a laydown painted in a shop (Appendix 4);
- An example protocol for measuring DFT on test panels (Appendix 5);
- An example protocol for measuring DFT of thin coatings on blast cleaned test panels (Appendix 6).

3. Calibration, Verification, Adjustment, and Measurement Procedures

3.1 GENERAL

3.1.1 ACCESS TO BARE SUBSTRATE: All gages are affected to some degree by substrate conditions such as roughness, shape, thickness, and composition (see Notes 7.3 to 7.8). To correct for this effect, access to the uncoated substrate is recommended. Another option is to use separate uncoated reference panels with similar roughness, shape, thickness, and composition (see Notes 7.3 to 7.8). These would be used as the bare substrate in the procedures of Sections 3.2, 3.3 and 3.4. Reference panels shall be of sufficient size to preclude edge effects (see Note 7.9). Other conditions that could affect measurements are described in Notes 7.10 to 7.14. Measurements on the bare substrate are taken before the coating is applied or by masking off small representative areas during painting. If the coating has already been applied to the entire surface, it is customary to remove small areas of coating for measurement and later patch them. Do not allow the removal process to alter the condition of the substrate. If chemical paint strippers are used, the existing profile will be retained (see Section A2.3).

3.1.2 SPOT MEASUREMENT: Repeated gage readings, even at points close together, often differ due to small surface irregularities of the coating and the substrate. Therefore, a minimum of three (3) gage readings shall be made for each spot measurement of either the substrate or the coating. For each new gage reading, move the probe to a new location within the 4 cm (1.5 inch) diameter circle defining the spot. Discard any unusually high or low gage reading that is not repeated consistently. Take the average of the acceptable gage readings as the spot measurement.

3.1.3 CALIBRATION: Gages must be calibrated by the manufacturer or a qualified lab. A Certificate of Calibration or other documentation showing traceability to a national standard is required. There is no standard time interval for re-calibration, nor is one absolutely required. Calibration intervals are usually established based upon experience and the work environment. A one-year calibration interval is a typical starting point suggested by gage manufacturers.

3.2 VERIFICATION OF ACCURACY

3.2.1 Measure the thickness of a series of reference standards covering the expected range of coating thickness (see Note 7.15). To guard against measuring with an inaccurate gage, the gage shall be checked at least at the beginning and the end of each work shift with one or more of the reference standards. If the gage is dropped or suspected of giving erroneous readings during the work shift, its accuracy shall be rechecked.

3.2.2 Record the serial number of the gage, the reference standard used, the stated thickness of the reference standard as well as the measured thickness value obtained, and the method used to verify gage accuracy. If the same gage, reference standard, and method of verification are used throughout a job, they need to be recorded only once. The stated value of the standard and the measured value must be recorded each time calibration is verified.

3.2.3 If readings do not agree with the reference standard, all measurements made since the last accuracy check are suspect. In the event of physical damage, wear, or high usage, or after an established calibration interval, the gage shall be rechecked for accuracy of measurement. If the gage is not measuring accurately, it shall not be used until it is repaired and/or recalibrated (usually by the manufacturer).

3.2.4 Shims of plastic or of non-magnetic metals which are acceptable for verifying the accuracy of Type 2 (electronic) gages are not used for verifying the accuracy of the Type 1 gages (see Note 7.2.1).

3.3 ADJUSTMENT AND MEASUREMENT - TYPE 1, PULL-OFF GAGES

3.3.1 Type 1 gages have nonlinear scales and any adjusting feature is linear in nature. Any adjustment of these gages will limit the DFT range for which the gage will provide accurate readings, and is not recommended.

3.3.2 Measure the bare substrate at a number of spots to obtain a representative average value. This average value is the base metal reading (BMR). CAUTION: the gage is not to be adjusted to read zero on the bare substrate.

3.3.3 Measure the dry coating at the number of spots specified in Section 4.

3.3.4 Subtract the base metal reading from the gage reading to obtain the thickness of the coating.

3.4 ADJUSTMENT AND MEASUREMENT - TYPE 2, ELECTRONIC GAGES

3.4.1 Different manufacturers of Type 2 (electronic) gages follow different methods of adjustment for measuring dry film thickness over a blast-cleaned surface. Adjust the gage according to the manufacturer's instructions (see Appendix 2).

3.4.2 Measure the dry coating at the number of spots specified in Section 4.

4. Required Number of Measurements for Conformance to a Thickness Specification

4.1 NUMBER OF MEASUREMENTS: Make five (5) separate spot measurements (average of the gage readings, see Section 3.1.2) spaced arbitrarily over each 10 m^2 (100 ft^2) area to be measured. If the contracting parties agree, more than five (5) spot measurements may be taken in a given area (see Section 4.1.5). The five spot measurements shall be made for each 10 m^2 (100 ft^2) of area as follows:

4.1.1 For structures not exceeding 30 m^2 (300 ft^2) in area, each 10 m^2 (100 ft^2) area shall be measured.

4.1.2 For structures not exceeding 100 m^2 (1,000 ft^2) in area, three 10 m^2 (100 ft^2) areas shall be arbitrarily selected by the inspector and measured.

