SSPC: The Society for Protective Coatings

PAINT APPLICATION STANDARD 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' instructions for the manual operation of the gages and are not intended to replace them.

1.2 The procedures for calibration and measurement are described for two types of gages: pull-off gages (Type 1) and constant pressure probe 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.

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 1.5 inch (4 cm) diameter circle.

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.

2.2.2 Type 1—Pull-Off Gages: In pull-off gages, a permanent magnet is brought into direct contact with the coated surface and a calibrated scale measures the force necessary to pull the magnet from the surface. Less force is required to remove the magnet from a thick coating. The scale is nonlinear.

- **Type 1A** - A magnet is attached to one end of a pivoting balance arm. This assembly is connected to a calibrated helical spring. By rotating a dial, the spring increases the force on the magnet and pulls it from the surface. The Type 1A gages are commonly called "banana" gages.
- **Type 1B** - A magnet is mounted directly or indirectly to a coil spring. The spring acts perpendicularly to the surface to pull off the magnet. The Type 1B gages are commonly called "pencil" gages.

2.2.3 Type 2—Constant Pressure Probe Gages: A constant pressure probe gage uses a probe which exerts a constant a coil spring. The spring acts perpendicularly to the surface to pull off the magnet. The Type 1B gages are commonly called "pencil" gages.

2.2.3 Type 2—Constant Pressure Probe Gages: A constant pressure probe gage uses a probe which exerts a constant pressure on the coated surface during the entire measuring operation. Electronic circuitry is used to convert a reference signal into coating thickness. (See 8.1.)

2.3 USE OF STANDARD: This document contains the following:

- Calibration, verification and measurement procedures (Section 4).
- Required number of measurements for conformance to a thickness specification (Section 5).
- Notes on gage principles and various factors affecting thickness measurement (Section 8).
- A numerical example of thickness measurement over an extended area (Appendix 1).
- A numerical example of verification of the calibration of Type 2 gages using plastic shims (Appendix 2).

3. Reference Standards

3.1 The documents and standards referenced in this standard are listed in Section 3.4 and form a part of this standard.

3.2 The latest issue, revision or amendment of the referenced documents in effect on the date of invitation to bid shall govern unless otherwise specified.

3.3 If there is a conflict between the requirements of any of the cited documents and this standard, the requirements of this standard shall prevail.

3.4 NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY (NIST) STANDARD REFERENCE MATERIALS. (See Section 8.15.)

4. Calibration, Verification and Measurement Procedures

4.1 GENERAL

4.1.1 Access to Bare Substrate: All gages are affected to some degree by substrate conditions such as roughness, shape, thickness and composition. 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 Sections 8.3 to 8.9.) These would be used as the bare substrate in the procedures of Sections 4.2 and 4.3. Reference panels shall be of sufficient size to preclude edge effects. (See Section 8.7.)

Measurements on the bare substrate can be taken before areas during painting. If the coating has already been applied to the entire surface, small areas of coating may be removed and later patched. Do not allow the removal process to alter the condition of the substrate. Paint strippers should be used in order to retain the profile.

4.1.2 Spot Measurement: Repeated gage readings, even at points close together, may 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 1.5 inch (4 cm) diameter circle defining the spot. Discard any unusually high or low gage reading that cannot be repeated consistently. Take the average of the acceptable gage readings as the spot measurement.

4.2 CALIBRATION, VERIFICATION AND MEASUREMENT: TYPE 1—PULL-OFF GAGES

4.2.1 For Type 1 gages, use test blocks bearing calibrated nonmagnetic coatings that are traceable to a suitable national standard. (See Section 8.15.) The standards must be large enough to exceed the critical mass of steel needed to satisfy the magnetic field of the Type 1 (pull-off) magnets. Shims of plastic or of non magnetic metals which are acceptable for calibration of Type 2 (constant pressure probe) gages should not be used for calibration of the Type 1 gages. (See Section 8.1.1.) If the manufacturer's instructions are in conflict with this standard by allowing the use of plastic or other nonmagnetic shims for the calibration of a Type 1 gage, the contracting parties must both be notified of this fact and agree on a method of calibration.

