

SSPC: The Society for Protective Coatings

Paint Application Standard No. 2

Procedure for Determining Conformance to Dry Coating Thickness Requirements

1. SCOPE

1.1 This standard describes a procedure for determining shop or field conformance to a specified coating dry film thickness (DFT) range on ferrous and non-ferrous metal substrates using two types of nondestructive coating thickness gages (Type 1, magnetic pull-off; and Type 2, electronic) described in ASTM D7091.¹

1.2 This standard defines a procedure to determine whether coatings conform to the minimum and the maximum thickness specified. See Note 12.1 for an example of a possible modification when measuring dry film thickness on overcoated surfaces.

1.3 This document contains the following non-mandatory appendices:

- Appendix 1 - Numerical Example of Average Thickness Measurement and Illustration of the Procedure for Determining the Magnitude of a Nonconforming Area
- Appendix 2 - Methods for Measuring Dry Film Thickness on Steel Beams (Girders)
- Appendix 3 - Methods for Measuring Dry Film Thickness for a Laydown of Beams, Structural Steel, and Miscellaneous Parts after Shop Coating
- Appendix 4 - Method for Measuring Dry Film Thickness on Coated Steel Test Panels
- Appendix 5 - Method for Measuring Dry Film Thickness of Thin Coatings on Coated Steel Test Panels that Have Been Abrasive Blast Cleaned
- Appendix 6 – Method for Measuring the Dry Film Thickness of Coatings on Edges
- Appendix 7 – Method for Measuring Dry Film Thickness on Coated Steel Pipe Exterior
- Appendix 8 – Examples of the Adjustment of Type 2 Gages Using Shims
- Appendix 9 – Precaution Regarding Use of the Standard for Coating Failure Investigations
- Appendix 10 -- Procedure for Obtaining a Greater Population of Thickness Measurements Using Type 2 Gage Continuous Read/Scanning Probe Technology

1.5 Units of Measure: This standard makes use of both the ASTM SI 10, “American National Standard for Metric Practice” International System Units (SI) and U.S. Customary units. The measurements are not exact equivalents; therefore, each system must be used independently of the other.

2. REFERENCED STANDARDS

2.1 The latest issue, revision, or amendment of the referenced standards in effect on the date of invitation to bid shall govern unless otherwise specified. Standards marked with an asterisk (*) are referenced only in the Notes, which are not requirements of this standard.

2.2 If there is a conflict between the requirements of any of the cited reference standards and this standard, the requirements of this standard shall prevail.

2.3 ASTM International

ASTM D7091 Standard Practice for Nondestructive Measurement of Dry Film Thickness of Nonmagnetic Coatings Applied to Ferrous Metals and Nonmagnetic, Nonconductive Coatings Applied to Non-Ferrous Metals

2.4 SSPC: The Society for Protective Coatings

*** PA Guide 11** Protecting Edges, Crevices, and Irregular Steel Surfaces by Stripe Coating

3. DEFINITIONS

3.1 Gage Reading: A single instrument reading.

3.2 Spot Measurement: The average of three, or at least three gage readings made within a 4-cm (approximately [~]1.5-in) diameter circle.

Discussion: Acquisition of more than three gage readings within a spot is permitted. Any unusually high or low gage readings that are not repeated consistently are discarded. The average of the acceptable gage readings is the spot measurement.

¹ ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959. For referenced ASTM standards visit the ASTM website <<https://www.astm.org>> For Annual Book of ASTM Standards volume information, or to review the scope of an ASTM standard, refer to the standard's Document Summary page on the ASTM website.

3.3 Area Measurement: The average of five spot measurements obtained over each 10 m² (~100 ft²) area of coated surface, or portion thereof.

3.4 Certified Standards: Coated or plated metal plates (containing an uncoated plate for zero reference) with assigned values traceable to a national metrology institution. Also, uncoated shims of flat plastic sheet with assigned values traceable to a national metrology institution.

4. DESCRIPTION OF GAGES

4.1 Gage Types: The gage type is determined by the operating principle employed in measuring the thickness and is not determined by the mode of data readout, i.e. digital or analog.

4.2 Type 1 – Magnetic Pull-Off Gages: For magnetic 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 an analog dial (scale) on the gage. Less force is required to remove the magnet from a thick coating. The gage scale is non-linear.

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

5. CALIBRATION, VERIFICATION OF ACCURACY AND ADJUSTMENT

5.1 Three operational steps are necessary to ensure accurate coating thickness measurement: calibration, verification of accuracy and adjustment. These steps shall be completed before taking coating thickness measurements to determine conformance to a specified coating thickness range. Verification of accuracy shall be performed using certified standards. Type 2 gage adjustment to compensate for characteristics including (but not limited to) substrate metallurgy, geometry, thickness/thinness and roughness shall be performed using certified shims. The measured shims commonly supplied with Type 2 gages are also acceptable for gage adjustment.

5.2 Gages shall be calibrated by the equipment manufacturer, their authorized agent or an accredited calibration laboratory. A test certificate or other documentation showing traceability to a national metrology institution 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, or when specified. A one-year calibration interval is a typical starting point suggested by gage manufacturers.

5.3 To guard against measuring with an inaccurate gage, gage accuracy shall be verified at a minimum of the beginning and end of each work shift according to the procedures

described in ASTM D 7091 or the gage manufacturer's instructions. The user is advised to verify gage accuracy during measurement acquisition (e.g., hourly) when a large number of measurements are being obtained. If the gage is dropped or suspected of giving erroneous readings during the work shift, its accuracy shall be rechecked.

5.4 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 accuracy is verified.

5.5 If the gage fails the post-measurement accuracy verification check, all measurements acquired since the last accuracy verification 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 gage manufacturer).

5.6 A Type 1 gage that does not meet the manufacturer's stated accuracy (when verified on certified standards) cannot be adjusted to correct for the out-of-tolerance condition and shall not be used until it is repaired and/or re-calibrated (typically by the gage manufacturer). Any manual adjustment of these gages will limit the DFT range for which the gage will provide accurate readings; therefore, adjustment of the gage is not permitted. Furthermore, the application of a single "correction value" representing the full range of the gage to compensate for a gage that is not measuring accurately is not appropriate, since the gage scale is non-linear.

6. MEASUREMENT PROCEDURE – TYPE 1 GAGES

6.1 Verify Type 1 gage accuracy using certified coated metal plates having at least one thickness value within the expected range of use. Unless explicitly approved by the gage manufacturer, certified shims of plastic or of non-magnetic metals that are acceptable for verifying the accuracy of Type 2 (electronic) gages shall not be used for verifying the accuracy of Type 1 gages.