4.1.3 For structures exceeding 100 m^2 (1,000 ft^2) in area, the first 100 m^2 (1,000 ft^2) shall be measured as stated in Section 4.1.2 and for each additional 100 m^2 (1,000 ft^2) of area or increment thereof, one 10 m^2 (100 ft^2) area shall be arbitrarily selected by the inspector and measured.

4.1.4 If the dry film thickness for any 10 m^2 (100 ft^2) area (see Sections 4.1.2 and 4.1.3) is not in compliance with the requirements of Sections 4.3.1 and 4.3.2, then additional measurements must be made to isolate the non-conforming area, and each 10 m^2 (100 ft^2) area painted during that work shift shall be measured.

4.1.5 Other size areas or number of spot measurements may be specified by the owner in the job specifications as appropriate for the size and shape of the structure to be coated (see Appendices 3, 4, 5, and 6).

4.2 SPECIFYING THICKNESS: It is recommended that both a maximum and a minimum DFT thickness be specified for the coating. If a maximum thickness value is not explicitly specified, the specified thickness shall be the minimum and Section 4.3.2 would not apply.

4.3 CONFORMANCE TO SPECIFIED THICKNESS

4.3.1 Minimum Thickness: The average of the spot measurements for each 10 m^2 (100 ft^2) area shall not be less than the specified minimum thickness. Although *no single spot measurement* in any 10 m^2 (100 ft^2) area shall be less than 80% of the specified minimum thickness, it is possible for *any single gage reading* to under-run by a greater amount. If the average of the spot measurements for a given 10 m^2 (100 ft^2) area meets or exceeds the specified minimum thickness, but one or more spot measurements is less than 80% of the specified minimum thickness, additional measurements will more precisely define the non-conforming area and facilitate repair (see Appendix 1 and Notes 7.16 and 7.17).

4.3.2 Maximum Thickness: The average of the spot measurements for each 10 m^2 (100 ft^2) area shall not be more than the specified maximum thickness. Although no *single spot measurement* in any 10 m^2 (100 ft^2) area shall be more than 120% of the specified maximum thickness, it is possible for *any single gage reading* to over-run by a greater amount. If the average of the spot measurements for a given 10 m^2 (100 ft^2) area meets or falls below the specified maximum thickness, but one or more spot measurements is more than 120% of the specified maximum thickness, additional measurements will more precisely define the non-conforming area and facilitate repair (see Appendix 1 and Notes 7.16 and 7.17).

5. Accuracy

5.1 To qualify under this standard, a gage must have an accuracy at least within ± 5% (see Note 7.18). For thicknesses less than 25 μm (1 mil), the gage must have an accuracy at least within ± 2.5 μm (0.1 mil).

6. Disclaimer

6.1 While every precaution is taken to ensure that all information furnished in SSPC standards and specifications is as accurate, complete, and useful as possible, SSPC cannot assume responsibility nor incur any obligation resulting from the use of any materials, coatings or methods specified therein, or of the specification or standard itself.

6.2 This standard does not attempt to address problems concerning safety associated with its use. The user of this standard, as well as the user of all products or practices described herein, is responsible for instituting appropriate health and safety practices and for ensuring compliance with all governmental regulations.

7. Notes

Notes are not requirements of this standard.

7.1 OVERCOATING: Maintenance painting often involves application of a new coating over an existing coating system. It is very difficult to accurately measure the DFT of this newly applied coating using non-destructive methods. First, access to the profile is not available, compromising the accuracy of the BMR or the adjustment of a Type 2 gage. Second, unevenness in the DFT of the existing coating necessitates careful mapping of the "before and after" DFT readings. This unevenness also adds to the statistical variation in trying to establish a base DFT reading to be subtracted from the final DFT.

A paint inspection gage (sometimes called a Tooke or PIG gage) will give accurate DFT measurements, but it cuts through the coating, so each measurement site must be repaired. Ultrasound gages may be used, but their accuracy is much less than a Type 1 or a Type 2 gage. A practical approach to monitoring DFT when overcoating is to compute DFT from wet film thickness readings and the volume solids of the coating being applied.

If the DFT of the existing coating is not too uneven, the average DFT of the existing coating can be measured to establish a base DFT. This base DFT is then subtracted from the total DFT to get the thickness of the overcoat(s).

7.2 PRINCIPLES OF THE MAGNETIC GAGE: Each of these gages can sense and indicate only the distance between the magnetic surface of the steel and the small rounded tip of the magnet or probe that rests on the top surface of the coating. For this measured distance (from the top surface of the coating to the magnetic zero) to equal the coating thickness above the peaks, the gage readings must be corrected for the profile of the steel surface and to a lesser extent the composition and shape of the steel. Such correction is made as described in Section 3.3 for Type 1 gages and Section 3.4 for Type 2 gages.

7.2.1 Type 1 (pull-off) gages measure the force needed to pull a small permanent magnet from the surface of the coated steel. The magnetic force holding the magnet to the surface varies inversely as a non-linear function of the distance between magnet and steel, i.e., the thickness of the dry coating (plus any other films present).

Normally, Type 1 gages are not adjusted or reset for each new series of measurements. Shims of sheet plastic or of non-magnetic metals, which are permissible for adjusting Type 2 (electronic) gages should not be used for adjusting Type 1 gages. Such shims are usually fairly rigid and curved and do not lie perfectly flat, even on a smooth steel test surface. Near the pull-off point of the measurement with any Type 1 gage, the shim frequently springs back from the steel surface, raising the magnet too soon and causing an erroneous reading.