If proprietary thickness standards are to be used, agreement between contracting parties should be reached prior to starting the job.

4.2.2 Using the Type 1 (pull-off) gage, measure the thickness of a series of calibration standards covering the expected range of coating thickness. To guard against measuring with an inaccurate gage, recheck the gage at the beginning and the end of each work shift with one or more of the standards. During the work shift, if the gage is dropped or suspected of giving erroneous readings, its calibration should be rechecked. If deemed appropriate by the contracting parties, initial agreement can be reached on the details and frequency of verification or calibration. Record the calibration data and the method used to verify the calibration. If the gage is found to be out of calibration at the end of the work shift, all measurements made since the last calibration are suspect.

4.2.3 When the gage no longer agrees with the standard, check the probe for cleanliness. If dirty, clean as described in Section 8.5.1. If the gage still does not agree with the standard, the gage is in need of repair or replacement. Some gages can be adjusted to read accurately in a given range. Adjust the gage to read correctly on a given standard. Then check the gage on nonlinear scales and any adjusting feature is linear in nature. Therefore, only a given segment of the scale can be accurate after adjustment.

4.2.4 Measure the bare substrate at a number of spots to obtain a representative average value. This average value is the base metal reading (BMR). Note the gage is not to be calibrated on the bare substrate.

4.2.5 Measure the dry coating at the number of spots specified in Section 5.

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

4.3 CALIBRATION, VERIFICATION AND MEASUREMENT: TYPE 2—CONSTANT PRESSURE PROBE GAGES

4.3.1 Different manufacturers of Type 2 (constant pressure probe) gages follow different methods of calibration or adjustment. Calibrate the gage according to manufacturer's instructions.

4.3.2 With a properly calibrated gage, measure the dry coating as specified. (See Section 4.1.2.)

4.3.3 Verify the calibration of the gage at the beginning and the end of each work shift with one or more of the standards. (See Appendix 2). During the work shift, if the gage is dropped or suspected of giving erroneous readings, its calibration should be rechecked. If deemed appropriate by the contracting parties, initial agreement can be reached on the details and frequency of verification or calibration. Record the calibration data and the method used to verify the calibration. If the gage is found to be out of calibration at the end of the works shift, all measurements made since the last calibration are suspect.

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

5.1 NUMBER OF MEASUREMENTS: Make five (5) separate spot measurements (average of the gage readings, see Section 4.1.2) spaced randomly 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 5.3.) The five spot measurements shall be made for each 10 m^2 (100 ft^2) of area as follows:

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

5.1.2 For structures not exceeding 100 m^2 (1,000 ft^2) in area, three 10 m^2 (100 ft^2) areas shall be randomly selected and measured.

5.1.3 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 5.1.2 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 randomly selected and measured.

5.1.4 If the dry film thickness for any 10 m^2 (100 ft^2) area (see Sections 5.1.2 and 5.1.3) is not in compliance with the requirements of Sections 5.2.1 and 5.2.2, then additional measurements must be made to isolate the nonconforming area.

5.2 SPECIFYING THICKNESS: Both a maximum and a minimum thickness should be specified for the coating. If a maximum thickness value is not explicitly specified, the specified thickness shall be the minimum.

5.2.1 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. No single spot measurement in any 10 m^2 (100 ft^2) area shall be less than 80% of the specified minimum thickness. Any gage reading may 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 may be made to define the nonconforming area. (See Appendix 1.)

5.2.2 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. No single spot measurement in any 10 m^2 (100 ft^2) area shall be more than 120% of the specified maximum thickness. Any gage reading may overrun 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 may be made to define the nonconforming area. Manufacturers' literature may be consulted to determine if higher maximum thickness readings are allowable under specific circumstances.

5.3 Other size areas or number of spot measurements may be specified in the procurement documents as appropriate for the size and shape of the structure to be measured.