6.2 In order to compensate for any effect of the substrate itself and surface roughness, obtain one reading from the bare, prepared substrate at each of a minimum of ten (10) arbitrarily spaced locations and calculate the average value. This value represents the effect of the substrate/surface roughness on a coating thickness gage. This average value is the base metal reading (BMR).

6.3 Measure the DFT of the coating at the number of spots specified in Section 8.

6.4 Subtract the BMR from the gage reading to obtain the thickness of the coating.

7. MEASUREMENT PROCEDURE – TYPE 2 GAGES

7.1 The manufacturers of Type 2 (electronic) gages prescribe different methods of adjustment to measure dry film thickness over roughened surfaces. Adjust the gage according to the manufacturer's instructions using one of the methods described in ASTM D 7091 or Appendix 8 of this standard.

7.2 Measure the DFT of the coating at the number of spots specified in Section 8.

8. REQUIRED NUMBER OF MEASUREMENTS FOR CONFORMANCE TO A THICKNESS SPECIFICATION

8.1 Number of Measurements: 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 the coating. For each new gage reading, move the probe to a new location within the 4-cm (approximately [~]1.5-in) diameter circle defining the spot. Discard any unusually high or low gage readings that are not repeated consistently. The average of the acceptable gage readings is the spot measurement.

8.2 Unless otherwise specified in the procurement documents (project specification), an area measurement is obtained by taking five (5) separate spot measurements (average of the gage readings described in Section 8.1) randomly spaced throughout each 10-m² (~100 ft²) area to be measured and representative of the coated surface. The five spot measurements shall be made for each 10-m² (~100 ft²) area as follows:

8.2.1 For areas of coating not exceeding 30 m² (~300 ft²) arbitrarily select and measure each 10-m² (~100 ft²) area.

8.2.2 For areas of coating greater than 30 m² (~300 ft²) and not exceeding 100 m² (~1,000 ft²), arbitrarily select and measure three 10-m² (~100 ft²) areas.

8.2.3 For areas of coating exceeding 100 m² (~1,000 ft²), arbitrarily select and measure the first 100 m² (~1,000 ft²) as stated in Section 8.2.2. For each additional 100 m² (~1,000 ft²) coated area (or increment thereof), arbitrarily select and measure one additional 10-m² (~100 ft²) area.

8.3 Nonconforming Areas: If the coating thickness for any 10-m² (~100 ft²) area is not in compliance with the contract documents, the procedure described here shall be followed to assess the magnitude of the nonconforming thickness.

8.3.1 Determine the spot DFT at 1.5-meter (5-foot) intervals in eight equally spaced directions radiating outward from the nonconforming 10-m² (100-ft²) area.

If there is no place to measure in a given direction, then no measurement in that direction is necessary. Acquire spot measurements in each direction (up to the maximum surface area coated during the work shift) until two consecutive conforming spot measurements are acquired in that direction or until no additional measurements are possible. Acceptable spot measurements are defined by the minimum and maximum values in the contract documents. No allowance is made for variant spot measurements, as is the practice when determining the area DFT. An illustration of this procedure is shown in Figure A1.2.

8.3.1.1 On complex structures or in other cases where making spot measurements at 1.5-meter (5-foot) intervals is not practical, spot measurements shall be performed on repeating structural units or elements of structural units. This method shall be used when the largest dimension of the unit is less than 3 meters (~10 feet). Make spot measurements on repeating structural units or elements of structural units until two consecutive units in each direction are conforming or until there are no more units to test.

8.3.2 Non-compliant areas shall be demarcated using removable chalk or other specified marking material and documented. All of the area within 1.5 meters (5 feet) of any non-compliant spot measurement shall be designated as non-compliant. For a given measurement direction or unit measurement, any compliant area or unit preceding a non-compliant area or unit shall be designated as suspect, and as such is subject to re-inspection after corrective measures are performed (see Note 12.2).

8.3.3 Appendices 2 through 7 and Appendix 10 provide specifiers with optional alternatives for defining the area size as well as the number and frequency of spot measurements to include in project specifications as appropriate for the size and shape of the item or structure to be coated.

9. CONFORMANCE TO SPECIFIED THICKNESS

9.1 A minimum and a maximum thickness are normally specified for each layer of coating. If a single thickness value is specified and the coating manufacturer does not provide a recommended range of thickness, then the minimum and maximum thickness for each coating layer shall be $\pm 20\%$ of the stated value.

9.2 Table 1 provides five thickness restriction levels. Level 1 is the most restrictive and does not allow for any deviation of spot or area measurements from the specified minimum and maximum thickness, while Level 5 is the least restrictive. Depending on the coating type and the prevailing service environment, the specifier selects the dry film thickness restriction level for a given project. If no restriction level is specified, then Level 3 is the default. It is possible to specify a maximum thickness threshold for Level 5 Spot or Area measurements for some generic product types and service environments.

TABLE 1
COATING THICKNESS RESTRICTION LEVELS

Thickness	Gage Reading	Spot Measurement	Area Measurement
Level 1			
Minimum	Unrestricted	As specified	As specified
Maximum	Unrestricted	As specified	As specified
Level 2			
Minimum	Unrestricted	As specified	As specified
Maximum	Unrestricted	120% of maximum	As specified
Level 3 (default)			
Minimum	Unrestricted	80% of minimum	As specified
Maximum	Unrestricted	120% of maximum	As specified
Level 4			
Minimum	Unrestricted	80% of minimum	As specified
Maximum	Unrestricted	150% of maximum	As specified
Level 5			
Minimum	Unrestricted	80% of minimum	As specified
Maximum	Unrestricted	Unrestricted	Unrestricted

9.3 For the purpose of final acceptance of the total dry film thickness, the cumulative thickness of all coating layers shall be no less than the cumulative minimum specified thickness and no greater than the cumulative maximum specified thickness.

10. Report

The following items shall be reported:

10.1 The type of instrument used, including manufacturer, model number, serial number and date of calibration.

10.2 The type of certified standard used to verify gage accuracy, including manufacturer, model number, serial number and thickness value(s).

10.3 The thickness of the measured shim(s) used to adjust a Type 2 gage.

10.4 The average BMR (if appropriate).

10.5 The spot and area measurements.

10.6 The gage operator and date of measurement acquisition.

11. Disclaimer

11.1 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.

11.2 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.

12. Notes

Notes are not requirements of this standard.

12.1 Overcoating: Maintenance painting often involves application of a new coating over an existing coating system. It can be 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 requires that an incision be made through the coating (overcoat only or total system), so each measurement site will require repair.