7.2.2 Type 2 (electronic) gages operate on two different magnetic principles. Some Type 2 gages use a permanent magnet. When the magnet is brought near steel, the magnetic flux density at the tip of the magnet is increased. By measuring this change in flux density, which varies inversely to the distance between the magnet and the steel substrate, the coating thickness can be determined. Hall elements and magnet resistance elements positioned at the tip of the magnet are the most common ways that this change in magnetic flux density is measured. Other Type 2 gages operate on the principle of electromagnetic induction. A coil containing a soft iron rod is energized with an AC current thereby producing a changing magnetic field at the tip of the probe. As with a permanent magnet, the magnetic flux density within the rod increases when the probe is brought near the steel substrate. This change is easy to detect by using additional coils. The output of these coils is related to coating thickness.

7.3 REPEATABILITY: Magnetic gages are necessarily sensitive to very small irregularities of the coating surface or of the steel surface directly below the probe center. Repeated gage readings on a rough surface, even at points very close together, frequently differ considerably, particularly for thin films over a rough surface with a high profile.

7.4 ZERO SETTING: Type 1 magnetic gages should not be adjusted or set at the scale zero (0) with the gage applied to either a rough or a smooth uncoated steel surface. Some Type 2 gages can be adjusted to read zero (0) on an uncoated blast cleaned surface. In all cases follow the manufacturer's recommendations.

7.5 ROUGHNESS OF THE STEEL SURFACE: If the steel surface is smooth and even, its surface plane is the effective magnetic surface. If the steel is roughened, as by blast cleaning, the "apparent" or effective magnetic surface that the gage senses is an imaginary plane located between the peaks and valleys of the surface profile. Gages read thickness above the imaginary magnetic plane. If a Type 1 gage is used, the coating thickness above the peaks is obtained by subtracting the base metal reading (see Section 3.3). With a correctly calibrated and adjusted Type 2 gage, the reading obtained indicates the coating thickness above the peaks (see Section 3.4).

7.6 DIRTY, TACKY, OR SOFT FILMS: The surface of the coating and the probe of the gage must be free from dust, grease, and other foreign matter in order to obtain close contact of the probe with the coating. The accuracy of the measurement will be affected if the coating is tacky or excessively soft. Tacky coating films may cause unwanted adhesion of the magnet of a Type 1 gage. Unusually soft films may be dented by the pressure of the probe of a Type 1 or a Type 2 gage. Soft or tacky films can sometimes be measured satisfactorily with Type 2 gages by putting a shim on the film, measuring total thickness of coating plus shim, and subtracting shim thickness.

7.6.1 Ordinary dirt and grease can be removed from a probe by wiping with a soft cloth. Magnetic particles adhering to the probe can be removed using an adhesive backed tape. Any adhesive residue left on the probe must then be removed.

7.7 ALLOY STEEL SUBSTRATES: Differences among most mild low-carbon steels and high strength low alloy (HSLA) steels will not significantly affect magnetic gage readings. For higher alloy steels, the gage response should be checked. Regardless of the alloy type, the gage should be adjusted to the same steel over which the coating has been applied.

7.8 CURVATURE OF STEEL SURFACE: Magnetic gage readings may be affected by surface curvature. If the curvature is appreciable, valid measurements may still be obtained by adjusting the gage on a similarly curved surface.

7.9 PROXIMITY TO EDGES: Magnetic gages are sensitive to geometrical discontinuities of the steel, such as holes, corners or edges. The sensitivity to edge effects and discontinuities varies from gage to gage. Measurements closer than 2.5 cm (1 inch) from the discontinuity may not be valid unless the gage is adjusted specifically for that location.

7.10 PROXIMITY TO OTHER MASS OF STEEL: The older two-pole gages with permanent magnets are sensitive to the presence of another mass of steel close to the body of the gage. This effect may extend as much as 8 cm (3 inches) from an inside angle.

7.11 TILT OF PROBE: All of the magnets or probes must be held perpendicular to the coated surface to produce valid measurements.

7.12 OTHER MAGNETIC FIELDS: Strong magnetic fields, such as those from welding equipment or nearby power lines, may interfere with operation of the gages. Residual magnetism in the steel substrate may also affect gage readings. With fixed probe two-pole gages in such cases, it is recommended that the readings before and after reversing the pole positions be averaged. Other gages may require demagnetization of the steel.

7.13 EXTREMES OF TEMPERATURE: Most of the magnetic gages operate satisfactorily at 4°C and 49°C (40°F and 120°F). Some gages function well at much higher temperatures. However, if such temperature extremes are met in the field, the gage might well be checked with at least one reference standard after both the standard and the gage are brought to the same ambient temperature. Most electronic gages compensate for temperature differences among the gage, the probe, and the surface.

7.14 VIBRATION: The accuracy of the Type 1 (pull-off) gages is affected by traffic, machinery, concussions, etc. When these gages are set up for verification of calibration or measurement of coating films, there should be no apparent vibration.