6. Accuracy

6.1 To qualify under this standard, a gage must have an accuracy at least within ±10%. For thicknesses less than 25 μm (1 mil), the gage must have an accuracy at least within ±2.5 μm (0.1 mil).

7. Disclaimer

7.1 While every precaution is taken to insure 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.

8. Notes

Notes are not a requirement of this standard.

8.1 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. This measured distance, from the top surface of the coating, must be corrected for the thickness of any extraneous films or other interfering conditions on the surface of the steel. Such correction is described in Section 4.2 for Type 1 gages and manufacturer's instructions for Type 2 gages.

8.1.1 Type 1 (pull-off) gages use a calibrated spring mechanism to 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 nonlinear function of the distance between magnet and steel, i.e., the thickness of the dry coating (plus any other films present).

The Type 1A "banana" gages use a helical spring to pull a small permanent magnet from the surface. Internal balancing mechanisms in most banana gages compensate for horizontal, vertical and overhead positions so that there is no need to recalibrate when changing orientation.

In a Type 1B "pencil" gage, a calibrated coil spring measures the force necessary to pull the permanent magnet

from the surface. Because of gravitational effects, these gages must be recalibrated when the orientation of the surface changes; e.g., a gage calibrated on a horizontal surface will not be accurate when measuring a vertical surface. Some gages have three separate indicators which compensate for horizontal, vertical and overhead positions. Type 1B gages are generally not as precise as Type 1A gages. Normally, Type 1 gages are not adjusted or reset for each new series of measurements.

Shims of sheet plastic or of nonmagnetic metals, which are permissible for calibrating Type 2, (constant pressure probe) gages, should not be used for calibration of 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 calibration measurements with any Type 1 gage, the shim frequently springs back from the steel surface, raising the magnet too soon and causing erroneous calibration readings.

8.1.2 Type 2 (constant pressure probe) 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 within 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 are the most common ways to measure magnetic flux density. However, the response of these elements is temperature dependent, so temperature compensation is required.

Other Type 2 gages operate on the principle of electromagnetic AC current thereby producing a changing magnetic field at 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 a second coil. The output of the second coil is related to coating thickness and this relationship can be determined experimentally.

8.2 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.

8.3 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.

8.4 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. With a correctly calibrated and adjusted Type 2 gage, the reading obtained indicates the coating thickness above this imaginary plane. (See Section 4.3.) If a Type 1 gage is used, the coating thickness is obtained by subtracting the base metal reading. (See Section 4.2.)

8.5 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 and also to avoid adhesion of the magnet. The accuracy of the measurement will be affected if the coating is tacky or excessively soft. Tacky coating films also cause unwanted adhesion of the magnet. Unusually soft films may be dented by the pressure of the probe. Soft or tacky films can sometimes be measured satisfactorily by putting a shim on the film, measuring total thickness of coating plus shim and subtracting shim thickness.

8.5.1 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.

8.6 ALLOY STEEL SUBSTRATES: Differences among most mild low-carbon steels will not significantly effect magnetic gage readings. For higher alloy steels, the gage response should be checked. In any event, the gage should be recalibrated on the same steel over which the coating has been applied.

8.7 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 in) from the discontinuity may not be valid unless the gage is calibrated specifically for that location.

8.8 PROXIMITY TO OTHER MASS OF STEEL: The older two-pole Type 2 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 three inches (7.6 cm) from an inside angle.

8.9 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 calibrating or adjusting the gage on a similarly curved surface.

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

8.11 OTHER MAGNETIC FIELDS: Strong magnetic fields, such as those from welding equipment or nearby power lines, may interfere with operation of the gages. Also, residual magnetism in the steel substrate may 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.

8.12 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, probe and surface.

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

8.14 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 in) 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 tolerance of the gage and calibration standards and for variations in the substrate.