A practical approach to monitoring DFT (when overcoating) is to compute the DFT using wet film thickness (WFT) readings, the percent volume solids of the coating being applied, and any thinner addition as shown here.

$$\begin{aligned} \text{DFT} &= \text{Measured WFT} \times \% \text{ Volume Solids,} \\ &\text{or} \\ \text{DFT} &= \text{Measured WFT} \times \% \text{ volume solids} \\ &\quad \div (100\% + \% \text{ thinner added}) \end{aligned}$$

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

12.2 Correcting for Low or High Thickness: The specifier should specifically state the methodology to correct the applied and cured film for low or high thickness. If this information is not contained in the specification, then the coating manufacturer's instructions should be followed.

APPENDIX 1 – NUMERICAL EXAMPLE OF AVERAGE THICKNESS MEASUREMENT AND ILLUSTRATION OF THE PROCEDURE FOR DETERMINING THE MAGNITUDE OF A NONCONFORMING AREA

Appendix 1 is not a mandatory part of this standard.

Considering Metric Measurements:

The following numerical example is presented as an illustration of Section 8. The example is based on a Level 3 Restriction (default).

Suppose the coated area is 30 m² in area. Divide the area into three equal parts, each being about 10 m².

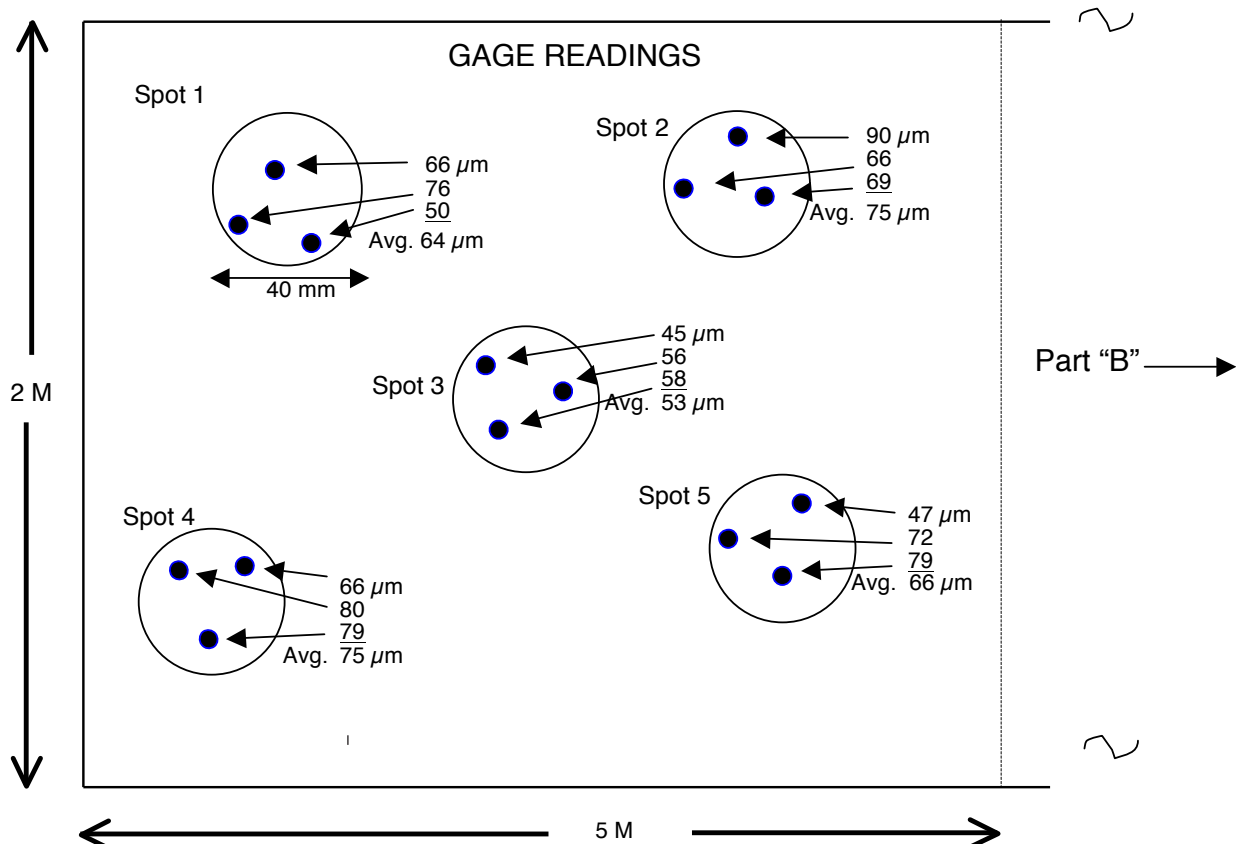
Part A - 10 m²
Part B - 10 m²
Part C - 10 m²

First, measure the coating thickness on Part A. This involves at least 15 gage readings with a Type 1 or Type 2 device (see Figure A1.1). Assume the specification calls for 64 μm minimum thickness. The coating thickness for area A is then the average of the five spot measurements made on area A, namely 67 μm.

Spot 1	64 μm
Spot 2	75
Spot 3	53
Spot 4	75
Spot 5	66
Average	67 μm

The average, 67 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 (based on Coating Thickness Restriction Level 3, or the default). Eighty percent of 64 μm is 51 μm (0.80 x 64 = 51). Although a measurement of 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 47 μm at Spot 5 and 45 μm at Spot 3, both of which are clearly less than 51 μm. This is allowed because only the average

Figure A1 (Metric). Part "A" of Structure
(area is 10 m²)



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 approximately 30 m^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 specified minimum, as must the thickness of part C.

To monitor the thickness of this entire 30- m^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 part of the structure are used to calculate the thickness of that part.

Considering the U.S. Customary Measurements

Suppose the coated area is 300 ft^2 in area. Divide the area into three equal parts, each being about 100 ft^2 .

Part A - 100 ft^2

Part B - 100 ft^2

Part C - 100 ft^2

First, measure the coating thickness on Part A. This involves at least 15 gage readings with a Type 1 or Type 2 device (see Figure A1.1). Assume the specification calls for 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 2.6 mils.

Spot 1	2.5 mils
Spot 2	2.9 mils
Spot 3	2.1 mils
Spot 4	2.9 mils
Spot 5	2.6 mils
Average	2.6 mils

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 (based on Coating Thickness Restriction Level 3, or the default). Eighty percent of 2.5 mils is 2.0 mils ($0.80 \times 2.5 = 2.0$). 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 1.8 mils at Spot 3 and 1.8 mils at Spot 5, 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.