7.15 COATING THICKNESS STANDARDS: Coating thickness standards consisting of coated steel plates with assigned thickness values traceable to national standards are available from several sources, including most manufacturers of coating thickness gages. Shims of known thicknesses are also available from most of these same sources.

7.16 VARIATION IN THICKNESS – 80% of MINIMUM/ 120% of MAXIMUM: In any measurement there is a certain level of uncertainty. Two inspectors using the same gage will not necessarily record the exact same number for a given spot measurement using the same 4 cm (1.5 inch) diameter circle. To allow for this natural fluctuation, an individual spot measurement is permitted to be below the specified minimum thickness as long as other spots in the 10 m^2 (100 ft^2) area are high enough to make the average thickness meet or exceed the specified minimum thickness. Similar reasoning applies to maximum thickness. The 80% of specified minimum and 120% of specified maximum allow for the accuracy of the gage and reference standards and for variations in the substrate.

7.17 CORRECTING LOW OR HIGH THICKNESS: The contracting parties should agree upon the method of correcting film thicknesses that are above the maximum or below the minimum specification. This method may be specified in the procurement documents, may follow manufacturer's instructions, or may be a compromise reached after the nonconforming area is discovered.

7.18 TYPE 1 PEN GAGES: Instances may arise where a pen-type pull-off gage is the only practical method for measuring DFT. Although these gages do not normally meet the 5% accuracy requirement, they may be used if the contracting parties agree.

APPENDIX 1 - Numerical Example of Average Thickness Measurement

Appendix 1 does not form a mandatory part of this standard.

The following numerical example is presented as an illustration of Section 4. Metric values are calculated equivalents from U.S. Customary measurements. (Reference *Journal of Protective Coatings and Linings*, Vol. 4, No 5, May 1987.)

Suppose this structure is 30 m^2 (300 ft^2) in area. Mentally divide the surface into three equal parts, each being about 10 m^2 (100 ft^2).

Part A - 10 m^2 (100 ft^2)
Part B - 10 m^2 (100 ft^2)
Part C - 10 m^2 (100 ft^2)

First, measure the coating thickness on Part A. This involves at least 15 readings of the thickness gage (see Figure A1). Assume the specification calls for 64 μm (2.5 mils) minimum thickness. The coating thickness for area A is then the average of the five spot measurements made on area A, namely 66 μm (2.6 mils).

Spot 1	64 μm	2.5 mils
Spot 2	76	3.0
Spot 3	53	2.1
Spot 4	76	3.0
Spot 5	58	2.3
Average	66 μm	2.6 mils

Considering the U.S. Customary Measurements: The average, 2.6 mils, exceeds the specified minimum of 2.5 mils and thus satisfies the specification. Next, determine if the lowest spot measurement, 2.1 mils, is within 80% of the specified minimum thickness. Eighty percent of 2.5 mils is 2.0 mils (0.80 x 2.5 = 2.0). Although 2.1 mils is below the specified minimum, it is still within 80 percent of it, so the specification is satisfied. There are individual gage readings of 1.5 mils at spot 5 and 1.8 mils at spot 3, both of which are clearly less than 2.0 mils. This is allowed because only the average of the three readings (i.e. the spot measurement) must be greater than or equal to 2.0 mils.

Considering Equivalent Metric Measurements: The average, 66 μm, exceeds the specified minimum of 64 μm and thus satisfies the specification. Next, determine if the lowest spot measurement, 53 μm, is within 80% of the specified minimum thickness. Eighty percent of 64 μm is 51 μm (0.80 x 64 = 51). Although 53 μm is below the specified minimum, it is still within 80% of it so the specification is satisfied. There are individual gage readings of 38 μm (1.5 mils) at spot 5 and 46 μm (1.8 mils) at spot 3, both of which are clearly less than 51 μm. This is allowed because only the average of the three readings (i.e., the spot measurement) must be greater than or equal to 51 μm.

Since the structure used in this example is about 30 m^2 (300 ft^2), the procedure used to measure the film thickness of part A must be applied to both part B and part C. The measured thickness of part B must exceed the 64 μm (2.5 mils) specified minimum, as must the thickness of part C.

