Designation: D7091 – 05

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[1]

This standard is issued under the fixed designation D7091; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice describes the nondestructive measurement of the dry film thickness of nonmagnetic coatings applied to the surface of ferrous metals using magnetic gages and the nondestructive measurement of the dry film thickness of electrically nonconductive, nonmagnetic coatings applied to the surface of nonferrous metals using eddy current gages. This practice is intended to supplement the manufacturers' instructions for the manual operation of the gages and is not intended to replace them. It includes definitions of key terms, reference documents, the significance and use of the practice, the advantages and limitations of coating thickness gages, and a description of test specimens. It describes the methods and recommended frequency for verifying the accuracy of gages and for adjusting (optimizing) the equipment, describes a frequency for measuring the thickness of the coating(s) and lists the reporting recommendations.

1.2 These procedures are not applicable to coatings that will be readily deformed under the load of the measuring gages/probes, as the gage probe must be placed directly on the coating surface to obtain a reading. Provisions for measuring on soft or tacky coatings are described in 5.6.

1.3 Use of film thickness measuring gages on metal-filled coatings may produce erroneous results, depending on the type and amount of metal in the coating film. The user should consult the manufacturers instructions regarding the use of coating thickness gages on these types of coatings.

1.4 Coating thickness can be measured using a variety of gages. These gages are categorized as "magnetic pull-off" and "electronic." They use a sensing probe or magnet to measure the gap (distance) between the base metal and the probe. This measured distance is displayed as coating thickness by the gages. Accordingly, these gages cannot distinguish the thickness of individual layers after they have all been applied. The thickness of each layer must be measured after it is applied. Even then, the thickness of the measured layer is the cumulative thickness of that layer and all layers beneath it, down to the base metal.

1.5 Gages which measure coating thickness using an ultrasonic principle may also be able to measure the thickness of coatings applied to metal surfaces. This practice does not address the use of ultrasonic coating thickness gages. Test Method D6132 should be referenced for this application.

1.6 Coating thickness can vary widely across a surface. As a result, obtaining single-point measurements may not accurately represent the actual coating system thickness. This practice provides guidance for the frequency of coating thickness measurements, based on large areas of coated surface, on test panels and on small parts/components. The governing specification is responsible for providing the user with the minimum and the maximum coating thickness for each layer, and for the total coating system.

1.7 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D609 Practice for Preparation of Cold-Rolled Steel Panels for Testing Paint, Varnish, Conversion Coatings, and Related Coating Products

D823 Practices for Producing Films of Uniform Thickness of Paint, Varnish, and Related Products on Test Panels

D1730 Practices for Preparation of Aluminum and Aluminum-Alloy Surfaces for Painting

D6132 Test Method for Nondestructive Measurement of Dry Film Thickness of Applied Organic Coatings Using an Ultrasonic Gage

2.2 *SSPC Standards:*

[1] This practice is under the jurisdiction of ASTM Committee D01 on Paint and Related Coatings, Materials and Applications and is the direct responsibility of Subcommittee D01.23 on Physical Properties of Applied Paint Films.

Current edition approved Aug. 1, 2005. Published September 2005. DOI: 10.1520/D7091-05.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

SSPC-PA2 Paint Application Standard No. 2 Measurement of Dry Coating Thickness with Magnetic Gauges[3]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *accuracy*, *n*—the measure of the magnitude of error between the result of a measurement and the true thickness of the item being measured.

3.1.1.1 *Discussion*—An accuracy statement predicts the ability of a coating thickness gage to measure the true thickness of a coating to be measured. Accuracy statements provide the performance capability across the full functional measurement range of the gage. Accuracy statements frequently include a fixed portion that remains constant across the measurement range, plus a variable portion that is related to the measurement result for a particular thickness.

3.1.2 *adjustment*, *n*—the physical act of aligning a gage's thickness readings to match those of a known thickness sample (removal of bias), in order to improve the accuracy of the gage on a specific surface or within a specific portion of its measurement range.

3.1.2.1 *Discussion*—An adjustment will affect the outcome of subsequent readings. Also known as "optimization."

3.1.3 *area measurement*, *n*—the average of several spot measurements obtained over the coated surface.

3.1.3.1 *Discussion*—For large surfaces, an area measurement is commonly the average of at least five spot measurements obtained in approximately 9 m^2 (100 ft^2) of surface area. For small test panels, it is commonly the average of three spot measurements on each test face (one from the top third, one from the middle third and one from the bottom third).

3.1.4 *base metal reading (BMR)*, *n*—a measurement obtained on the uncoated substrate using a coating thickness gage.