Figure A1 (U.S Custom Units). Part "A" of Structure
(area is 100 ft^2)

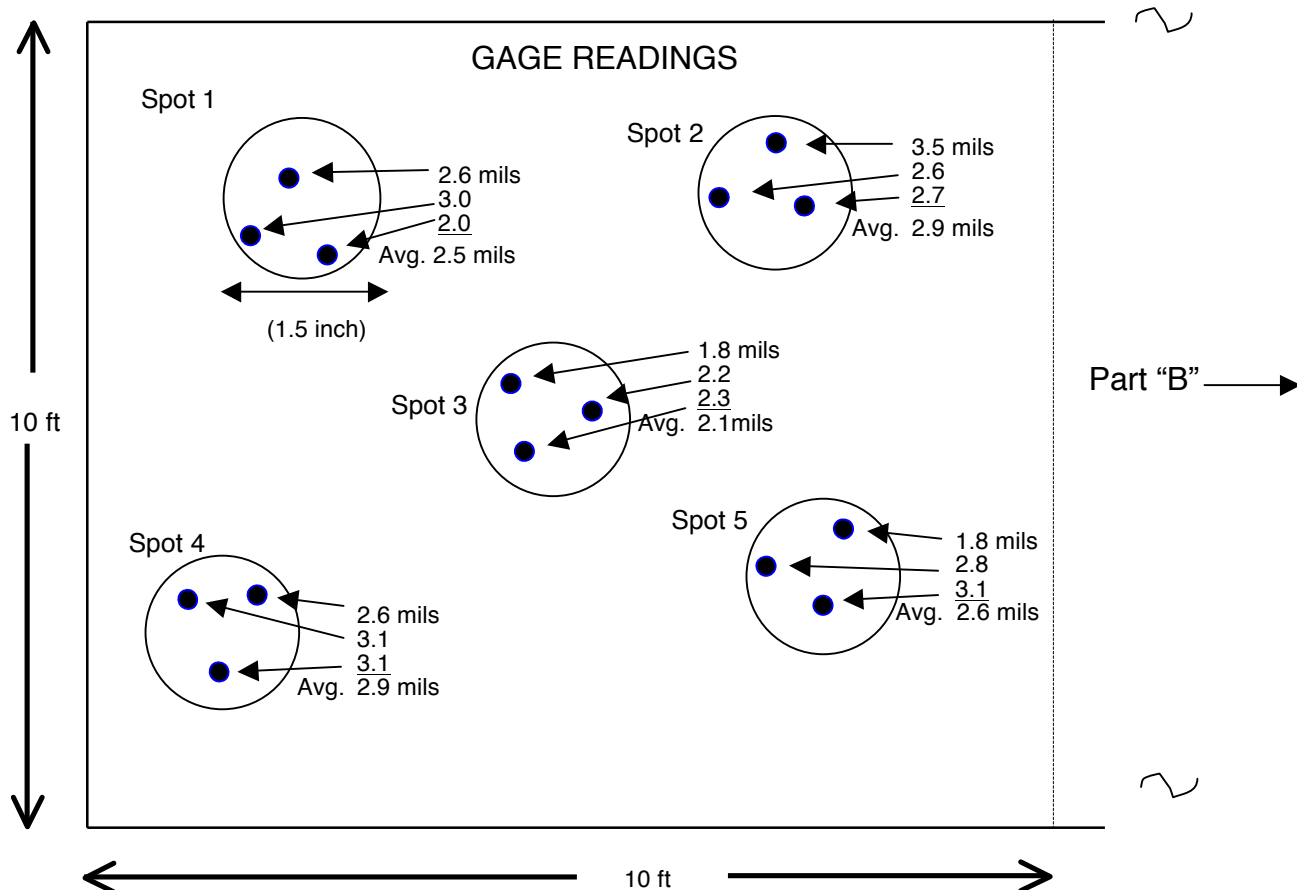


FIGURE A1.2
DETERMINING EXTENT OF NONCONFORMING AREAS

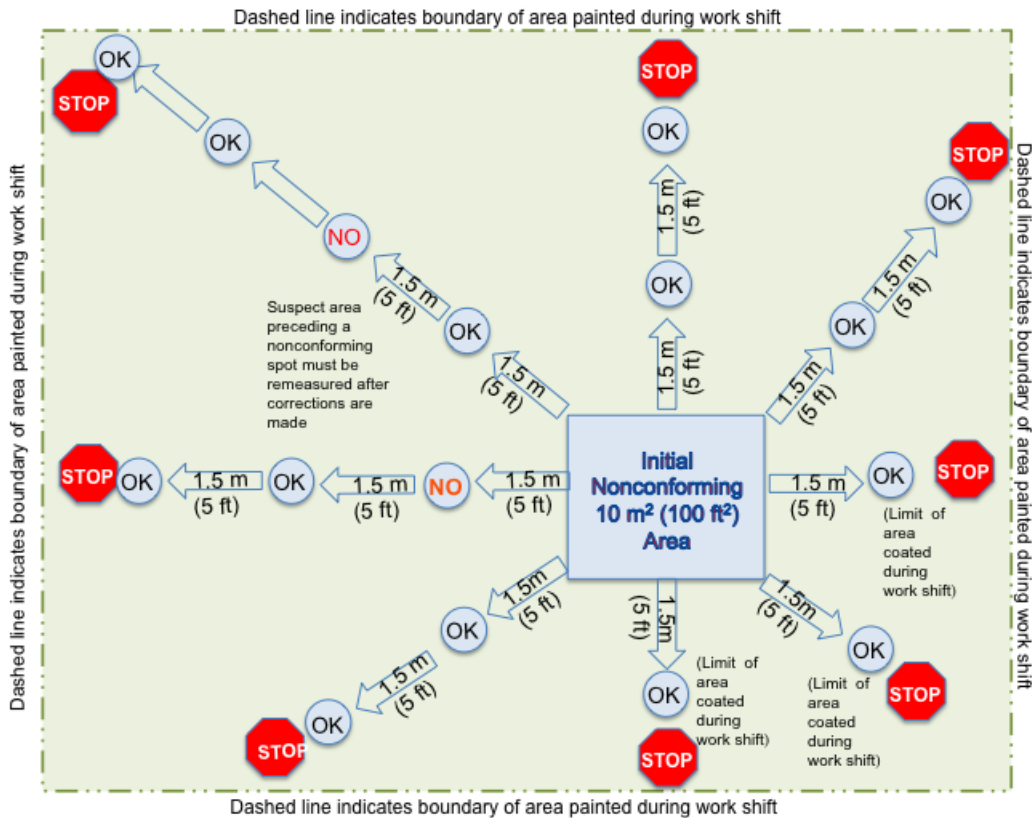


Figure A1.2 illustrates the procedure described in Section 8.3 of this standard for determining the magnitude of the nonconforming thickness.

APPENDIX 2 – METHODS FOR MEASURING DRY FILM THICKNESS ON STEEL BEAMS (GIRDERS)

Appendix 2 is not a mandatory part of this standard, but it provides two sample protocols for measuring DFT on beams and girders.

A2.1 A challenge 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 m² (100 ft²)”

required in the standard. The full DFT determination, described in Section A2.2, 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. Note that for existing structures, the top side of the top flange (Surface 1) may not be accessible for measuring coating thickness.