8.15 Polished metal calibration standards are manufactured by the National Institute of Standards and Technology (NIST). The chrome plated panels are flat smooth steel 2.86 x 2.86 cm (1.125 x 1.125 in) in size. Examples of some NIST standards are:

Certified Coating Thickness Calibration Standards
Nonmagnetic Coating on Steel

SRM 1358	Set of 3	80, 225, 1000 μm (3, 9, 40 mil)
SRM 1359	Set of 4	48, 140, 505, 800 μm (2, 5.5, 20, 31 mil)
SRM 1362a	Set of 4	40, 80, 140, 205 μm (1.6, 3, 5.5, 8 mil)
SRM 1331a to 1339a		Single standards from 3 μm (0.1 mil) to 62 μm (2.4 mil)

8.16 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.

APPENDIX 1—Numerical Example of Average Thickness Measurement

The following numerical example is presented as an illustration of Section 5. (Reference JPCL, 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)

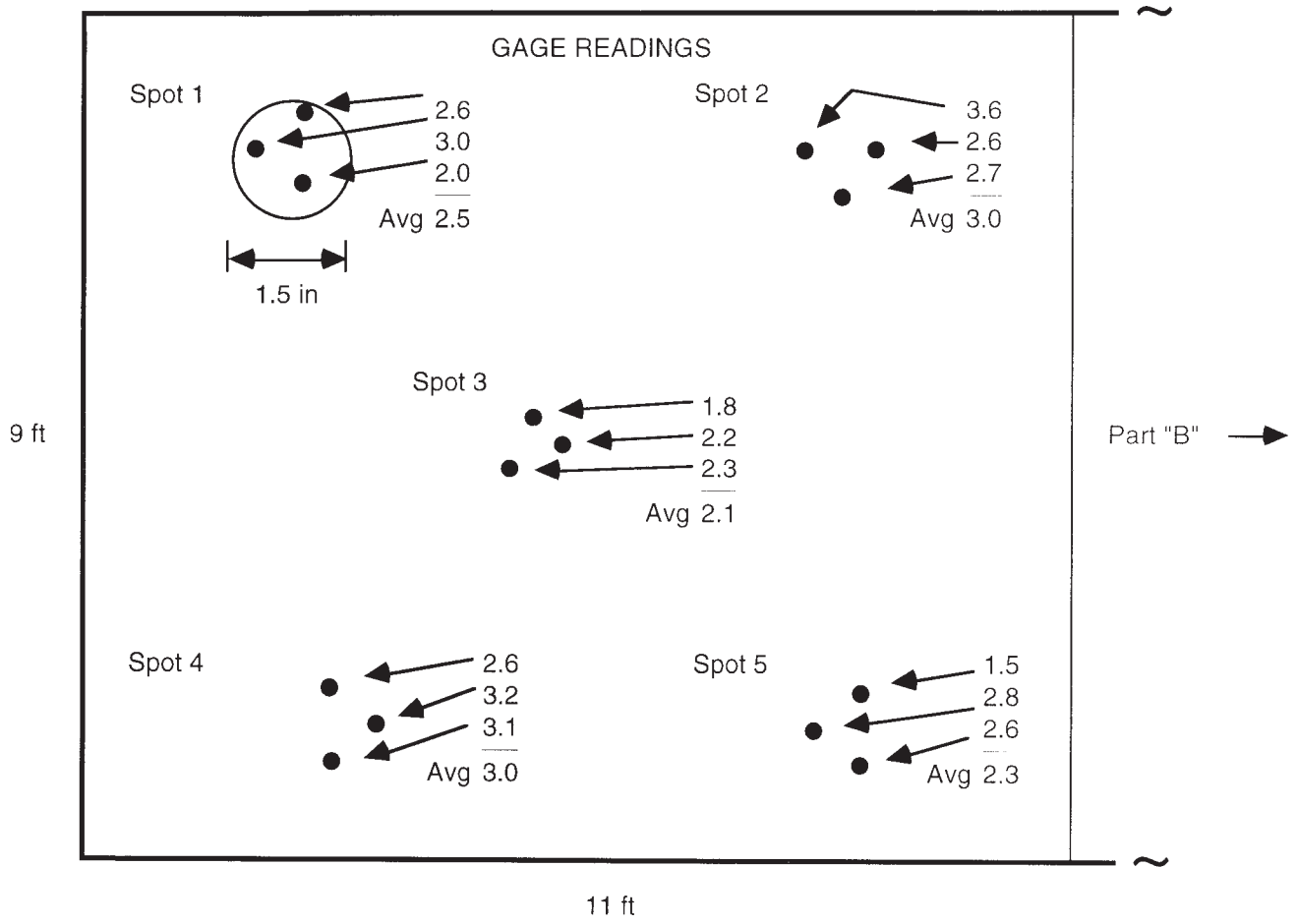
First, measure the coating thickness on Part A. This involves at least 15 readings of the thickness gage. (See Figure A1.) Assume the specification calls for 64 μm (2.5 mils) minimum thickness. The average thickness for area A is then the average of the five spot measurements made on area A, namely 66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