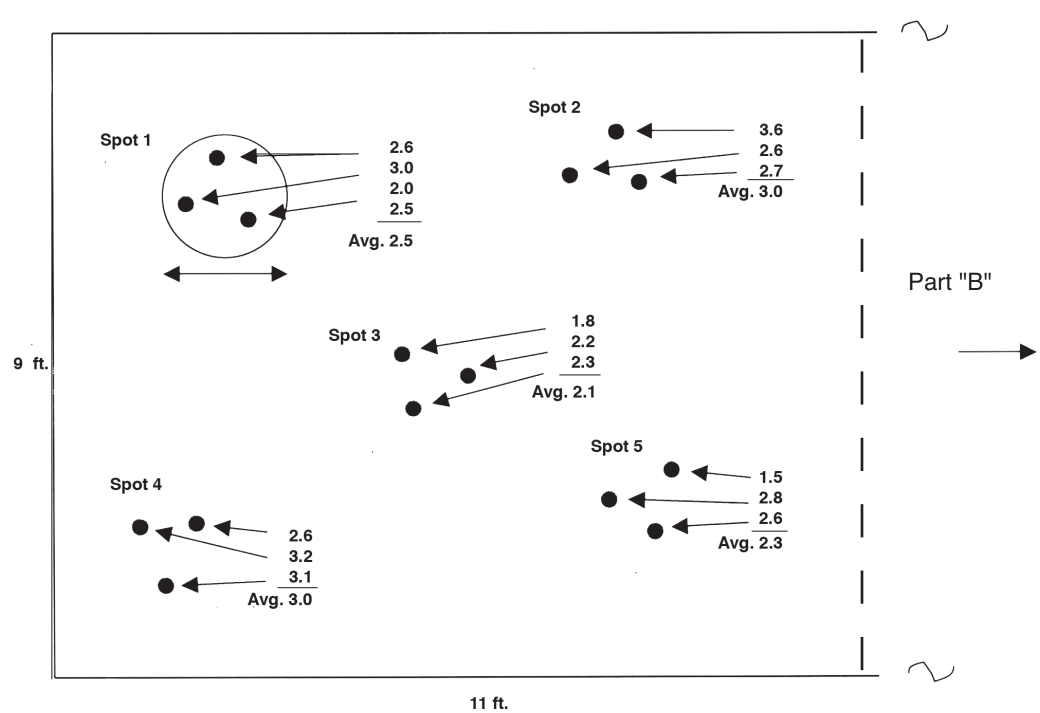
To monitor the thickness of this entire 30 m^2 (300 ft^2) structure, at least 45 individual gage readings must be taken, from which 15 spot measurements are calculated. The five spot measurements from each 10 m^2 (100 ft^2) part of the structure are used to calculate the thickness of that part.

APPENDIX 2 - Examples of the Adjustment of Type 2 Gages Using Shims

Appendix 2 does not form a mandatory part of this standard.

This example describes a method of adjustment to improve the effectiveness of a Type 2 (electronic) gage on a

FIGURE A1
PART "A" OF STRUCTURE
(APPROXIMATELY 10 M^2 [100 FT^2])



blast cleaned or otherwise roughened surface. Blast cleaning is used throughout this example, but these methods are applicable to other types of surface preparation. A less uniform surface, such as partially rusted hand tool cleaned steel, may require more gage readings to achieve a satisfactory level of statistical significance. Since gage operation differs among manufacturers, follow the manufacturer's instructions for adjustment of a particular gage.

A Type 2 gage needs to be adjusted to account for the profile of the substrate in order to read the coating thickness directly.

A portion of the substrate, after blast cleaning but prior to coating, can be used to adjust the gage. Alternatively, an uncoated test panel, blasted at the time the structure was blast cleaned and having a profile representative of the structure can be used to adjust the gage provided the test panel is of material with similar magnetic properties and geometry as the substrate to be measured. If this is not available then a correction value can be applied to a smooth surface adjustment as described below.

Three adjustment techniques can be used depending on the capability and features of the gage to be used for the inspection. Note that due to the statistical variation produced by a roughened surface, individual readings taken using these three methods may not perfectly agree.

The first two examples describe adjustment and verification to one or more shims. When shims are used, resultant gage measurements are less accurate and must be recalculated. For example, the accuracy of a properly calibrated gage is probably ± 2%. The thickness of a shim might be accurate to within ± 3%. The combined tolerance of the gage and the shim will be ± 4% as given by the sum of squares formula:

$$\sqrt{2^2 + 3^2} = 3.6055 \approx 4$$

For the gage to be in agreement with the shim, the average thickness measured by the gage must be within ±4% of the shim's thickness. If the average thickness measured on a 250 μm (10 mil) shim is between 240 μm (9.6 mils) and 260 μm (10.4 mils), the gage is properly adjusted. The minimum 240 is 250 minus 4% of 250 (9.6 is 10 minus 4% of 10); the maximum of 260 is 250 plus 4% of 250 (10.4 is 10 plus 4% of 10). [4% of 250 is 10; 4% of 10 is 0.4.]

A2.1 SINGLE POINT CALIBRATION ADJUSTMENT: This example uses a single shim value at or close to the thickness to be measured. The thickness range over which this adjustment achieves the required accuracy will vary with gage design.

Assuming that the coating thickness to be measured is 100 μm (4.0 mil), then a shim of approximately 100 μm (4.0 mil) should be used to adjust the gage. The shim is placed on an area of the substrate that has been blast cleaned to the required standards, or on a blasted test coupon with a similar surface profile.

The average of 10 readings on the shim is sufficient to allow for the statistical variation in the blast profile.

A2.2 TWO POINT CALIBRATION ADJUSTMENT: This example uses two shim values, one above and one below the expected film thickness to be measured. It should be noted that not all film thickness gages can be adjusted in this manner.

Assuming that the coating thickness to be measured is 100 μm (4.0 mil), then shims of 250 μm (10.0 mil) and 50 μm (2.0 mil) are appropriate for setting the upper and lower values on the scale of the gage.

As protective coatings are normally applied to blast cleaned metal surfaces, a statistical approach is required to obtain a typical value for the adjustment. Ten readings on a shim are sufficient to establish a reliable average value for that shim on the roughened surface. Following the manufacturer's instructions, the gage is adjusted so that the actual shim thickness is then used to set the gage.

This procedure should be repeated for both the upper and lower shim values.