A beam has twelve different surfaces as shown in Figure A2 (page 8). 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 in), the contracting parties may choose not to measure the DFT on the toe, i.e., surfaces 2, 6, 8, and 12 of Figure A2. 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.

A2.2 Full DFT Determination of a Beam: Divide the beam or girder into five equal sections along its length. Identify

FIGURE A2
THE SURFACES OF A STEEL BEAM
(36 in [91 cm] in height)

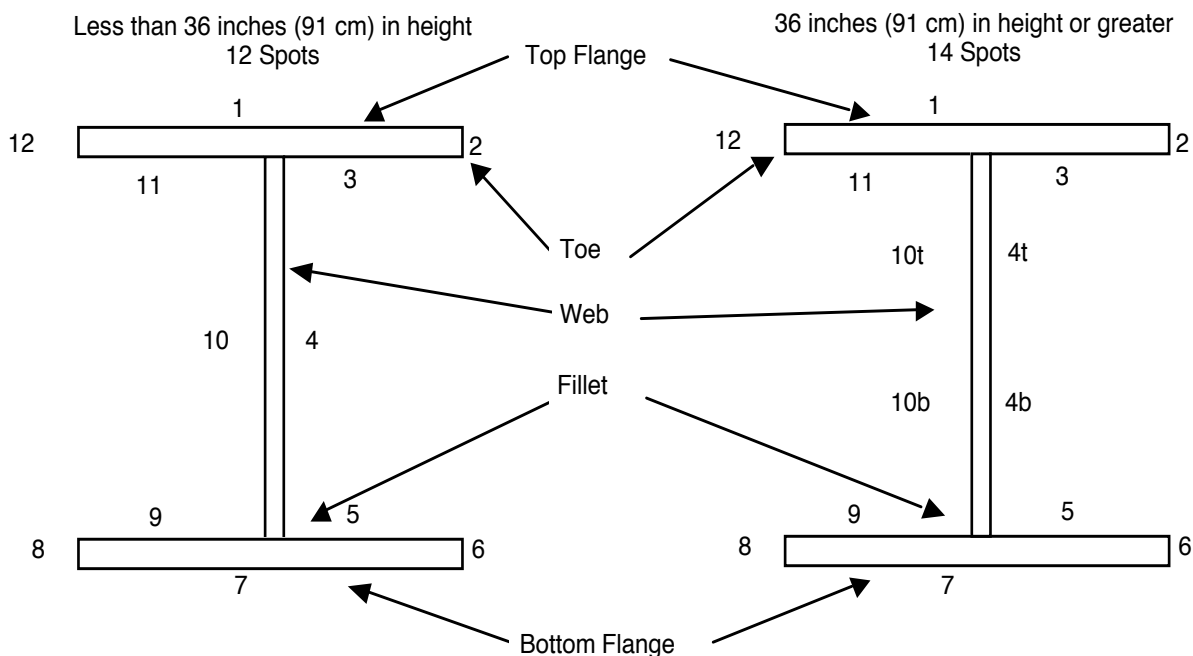


TABLE A2.1
DATASHEET FOR RECORDING SPOT MEASUREMENTS AND
AVERAGE DFT VALUES FOR THE 12 SURFACES OF A BEAM OR GIRDER

Spot Measurements of DFT on Beam # _____

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

¹ Rows 4 and 10 apply to beams with a web height <36 inches (~1 meter)

² Rows 4T/4B and 10T/10B apply to beams with a web height ≥36 inches (~1 meter)

**TABLE A2.2 – NUMBER OF SPOT MEASUREMENTS NEEDED
ON EACH SURFACE OF A BEAM FOR A FULL OR A SAMPLE DFT DETERMINATION**

Length of Beam	Number of Spot Measurements per Surface	
	Full DFT Determination*	Sample DFT Determination
less than 20 ft (6 m)	5	2
from 20 to 60 ft (6 to 18 m)	5	3
over 60 ft (18 m)	5	NA

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

the 12 surfaces of the beam as shown in Figure A2 for each section. For tall beams, where the height of the beam is 91 cm (36 in) 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 8.1) 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 A2.1.

A2.3 If Coating Thickness Restriction Level 3 is invoked by the specification (or if no Restriction Level is invoked by the specification), then no single spot measurement can be less than 80% of the specified minimum DFT, and 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 beams with height greater than 36 in).

A2.4 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 beams greater than 0.9 m (36 in) in height is not split.

A2.4.1 Beams less than 6 m (20 ft) in length: For beams less than 6 m (20 ft) in length, 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 A2. Each spot measurement must conform to the specified DFT.

A2.4.2 Beams 6 m (20 ft) up to 18 m (60 ft) in length: For beams 6 m (20 ft) up to 18 m (60 ft) in length, 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 A2. Each spot measurement must conform to the specified DFT.

A2.5 NON-CONFORMANCE: If any spot measurement falls outside the specified range, additional measurements may be made to define the non-conforming area.

A2.6 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 A2.2 or Section A2.4 through A2.4.2, as specified.

A2.7 ATTACHMENTS: Stiffeners and other attachments to a beam should be arbitrarily measured.

APPENDIX 3 – METHODS FOR MEASURING DRY FILM THICKNESS FOR A LAYDOWN OF BEAMS, STRUCTURAL STEEL, AND MISCELLANEOUS PARTS AFTER SHOP COATING

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

A3.1 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.

A3.2 FULL DFT DETERMINATION

A3.2.1 Beam (Girder): Follow the procedure described in Section A2.2.

A3.2.2 Miscellaneous Parts: Take one spot measurement (as defined in Section 8.1) 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 m² (100 ft²), take 5 spot measurements randomly distributed over the part for each 10 m² (100 ft²) or fraction thereof.

A3.3 If Coating Thickness Restriction Level 3 is invoked by the specification (or if no Restriction Level is invoked by the specification), then no single spot measurement can be less than 80% of the specified minimum DFT, and 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.

A3.4 SAMPLE DFT DETERMINATION: In lieu of a full DFT determination of each painted piece as described in Section A2.2, the job specification may require only a sample DFT determination for selected pieces.

A3.4.1 Beams less than 6 m (20 ft) in length: Follow the procedure described in Section A2.4.1.

A3.4.2 Beams greater than 6 m (20 ft) up to 18 m (60 ft) in length: Follow the procedure described in Section A2.4.2.

A3.4.3 Miscellaneous parts: For a miscellaneous part, take three spot measurements, randomly distributed on the part. Each spot measurement must conform to the specified DFT.

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 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 A2.2 or Section A2.4, as specified.

A3.7 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 A3.2, and perform a sample DFT determination on every third piece in accordance with Section A3.4.