The average, 66 μm, exceeds the specified minimum of 64 μm and thus satisfies the specification. However it must be decided 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 percent of it, so the specification is satisfied. [The average, 2.6 mils, exceeds the specified minimum of 2.5 mils and thus satisfies the specification. However it must be decided 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 38 μm at spot 5 and 46 μm 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. [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.]

FIGURE A1
Part "A" of Structure (Area Approx. 10 m² [100 ft²])



Since the structure used in this example is about 30 m² (300 ft²), 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 m² (300 ft²) structure, at least 45 individual gage readings must be taken, from which 15 spot measurements are calculated. The five spot measurements from each 10 m² (100 ft²) part of the structure are used to calculate the thickness of that part.

Appendix 2—Example of Verification of the Calibration of Type 2 Gages Using Plastic Shims

This example describes a method to check if a Type 2 gage is properly calibrated.

Suppose the coating thickness is specified at 100 µm (4.0 mils). The Type 2 constant pressure probe gage being used has been calibrated according to the manufacturer's recommendation. Now its calibration over blast cleaned steel must be verified. A test coupon which had been blast cleaned during the time the structure was blasted and has a profile representative of that under the coating is available. After selecting a 50 µm (2.0 mil) and a 250 µm (10.0 mil) plastic shim, proceed to take thickness readings of the shims lying on the bare blasted surface.

Because of the randomized nature of a blast cleaned surface, repeated readings may exhibit significant variation. Thus, make at least 10 measurements on each shim and record their averages. There is no need to keep track of each individual reading. Many gages will compute the average for you.

The thickness of a plastic shim is typically accurate to within ±5%. After calibration according to manufacturer's instructions, the gage is probably accurate to within ±5% also. Therefore, for the gage to be in agreement with the shim, the average thickness measured by the gage should be within ±10% of the shim's thickness. If the average thickness measured on the 51 µm (2.0 mil) shim is 56 µm (2.2 mils), the gage is in agreement with the shim because 56 is within ±10% of 51 (2.2 is within 10% of 2.0).

Similarly, if the average thickness of the 254 μm (10.0 mil) shim is measured to be 279 μm (11.0 mils), the gage calibration is verified because 279 is within ±10% of 254 (11.0 is within ±10% of 10.0).

In summary, if the average measurement of the 51 μm (2 mil) shim is between 46 and 56 μm (1.8 and 2.2 mils), and if the average measurement of the 254 μm (10.0 mil) shim is between 229 and 279 μm (9.0 and 11.0 mils), the calibration is verified.

Check that another shim of intermediate thickness, for example 127 μm (5.0 mils), is also within ±10%. If the calibration is verified on both the high and the low shims, it is almost always verified on the intermediate value shim.

NOTE: With some gages it may be more practical to adjust the gage at the intermediate thickness (e.g., 127 μm shim) first and then verify that the gage also reads the high and the low shims correctly.