The average of 10 readings on an intermediate shim, approximately 100 μm (4.0 mil) thick in the case described above, will confirm that the gage has been adjusted correctly. It is acceptable for the average reading to be within ± 4% of the shim thickness.

This method ensures that the gage reads the thickness of the coating over the peaks of the profile.

A2.3 SMOOTH SURFACE CALIBRATION ADJUSTMENT: If access to the bare blast cleaned substrate is not available because the coating already covers it, a smooth surface can be used to adjust the gage. Adjust the gage on a smooth surface according to the manufacturer's instructions.

Readings taken on the blast-cleaned substrate will be higher than the true value by an amount dependant on the surface profile and the gage probe design. For most applications a correction value of 25 μm (1.0 mil) is generally applicable. Note that this value is not related to the actual surface profile measurement. This correction value must be subtracted from each gage reading to correct for the effect of the profile. The resulting corrected reading represents the thickness of the coating over the peaks.

For fine profiles the correction value may be as low as 10 μm (0.4 mil) but for coarse profiles it could be as high as 40 μm (1.6 mil). Table A2 gives approximate correction values to be used when a blast cleaned surface is not available to adjust the gage.

The use of coated standards to adjust gages means that a correction value must be applied to readings as the coated standards make use of smooth substrate surfaces.

APPENDIX 3 - Methods for Measuring Dry Film Thickness on Steel Beams (Girders)

Appendix 3 is not a mandatory part of this standard, but it provides two sample protocols for measuring DFT on beams and girders.

A3.1 A problem for the painter in coating steel beams or girders is providing the same uniform thickness over high and low vertical surfaces as over horizontal surfaces. On a beam, there are proportionately more edges that tend to have low dry film thickness (DFT) and inside corners that tend to have high DFT compared to the center of the flat surfaces. Each painter usually develops a pattern of work for a specific task. Hence, the DFT on the underside of the top flange, for example, may be consistently on the high side or the low side of the target DFT. This type of error is easy to detect and correct. Random errors pose a more difficult problem. Gross errors where the paint is obviously too thin or too thick must be corrected and are beyond the scope of this standard.

The number of spot measurements in these protocols may far exceed the “5 spot measurement per 10 m^2 (100 ft^2)” required in the standard. The full DFT determination, described in Section A3.2, provides a very thorough inspection of the beam. The sample DFT determination, described in Section A3.4, allows for fewer spot measurements. The user does not have to require a full DFT determination for every beam in the structure. For example, the requirement may be for a full DFT determination on one beam out of ten, or a sample DFT determination on one beam out of five, or a combination of full and sample DFT determinations.

A beam has twelve different surfaces as shown in Figure A3. Any one of these surfaces may have a DFT outside the specified range, and hence, shall be measured. If the thickness of the flange is less than 25 mm (1 inch), the contracting parties may choose not to measure the DFT on the toe,[2] i.e., surfaces 2, 6, 8, and 12 of Figure A3. As an informal initial survey, the inspector may want to check for uniformity of DFT across each surface. Is the DFT of the flange near the fillet the same as near the toe? Is the DFT uniform across the web? The inspector must be sure to use a gage that is not susceptible to edge effects. Follow the gage manufacturer’s instructions when measuring the edges.

TABLE A2
TYPICAL GAGE CORRECTION VALUES USING ISO 8503 PROFILE GRADES (SOURCE: prEN ISO 19840)[1]

ISO 8503 Profile Grade	Correction Value (μm)	Correction Value (mil)
Fine	10	0.4
Medium	25	1.0
Coarse	40	1.6

A3.2 FULL DFT DETERMINATION OF A BEAM: Divide the beam or girder into five equal sections along its length. Identify the 12 surfaces of the beam as shown in Figure A3 for each section. For tall beams where the height of the beam is 91 cm (36 inches) or more, divide the web in half along the length of the beam. For the full DFT determination, each half of the web is considered a separate surface. Take one spot measurement (as defined in Section 3.1.2) on surface 1 in each of the five sections. The location of the surface 1 measurement within a section is arbitrarily chosen by the inspector in each of the five sections. The average of these five spot measurements is the DFT of surface 1. Repeat for the other 11 surfaces (7 surfaces if the toe is not measured; 14 surfaces for tall beams). The data can be reported in a format shown in Table A3.1.

A3.3 No single spot measurement can be less than 80% of the specified minimum DFT. No single spot measurement can be more than 120% of the specified maximum DFT. The average value for each surface must conform to the specified DFT. (There will be only eight average values if the DFT of the toe is not measured; there may be as many as 14 average values for tall beams.)

A3.4 SAMPLE DFT DETERMINATION OF A BEAM: In lieu of a full DFT determination of each beam, the job specification may require only a sample DFT determination for selected beams less than 18 m (60 ft) long. For a sample DFT determination, the web of tall beams is not split.

A3.4.1 Beams less than 6 m (20 ft): For beams less than 6 m (20 ft), take two spot measurements, randomly distributed, on each of the 12 surfaces (8 surfaces if the toe is not measured) of the beam as defined in Figure A3. Each spot measurement must conform to the specified DFT.

A3.4.2 Beams between 6 m (20 ft) and 18 m (60 ft): For beams between 6 m (20 ft) and 18 m (60 ft), take three spot measurements, randomly distributed, on each of the 12 surfaces (8 surfaces if the toe is not measured) of the beam as defined in Figure A3. Each spot measurement must conform to the specified DFT.