3.1.4.1 *Discussion*—The BMR is the measured effect of substrate roughness on a coating thickness gage that is caused by the manufacturing process (for example, castings) or surface profile (roughness)-producing operations (for example, power tool cleaning, abrasive blast cleaning, etc.). Non-compensation for the base metal effect can result in an overstatement of the true thickness of the coating. The base metal reading is measured, recorded and deducted from the thickness of each coat, in order to correctly state the thickness of the coating over the surface roughness.

3.1.5 *calibration*, *n*—the high-level, controlled and documented process of obtaining measurements on traceable calibration standards over the full operating range of the gage, then making the necessary gage adjustments (as required) to correct any out-of-tolerance conditions.

3.1.5.1 *Discussion*—Calibration of coating thickness gages is performed by the equipment manufacturer, an authorized agent, or by an authorized, trained calibration laboratory in a controlled environment using a documented process. The outcome of the calibration process is to restore/realign the gage to meet/exceed the manufacturer's stated accuracy.

3.1.6 *certification*, *n*—documentation of the state of condition of the gage, which can (but not required by definition) be accompanied by corrective action (such as adjustment or calibration, or both, or the replacement of components) necessary to correct any out-of-tolerance conditions.

3.1.7 *coating thickness standard (test block)*, *n*—a smooth, metal substrate with a coating of known thickness that is traceable to a national standard.

3.1.8 *compensation value*, *n*—generating a verifiable value, which is deducted from a measured value read from the gage, to correct for any surface conditions (that is, base metal effect).

3.1.9 *dry film thickness*, *n*—the thickness of a coating (or coating layers) as measured from the surface of the substrate.

3.1.9.1 *Discussion*—If the surface is roughened, the dry film thickness is considered the thickness of the coating or coating layers above the peaks of a surface profile.

3.1.10 *ferrous*, *n*—a magnetic material such as carbon steel.

3.1.10.1 *Discussion*—Also known as ferro-magnetic.

3.1.11 *gage*, *n*—an instrument for measuring quantity, or an instrument for testing.

3.1.11.1 *Discussion*—In this practice, the term "gage" refers to an instrument for quantifying coating thickness.

3.1.12 *manufacturer's specifications*, *n*—a statement or set of statements that describes the performance characteristics of the gage under a given set of conditions.

3.1.12.1 *Discussion*—Manufacturer's specifications typically includes the range of measurement, accuracy statement, operating temperature range, power source, dimensions and weight, and conformance to industry standards.

3.1.13 *measurement*, *n*—the value obtained when placing the probe of a thickness gage in contact with a surface.

3.1.14 *micrometer (micron)*, *n*—one one-thousands of a millimeter (0.001 mm); 25.4 microns = 1 mil.

3.1.15 *mil*, *n*—an imperial unit of measure; one one-thousands of an inch (0.001 in.); 1 mil = 25.4 microns.

3.1.16 *non-conductive*, *n*— a material that is unable to conduct electricity.

3.1.17 *non-ferrous metal*, *n*—a non-magnetic metal such as aluminum.

3.1.18 *reference standard*, *n*—a specimen of known thickness used to verify the accuracy of a coating thickness measuring gage.

3.1.18.1 *Discussion*—A reference standard may or may not be traceable to a National or International registry. References should include notations stating the accuracy of the standard. Reference Standards may be coated or plated metal plates, or may be shims (with samples of substrate material). Subject to agreement between the buyer and the seller, a piece of coated substrate may also be used as a project-specific reference standard. Traceability may not be required for reference standards used on a day-to-day basis. However, the reference standard should contain the stated value and the degree of accuracy.

3.1.19 *shims*, *n*—strips of flat, non-metallic sheet (typically polyester, with the thickness stated or referenced in some form) used to adjust (optimize) a coating thickness gage in the intended range of use, over the surface of the representative substrate material.

[3] Available from Society for Protective Coatings (SSPC), 40 24th St., 6th Floor, Pittsburgh, PA 15222-4656. (see www.sspc.org)

3.1.19.1 *Discussion*—Other uses include: placement over soft coatings to obtain thickness measurements without the gage probe depressing the coating film, and verification of gage operation. Also known as "foils."

3.1.20 *spot measurement*, *n*—the average of at least three measurements made within a 12 mm (½ in.) diameter circle.

3.1.21 *substrate*, *n*—the base material, the type of surface, or the component that is being coated.

NOTE 1—This practice addresses only metal substrates.

3.1.22 *surface profile*, *n*—surface roughness generated during the manufacturing process (for example, casting), or the average peak-to-valley depth generated by some power tools and by abrasive blast cleaning operations.