A3.8 ATTACHMENTS: Stiffeners and other attachments to a beam shall be arbitrarily measured.

APPENDIX 4 – METHOD FOR MEASURING DRY FILM THICKNESS ON COATED STEEL TEST PANELS

Appendix 4 is not a mandatory part of this standard, but it provides a sample protocol for measuring DFT on coated steel test panels.

A4.1 PANEL SIZE: The test panel shall have a minimum area of 116 cm² (18 in²) and a maximum area of 930 cm² (144 in²); e.g., minimum 7.5 x 15 cm (3 x 6 in) and maximum 30 x 30 cm (12 x 12 in).

A4.2 PROCEDURE: Use a Type 2 electronic gage. Take two spot measurements from the top third, the middle third, and the bottom third of the test panel. Readings shall be taken at least 12 mm (0.5 in) from any edge and 25 mm (1 in) from any other spot measurements. 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 spot measurements.

A4.3 MINIMUM THICKNESS: The average of the acceptable spot measurements shall be no less than the specified minimum thickness. No single spot measurement shall be less than 80% of the specified minimum.

A4.4 MAXIMUM THICKNESS: The average of the acceptable spot measurements shall be no more than the specified maximum thickness. No single spot measurement shall be more than 120% of the specified maximum.

A4.5 REJECTION: If a spot measurement 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 spot measurement. 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 5 – METHOD FOR MEASURING DRY FILM THICKNESS OF THIN COATINGS ON COATED STEEL TEST PANELS THAT HAVE BEEN ABRASIVE BLAST CLEANED

Appendix 5 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.

A5.1 For the purposes of this standard, 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.

A5.2 PANEL SIZE: The test panel shall have a minimum area of 116 cm² (18 in²) and a maximum area of 930 cm² (144 in²); e.g., minimum 7.5 x 15 cm (3 x 6 in) and maximum 30 x 30 cm (12 x 12 in).

A5.3 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 (0.5 in) 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.

A5.4 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.

A5.5 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.

APPENDIX 6 – METHOD FOR MEASURING THE DRY FILM THICKNESS OF COATINGS ON EDGES WITH TYPE 2 GAGES

Appendix 6 is not a mandatory part of this standard, but it provides a sample protocol for measuring DFT of coatings on edges.

A6.1 Type 2 gage manufacturers offer a variety of probe configurations, some of which are less affected by proximity to edges and are designed to better measure the thickness of coatings on edges. The user should consult the gage manufacturer's instructions before measuring coating thickness on edges. SSPC-PA Guide 11 describes the use of coatings with edge retention properties and references a method (MIL-PRF-23236D, Coating Systems for Ship Structures) for assessing edge retention properties of coatings.

A6.2 Prior to measurement of coating on edges, the gage and probe should be verified for accuracy by placing a thin, flexible shim onto the prepared, uncoated edge. Adjustments to the gage may or may not be required. This procedure also verifies that the probe configuration will accommodate the edge configuration prior to coating thickness data acquisition.

A6.3 Obtain a minimum of three gage readings within 4 linear cm (~1.5 linear in) of coated edge. The average of the gage readings is considered a spot measurement. The number of spot measurements along the edge will vary depending on the total length of the coated edge.

APPENDIX 7 – METHOD FOR MEASURING DRY FILM THICKNESS ON COATED STEEL PIPE EXTERIOR

Appendix 7 is not a mandatory part of this standard, but it provides a sample protocol for measuring DFT of the exterior of coated pipe.

A7.1 Pipe sections that are loaded onto a cart or rack are considered a complete unit, as opposed to a single joint of pipe. The total number of spot and area measurements is based on the total square footage of pipe on the cart or rack. The square footage can be calculated using the formula here:

Circumference of pipe = π (π) × diameter

Area = (length of each pipe x circumference) × no. of pipe sections on cart or rack

Example (U.S. Units):

- 10 pieces of 48-in long x 9-in diameter pipe = 4 ft x (3.14 x 0.75 ft) = 9.4 ft² area per pipe section.
- 9.4 ft² per pipe section x 10 pipe sections = 94 ft² total coated area

Since the total area is less than 100 ft², 5 spots (each spot is a minimum of 3 gage readings) are measured, according to Section 8.2.1 of SSPC-PA 2.

A7.2 Pipe DFT Frequency Factors: Some carts may contain multiple small pipe sections, resulting in a total coated surface area in excess of 100 ft². In such cases, the specifier may require additional spot measurements, due to a large number of items on the cart. Using Section 8.2.1 of this standard, five readings are required for the first 100 ft² of coated pipe. In addition, the Owner/Contractor may specify one of the Pipe DFT Frequency Factors shown here. Based on the example in Section A7.1, if "Pipe DFT Frequency Factor 4" was invoked, 20 spot measurements would be acquired (5 spots [for the first 100 ft²] x 4 frequency factor). In such a case, more of the items on the cart are measured, giving a better sampling to determine compliance.

Example (U.S. Units) if total coated area exceeds 100 ft² and Frequency Factor 2 is invoked:

- Total coated square footage on a cart = 175 ft²
- Section 8.2.1 of SSPC-PA 2 requires 2 sets of 5 spot measurements (5 spots on each of two 100-square foot areas) = 10 spot measurements.

Pipe DFT Frequency Factor of 2 x 10 spots = 20 spot measurements

A7.2.1 Pipe DFT Frequency Factor 2 = (length of each pipe x circumference) x no. of pipe sections on cart or rack = (number of spot measurements) x 2

A7.2.2 Pipe DFT Frequency Factor 3 = (length of each pipe x circumference) x no. of pipe sections on cart or rack = (number of spot measurements) x 3

A7.2.3 Pipe DFT Frequency Factor 4 = (length of each pipe x circumference) x no. of pipe sections on cart or rack = (number of spot measurements) x 4

TABLE A7
NUMBER AND LOCATIONS OF SPOT MEASUREMENTS – PIPE SPOOLS

Pipe Diameter	Circumferential Spot Measurements	Interval Spacing
Up to 12 in (30 cm)	4 evenly spaced	10 feet (3 meters) apart
14 to 24 inches (36-60 cm)	6 evenly spaced	10 feet (3 meters) apart
Greater than 24 inches (60 cm)	8 evenly spaced	10 feet (3 meters) apart

A7.2.4 Pipe DFT Frequency Factor 5 = (length of each pipe x circumference) x no. of pipe sections on cart or rack = (number of spot measurements) x 5

A7.2.5 Pipe DFT Frequency Factor 6 = (length of each pipe x circumference) x no. of pipe sections on cart or rack = (number of spot measurements) x 6

A7.3 Measurements on Individual Pipe Spools: Pipe spools that are not loaded onto a rack or cart are measured individually. The number and locations of spot measurements are based on Table A7. Three sets of 4 circumferential spot measurements should be obtained on pipe spools less than 3 meters (10 feet) in length.