A3.5 NON-CONFORMANCE: If any spot measurement falls outside the specified range, additional measurements may be made to define the non-conforming area.

A3.6 RESTRICTED ACCESS: If the beam is situated such that one or more of the surfaces are not accessible, take measurements on each accessible surface in accordance with Section A3.2 or Section A3.4, as specified.

[1] International Organization for Standardization (ISO), Case Postale 56, Geneva CH-1211, Switzerland. ISO standards may be obtained through the American National Standards Institute (ANSI), 1819 L Street NW, Suite 600 Washington DC 20036. Standards may also be downloaded from http://www.ansi.org. The standard from which this data originates is under development and has not formally been adopted as of June 1, 2004.
[2] On rolled beams, measurement of surfaces 2, 6, 8, and 12 may not be practical.

FIGURE A.3
THE SURFACES OF A STEEL BEAM

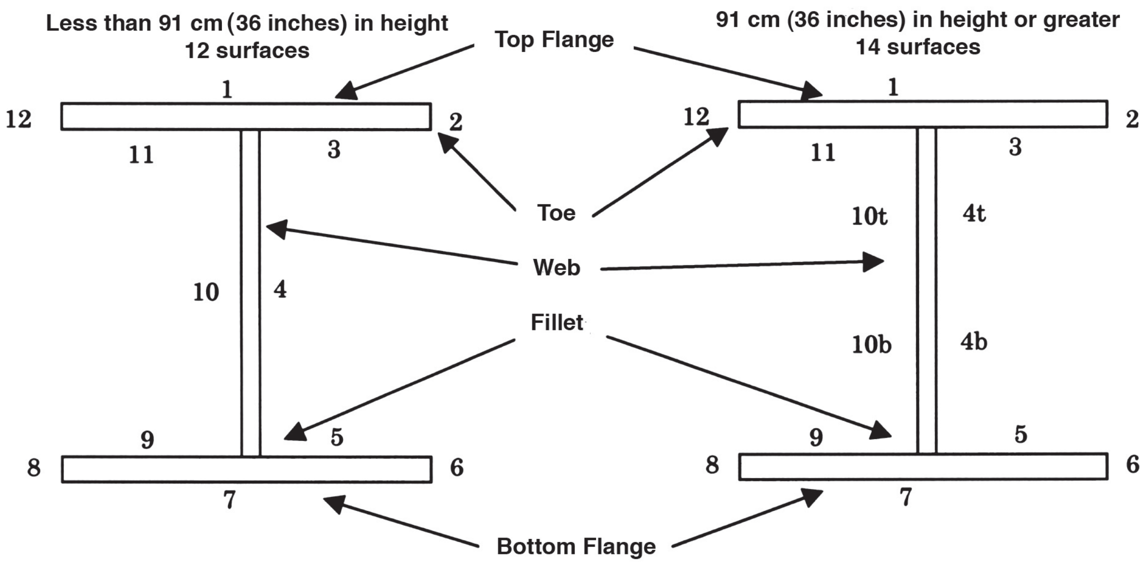


TABLE A3
DATASHEET FOR RECORDING SPOT MEASUREMENTS AND AVERAGE DFT VALUES FOR THE 12 SURFACES OF A BEAM OR GIRDER

Surface*	Section 1	Section 2	Section 3	Section 4	Section 5	Average
1						
2						
3						
4t						
4b						
5						
6						
7						
8						
9						
10t						
10b						
11						
12						

* t = top half of web (for tall beams)
b = bottom half of web (for tall beams)

A3.7 ATTACHMENTS: Stiffeners and other attachments to a beam shall be arbitrarily measured at a frequency specified in the job specification.

APPENDIX 4 - Methods for Measuring Dry Film Thickness for a Laydown of Beams, Structural Steel, and Miscellaneous Parts After Shop Coating

Appendix 4 is not a mandatory part of this standard, but it provides two sample protocols for measuring DFT for a laydown.

A4.1 GENERAL: A "laydown" is a group of steel members laid down to be painted in one shift by one painter. For inspection of a laydown, first make a visual survey to detect areas with obvious defects, such as poor coverage, and correct as necessary. As an informal initial survey, the inspector may want to check for uniformity of DFT across each surface.

A4.2 FULL DFT DETERMINATION

A4.2.1 Beam (Girder): Follow the procedure described in Section A3.2.

A4.2.2 Miscellaneous Part: Take one spot measurement (as defined in Section 4.1.2) on each surface of the part. If the part has fewer than five surfaces, take multiple spot measurements on the larger surfaces to bring the total to five. If the total area of the part is over 10 m^2 (100 ft^2), take 5 spot measurements randomly distributed over the part for each 10 m^2 (100 ft^2) or fraction thereof.

A4.3 No single spot measurement can be less than 80% of the specified minimum DFT. No single spot measurement can be more than 120% of the specified maximum DFT. The average value of the spot measurements on each surface must conform to the specified DFT. If there is only a single spot measurement on a surface, it must conform to the specified DFT.

A4.4 SAMPLE DFT DETERMINATION: In lieu of a full DFT determination of each painted piece as described in Section A4.2, the job specification may require only a sample DFT determination for selected pieces.