3.1.23 *Type 1 gage*, *n*—a magnetic pull-off instrument that measures the dry film thickness of non-magnetic coatings over a ferrous metal base.

3.1.23.1 *Discussion*—For Type 1 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. Also known as "pull-off gage."

3.1.24 *Type 2 gage*, *n*—an electronic instrument that uses electronic circuitry and (but not limited to) the magnetic induction, Hall-effect or the eddy current principles, or both, to convert a reference signal into a coating thickness reading.

3.1.24.1 *Discussion*—The probe of a Type 2 gage remains on the surface during the measurement process. Also known as "constant pressure probe" or "electronic" gages.

3.1.25 *verification of accuracy*, *n*—obtaining measurements on a reference standard prior to gage use for the purpose of determining the ability of the coating thickness gage to produce reliable values, compared to the combined gage manufacturer's stated accuracy and the stated accuracy of the reference standard.

4. Significance and Use

4.1 Most specifications for commercial and industrial coatings projects stipulate a minimum and a maximum dry film thickness for each layer in a coating system. Additionally, most manufacturers of high performance coatings will warranty coating systems based upon, in part, achieving the proper thickness of each layer and the total coating system. Even if a project specification is not provided, the coating manufacturer's recommendations published on product data sheets can become the governing document(s). Equipment manufacturers produce non-destructive coating thickness testing gages that are used to measure the cumulative thickness of the coating layers, after they are dry. The manufacturers provide information for the adjustment and use of these gages, normally in the form of operating instructions. The user of this equipment must be knowledgeable in the proper operation of these devices, including methods for verifying the accuracy of the equipment prior to, during and after use as well as measurement procedures.

4.2 This practice was prepared to describe the proper methods for verifying the accuracy of coating thickness measuring gages, as well as the proper methods for obtaining coating thickness measurements on both ferrous and non-ferrous metal substrates.

5. Principles, Advantages, and Limitations of Gages

5.1 Type 1 Magnetic Pull-Off gages are mechanical instruments that measure the force required to pull a permanent magnet from a coated ferrous metal substrate. The magnetic force of attraction to the steel substrate beneath the coating is opposed by a spring or coil. Tension is applied to the spring/coil until the magnetic attraction to the steel is overcome. The gage must be placed directly on the coated surface to obtain a measurement. The force holding the permanent magnet to the ferrous base is inversely proportional to the thickness of the coating layer(s) between the magnet and the ferrous substrate. For example, a thin coating applied to a ferrous substrate will require greater spring tension to pull the magnet off than will a thicker coating, since the magnet is closer to the ferrous substrate with the thinner coating. This inverse relationship is reflected on the nonlinear gage scale. Most Type 1 magnetic pull-off gages do not require a power source (for example, batteries). The manufacturer's stated accuracy is typically 5 to 10 % of the reading.

5.2 Type 1 magnetic pull-off gages are susceptible to vibrations, which may cause the magnet to release from the coated substrate prematurely, yielding a false high value. The manually operated gages may be susceptible to human error caused by inadvertently turning the dial wheel past the point at which the magnet pulls from the surface, yielding a false low measurement. Type 1 gages should not be used on soft or tacky coatings, as the magnet may adhere to the coating causing false low measurements, or coating materials may dry on the magnet causing false high measurements. The exposed magnet may attract metal filings, which can contaminate the magnet and cause false high measurements. Type 1 gages cannot be used to measure the thickness of coatings applied to non-ferrous metal substrates. The manufacturer's specifications will contain a temperature operating range. Use of the gage outside of this range may generate false coating thickness measurements and may damage the instrument.

5.3 Type 2 gages are instruments that employ a measuring probe and the magnetic induction, Hall-effect or eddy-current measurement principle in conjunction with electronic microprocessors to produce a coating thickness measurement. The gage probe must be placed directly (in a perpendicular position) on the coated surface to obtain a measurement. For gages measuring on ferrous substrates, the magnetic induction or Hall-effect principles determine the effect on the magnetic field generated by the probe due to the presence of the substrate. For gages measuring on non-ferrous metals, the gage probe is energized by alternating current that induces eddy currents in the metal substrate. Note that gages/probes for measuring coating thickness on non-ferrous metals should not be used to measure coating thickness on ferrous surfaces, even though a reading may be displayed.

5.4 Type 2 gages are available with integral, separate or remote (unconnected) probes, and they can be used to measure coating thickness on ferrous or non-ferrous metal substrates, or both, depending on the probes supported by the particular gage