A7.4 A challenge for the painter in coating fabricated pipe spools is providing a uniform thickness throughout the entire surface. On a fabricated pipe spool, there are potentially valves, flanges, and elbows that tend to have low or high DFT compared to the straight run section. Painters may develop a pattern of work for a specific task. Hence, the DFT on the flange and valves 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 this protocol may far exceed the "5 spot measurements per 10 m² (100 ft²)" required in the standard. The full DFT determination, described in Table A7, provides a very thorough inspection of a joint of pipe. The DFT determination, described in Section A7.1, may allow for fewer spot measurements. The user does not have to require a full DFT determination for every joint of pipe. For example, the requirement may be for a full DFT determination on one pipe out of ten, or a sample DFT determination on one pipe out of five, or a combination of full and sample DFT determinations.

APPENDIX 8 – EXAMPLES OF THE ADJUSTMENT OF TYPE 2 GAGES USING SHIMS

Appendix 8 does not form a mandatory part of this standard, but it provides examples of how to adjust Type 2

gages using certified shims or measured shims on roughened (e.g., abrasive blast cleaned) surfaces.

This example describes a method of adjustment to improve the effectiveness of a Type 2 (electronic) gage on a 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. Type 2 gages equipped with double pole probes may provide greater measuring precision on rough surfaces compared to single pole probes.

A portion of the substrate, after blast cleaning but prior to coating, can be used to adjust the gage. Alternatively, an uncoated test panel, blast cleaned 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 in A8.3.

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, if the accuracy of a properly calibrated gage is $\pm 2\%$ and the thickness of a shim is accurate to within $\pm 3\%$, the combined tolerance of the gage and the shim will be $\pm 4\%$ 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 $\pm 4\%$

TABLE A8
TYPICAL GAGE CORRECTION VALUES USING ISO 8503 PROFILE GRADES
(SOURCE: ISO 19840)¹

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

¹ International Organization for Standardization (ISO), Case Postale 56, Geneva CH-1211, Switzerland. ISO standards are available online from the American National Standards Institute (ANSI), 1819 L Street, NW, Suite 600, Washington, DC 20036 or at <<http://www.ansi.org>>

of the shim's thickness. If the average thickness measured on a 250-micrometer (μm) (10-mil) shim is between 240 μm (9.6 mils) and 260 μm (10.4 mils), the gage is properly adjusted. The minimum of 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.]

A8.1 SINGLE-POINT 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) or slightly greater 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.

A8.2 TWO-POINT 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 here, will confirm that the gage has been adjusted correctly. It is acceptable for the average reading to be within $\pm 4\%$ of the shim thickness.

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

A8.3 SMOOTH SURFACE 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. Alternatively, it may be possible to adjust some Type 2 gages through the coating already applied to an abrasive blast cleaned substrate (may be necessary if no uncoated substrate exists). This procedure should be performed 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 peak

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 A8 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 9 – PRECAUTION REGARDING USE OF THE STANDARD FOR COATING FAILURE INVESTIGATIONS

During a coating failure investigation, coating thickness measurements are not typically acquired as described in Sections 8.2.1 through 8.2.3, but rather from failing and non-failing areas based on observed patterns of failure and other observations made during the site investigation. Acquiring measurements in 100 ft² areas across the structure during a coating failure investigation may be of lesser value and may be cost-prohibitive. Accordingly, ASTM D7091 may be a more appropriate reference standard for this application.

APPENDIX 10 – PROCEDURE FOR OBTAINING A GREATER POPULATION OF THICKNESS MEASUREMENTS USING TYPE 2 GAGE CONTINUOUS READ/SCANNING PROBE TECHNOLOGY

Appendix 10 is not a mandatory part of this standard, but it provides a protocol for measuring the dry film thickness (DFT) of coatings with Type 2 (electronic) gages utilizing scanning technology. Statistical analysis of data suggests that greater precision of DFT measurements can be achieved by obtaining a greater population of measurements over a larger area using the scanning method over the traditional "place and remove probe" frequency described in Section 8 of this standard. Also, scanning technology enables an operator to collect a greater number of DFT measurements in a shorter time frame than the traditional method described in Section 8. Due to the increased number of measurements being collected, better indication of the sample mean can be obtained through increased precision.

A10.1 DEFINITIONS

A10.1.1 Scanning Batch Measurement: The mean of no less than 12 DFT readings and up to 24 readings, without lifting the probe from the coated surface, using an "infinity symbol motion" ∞ [vertical or horizontal orientation] obtained within a 645 cm² (~100 in²) segment of the coated area.

A10.1.2 Scanning Area Measurement: The sample mean of five scanning batch measurements obtained over each 10 m² (~100 ft²) area of coated surface, or portion thereof.

A10.2 PROCEDURE

A10.2.1 The procedures for gage calibration, verification of accuracy, and adjustment described in Section 5 of this standard shall be completed prior to acquisition of coating thickness readings described in this Appendix.

A10.2.2 Obtain Scanning Batch Measurement: Using a Type 2 gage set to the continuous read mode, traverse the probe across the surface of a coating in an “infinity symbol motion” [∞], within a 645 cm² (~100 in²) segment at the rate necessary to acquire a minimum of 12 readings and a maximum of 24 readings before lifting the probe. While more than 24 readings may be acquired during the scan, research has indicated that there is little improvement to the statistical validity of the data set with additional readings beyond 24. Any unusually high or low gage readings in a scan batch that are not repeated consistently (outliers) may be discarded. Record the mean of the acceptable scanning gage readings (Scanning Batch Measurement), as well as highest and lowest readings (after discarding outliers, if applicable) as shown in the Sample Table A10.1, below. The standard deviation may also be reported if required.

A10.2.3 Obtain Scanning Area Measurements: Repeat the procedure described in A10.2.2 in four additional 645 cm² (~100 in²) segments (total of five segments) over each 10 m² (~100 ft²) area of coated surface, or portion thereof (see Figure A10). The Coating Thickness Restriction Table (Table 1) in Section 9 of this Standard is used to verify conformance to the coating thickness specified in the contract documents. The “Spot Measurement” column in Section 9, Table 1 shall be referenced for the Scanned Batch Measurements.

A10.2.4 Calculate the Scanning Area Measurement: Calculate the total mean of the five scanning batch measurements obtained over each 10 m² (~100 ft²) area of coated surface, or portion thereof and record the information as shown in the Sample Table A10.2, below. The Coating Thickness Restriction Table (Table 1) in Section 9 of this Standard is used to verify conformance to the coating thickness specified in the contract documents. The “Area Measurement” column in Section 9, Table 1 shall be referenced for the Scanned Area Measurements.