A4.4.1 Beams less than 6 m (20 ft): Follow the procedure described in Section A3.4.1.

A4.4.2 Beams between 6 m (20 ft) and 18 m (60 ft): Follow the procedure described in Section A3.4.2.

A4.4.3 Miscellaneous parts: For a miscellaneous part, take three spot measurements, randomly distributed on the part. Each spot measurement must conform to the specified DFT.

A4.5 NON-CONFORMANCE: If any spot measurement falls outside the specified range, additional measurements may be made to define the non-conforming area.

A4.6: RESTRICTED ACCESS: If a beam or miscellaneous part is situated such that one or more of the surfaces are not accessible, take measurements on each accessible surface in accordance with Section A4.2 or Section A4.4, as specified.

A4.7 NUMBER OF BEAMS OR PARTS TO MEASURE: In a laydown, the number of beams or parts to receive a full DFT determination and the number to have a sample DFT determination can be specified. For example, do a full DFT determination on a piece painted near the beginning of the shift, near the middle of the shift, and near the end of the shift in accordance with Section A4.2; and perform a sample DFT determination on every third piece in accordance with Section A4.4.

A4.8 ATTACHMENTS: Stiffeners and other attachments to a beam shall be arbitrarily measured at a frequency specified in the job specification.

TABLE A3.1
NUMBER OF SPOT MEASUREMENTS NEEDED ON EACH SURFACE OF A BEAM FOR A FULL OR A SAMPLE DFT DETERMINATION

	NUMBER OF SPOT MEASUREMENTS PER SURFACE	
LENGTH OF BEAM	FULL DFT DETERMINATION[1]	SAMPLE DFT DETERMINATION
less than 6 m (20 ft)	5	2
from 6 to 18 m (20 to 60 ft)	5	3
over 18 m (60 ft)	5	NA

[1] For tall beams (91 cm [36 inches]) or more, the top half and bottom half of the web are treated as separate surfaces in a full DFT determination.

APPENDIX 5 - Method for Measuring Dry Film Thickness on Coated Steel Test Panels

Appendix 5 is not a mandatory part of this standard, but it provides a sample protocol for measuring DFT on coated steel test panels.

A5.1 Panel Size: The test panel shall have a minimum area of 116 cm^2 (18 in^2) and a maximum area of 930 cm^2 (144 in^2); e.g., minimum 7.5 x 15 cm (3 x 6 inch) and maximum 30 x 30 cm (12 x 12 inch).

A5.2 Procedure: Use a Type 2 electronic gage. Take two gage readings from the top third, the middle third, and the bottom third of the test panel. Readings shall be taken at least 12 mm (one-half inch) from any edge and 25 mm (one inch) from any other gage reading. Discard any unusually high or low gage reading that cannot be repeated consistently. The DFT of the test panel is the average of the six acceptable gage readings.

A5.3 Minimum Thickness: The average of the acceptable gage readings shall be no less than the specified minimum thickness. No single gage reading shall be less than 80% of the specified minimum.

A5.4 Maximum Thickness: The average of the acceptable gage readings shall be no more than the specified maximum thickness. No single gage reading shall be more than 120% of the specified maximum.

A5.5 Rejection: If a gage reading is less than 80% of the specified minimum DFT or exceeds 120% of the specified maximum DFT, additional measurements may be made to reevaluate the DFT on the area of the test panel near the low or high gage reading. If the additional measurements indicate the DFT in the disputed area of the panel to be below the minimum or above the maximum allowable DFT, the panel shall be rejected.

APPENDIX 6 - Method for Measuring Dry Film Thickness of Thin Coatings on Coated Steel Test Panels that Had Been Abrasive Blast Cleaned

Appendix 6 is not a mandatory part of this standard, but it provides a sample protocol for measuring DFT of thin coatings on coated steel test panels that had been abrasive blast cleaned.

A6.1 A coating is defined as thin if the dry film thickness (DFT) is on the order of 25 micrometers (1 mil) or less. Because the DFT is the same order as the statistical fluctuations of a DFT gage on bare blast cleaned steel, many gage readings must be taken to get a meaningful average.

A6.2 Panel Size: The test panel shall have a minimum area of 116 cm^2 (18 in^2) and a maximum area of 930 cm^2 (144 in^2); e.g., minimum 7.5 x 15 cm (3 x 6 inch) and maximum 30 x 30 cm (12 x 12 inch).

A6.3 Procedure: Use a properly adjusted Type 2 electronic gage. Take ten gage readings randomly distributed in the top third of the panel. Compute the mean (average) and standard deviation of these ten readings. Similarly, take ten readings from the middle third and ten readings from the bottom third of the test panel and compute their means and standard deviations. Readings shall be taken at least 12 mm (one-half inch) from any edge and 25 mm (one inch) from any other gage reading. Discard any unusually high or low gage reading, i.e., a reading that is more than three standard deviations from the mean. The DFT of the test panel is the average of the three means.

A6.4 Minimum Thickness: The average of the means shall be no less than the specified minimum thickness. No single mean shall be less than 80% of the specified minimum.

A6.5 Maximum Thickness: The average of the means shall be no more than the specified maximum thickness. No single mean shall be more than 120% of the specified maximum.