SAMPLE TABLE A10.1

Scanned Batch Measurement Segment	Mean	Standard Deviation ¹	Highest Reading ²	Lowest Reading ²
1				
2				
3				
4				
5				

¹ Optional.

² After discarding outliers, if applicable.

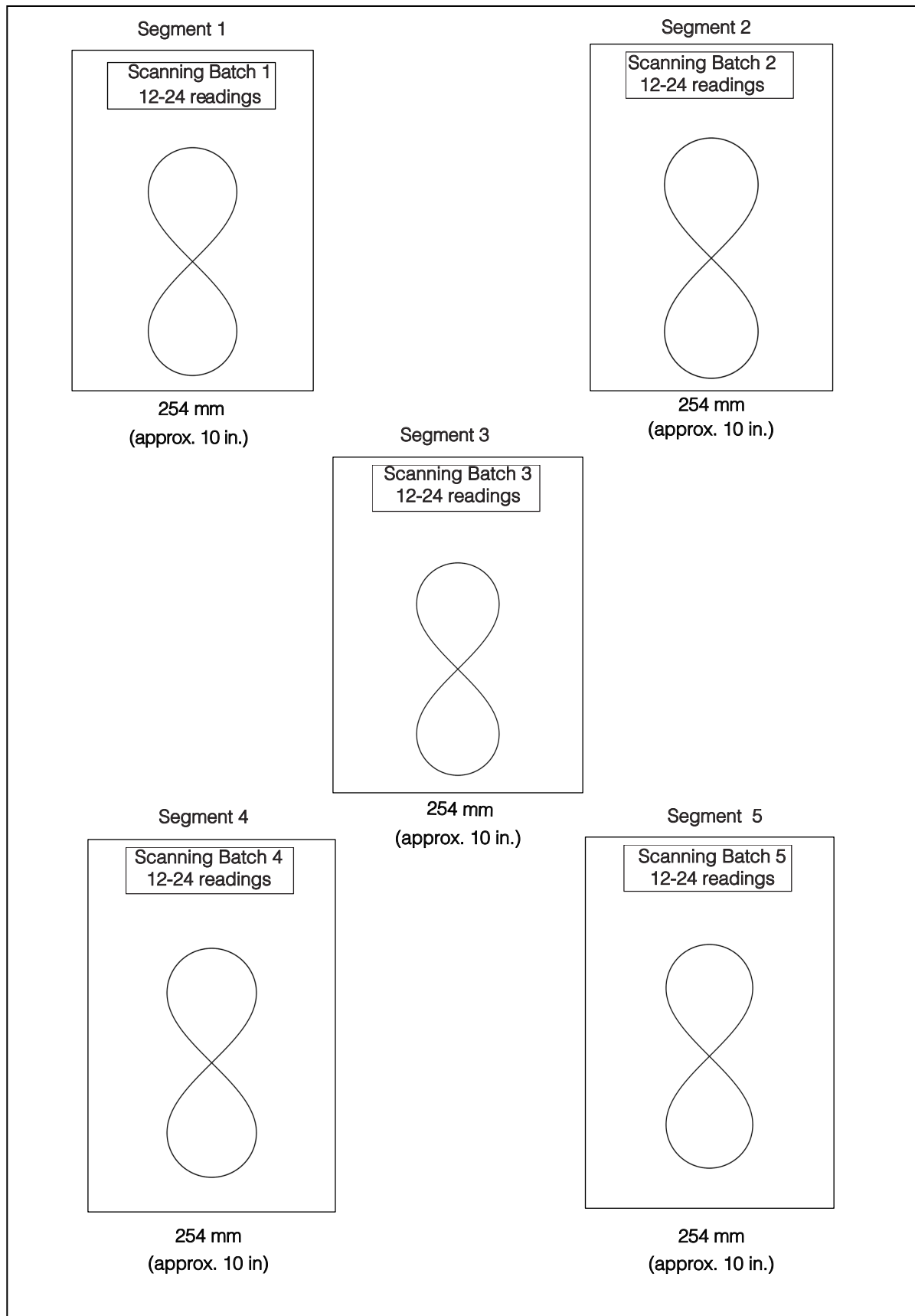
SAMPLE TABLE A10.2

Scanned Area Measurement Location	Mean	Standard Deviation ¹	Highest Reading ²	Lowest Reading ²

¹ Optional.

² After discarding outliers, if applicable.

FIGURE A10
SCANNING AREA MEASUREMENT



Editorial Revisions since January 26, 2015: The revisions listed below are editorial clarifications or corrections of obvious errors identified since the date of the last technical revision of the standard dated January 26, 2015, and the previous editorial revision of March 15, 2017.

- (1) Section 1.5 (September 14, 2016): Removed following text: "This standard is not intended to be used for measurement of thermal spray coatings. The thickness measurement procedures for thermal spray coatings applied over steel substrates are described in SSPC-CS 23.00/AWS C2.23M/NACE No. 12." (Use of SSPC-PA 2 is required in the September 2016 revision of SSPC-CS 23.00/AWS C2.23M/NACE No. 12.) Added text: "Units of Measure: This standard makes use of both the ASTM SI 10, "American National Standard for Metric Practice" International System Units (SI) and U.S. Customary units. The measurements are not exact equivalents; therefore, each system must be used independently of the other." (Added text clarifies that the user should not attempt to convert values from one system to the other.)
- (2) Appendix A (September 14, 2016): Divided Appendix A into two sections, one using S.I. units, the other using U.S. Custom units.
- (3) Section 6.2, (March 15, 2017): Reorganized sentence 1 for clarity. Replaced the word "measurements" with "one reading," as this sentence refers to multiple gage readings. Formerly read: "In order to compensate for any effect of the substrate itself and surface roughness, obtain measurements from the bare, prepared substrate at a minimum of ten (10) locations (arbitrarily spaced) and calculate the average value."
- (4) Appendix A7 (March 15, 2017): Sequential numbering corrected. Text unchanged.
- (5) Section 1.1 (October 1, 2018): Removed Section 1.2 and revised Scope to conform to description of gages in revised ASTM D7091,
- (6) Section 1.4 (October 1, 2018): Added Appendix A10 to list of appendices
- (7) Section 2.3 (October 1, 2018): Deleted parenthetical statement that ASTM D7091 is a mandatory document required to use SSPC-PA 2.
- (8) Section 5.1 (October 1, 2018): Revised first sentence to remove reference to ASTM D7091.
- (9) Section 5.3 (October 1, 2018): Revised first sentence to allow use of gage manufacturer's instructions as an alternative to use of ASTM D7091 for verification of gage accuracy.
- (10) Added Appendix A10 (November 1, 2018) to address use of continuous read/scanning probe technology for obtaining a greater population of measurements over a larger area.

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