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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.

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

1. Scope

1.1 This practice describes the use of magnetic and eddy current gages for dry film thickness measurement. 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 the equipment 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 5.7.

1.3 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.

1.4 Coating thickness can vary widely across a surface. As a result, obtaining single-point measurements may not accurately represent the actual coating system thickness. SSPC-PA 2 prescribes a frequency of coating thickness measurement based on the size of the area coated. A frequency of measurement for coated steel beams (girders) and coated test panels is also provided in the appendices to SSPC-PA 2. 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.

1.5 The values stated in SI units are to be regarded as standard. The values given in parentheses after SI units are provided for information only and are not considered standard.

1.6 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

[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.

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1.7 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

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, Coatings and Related Products on Test Panels

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

2.2 *SSPC Standard:*[3]

SSPC-PA 2 Procedure for Determining Conformance to Dry Coating Thickness Requirements

2.3 *ISO Standard:*[4]

ISO 19840 Paints and varnishes—corrosion protection of steel structures by protective paint systems—Measurement of, and acceptance criteria for, the thickness of dry films on rough surfaces

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 (optimization), 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.

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

3.1.3.1 *Discussion*—

The BMR is the determined 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.

3.1.4 *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.

3.1.4.1 *Discussion*—

Calibration of coating thickness gages is performed by the equipment manufacturer, their authorized agent, or by an accredited 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.

3.1.5 *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.

[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.

[3] Available from Society for Protective Coatings (SSPC), 800 Trumbull Dr., Pittsburgh, PA 15205, http://www.sspc.org.

[4] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

3.1.6 *coating thickness standard, n*—coated or plated metal plates, or uncoated shims of flat sheet, with assigned values traceable to a National Metrology Institution.

3.1.6.1 *Discussion*—

In the case of the eddy current principle, the coating and shim material must be non-metallic, whereas in the case of the magnetic induction and the Hall-effect methods the material must be nonmagnetic.

3.1.7 *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).

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

3.1.8.1 *Discussion*—

If the surface of the substrate is roughened, the dry film thickness is considered the thickness of the coating or coating layers above the peaks of the surface profile.

3.1.9 *ferrous, n*—containing iron.

3.1.9.1 *Discussion*—

Describes a magnetic material such as carbon steel. That material may also be known as ferromagnetic.

3.1.10 *gage (gauge), n*—an instrument for measuring quantity, or an instrument for testing.

3.1.10.1 *Discussion*—

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

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

3.1.11.1 *Discussion*—

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

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

3.1.13 *micrometer (micron), n*—one one-thousandth of a millimeter [0.001 mm]; 25.4 microns = 1 mil.

3.1.14 *mil, n*—a U.S. term referring to the imperial unit of measure of one one-thousandth of an inch [0.001 in.] referred to elsewhere in the world as "one thou;" 1 mil = 25.4 microns.

3.1.15 *nonconductive, n*—a material that is unable to conduct electricity.

3.1.16 *non-ferrous metal, n*—a nonmagnetic metal or metal alloy (for example, copper, aluminum or brass).

3.1.17 *reference sample, n*—a coated or uncoated metal specimen of the same material and geometry as the specific measuring application used to adjust and/or verify the accuracy of a coating thickness measuring gage for a specific project.

3.1.17.1 *Discussion*—

A coated reference sample may or may not have thickness values traceable to a National Metrology Institution. However, the reference sample should be marked with the stated value and the degree of accuracy. The coating thickness of the sample should be close to the user's coating thickness measurement requirement.

3.1.18 *shims (foils), n*—strips of flat sheet, with the thickness stated or referenced in some form, which can be used to adjust a Type 2 coating thickness gage in the intended range of use over the surface of the representative substrate material.

3.1.18.1 *Discussion*—

Other uses with Type 2 gages include: placement over soft coatings to obtain thickness measurements without the gage probe depressing the coating film, and verification of gage operation.

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

NOTE 1—This practice addresses only metal substrates.

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

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

3.1.21.1 *Discussion*—

For Type 1 gages, a probe containing 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.

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

3.1.22.1 *Discussion*—

The probe of a Type 2 gage remains on the surface during the measurement process.

3.1.23 *verification of accuracy, n*—obtaining measurements on coating thickness standards, comprising of at least one thickness value close to the expected coating thickness, prior to gage use for the purpose of determining the ability of the coating thickness gage to produce thickness results within the gage manufacturer's stated accuracy.

4. Significance and Use

4.1 This practice describes three operational steps necessary to ensure accurate coating thickness measurement: calibration, verification and adjustment of coating thickness measuring gages, as well as proper methods for obtaining coating thickness measurements on both ferrous and non-ferrous metal substrates.

4.2 Many 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 nondestructive coating thickness testing gages that are used to measure the cumulative or individual 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.

5. Principles, Advantages, and Limitations of Gages

5.1 Type 1 magnetic pull-off gages employ an attraction principle and a static (non-time varying) magnetic field. These mechanical instruments 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.

5.3.1 For gages measuring on ferrous substrates, the magnetic induction or Hall-effect principles are used to measure a change in magnetic field strength within their probes to produce a coating thickness measurement. These gages determine the effect on the magnetic field generated by the probe due to the proximity of the substrate.

5.3.2 For gages measuring on non-ferrous metals, the gage probe coil is energized by alternating current that induces eddy currents in the metal substrate. The eddy currents in turn create a secondary magnetic field within the substrate. The characteristics of this secondary field are dependent upon the distance between the probe and the basis metal. This distance (gap) is measured by the probe and shown on the gage display as the thickness (microns or mils) of the intervening coating. 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 or separate (wired or wireless) 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 platform. The thickness of the coating is displayed digitally. In general, access to tight areas is easier with Type 2 gages, especially those equipped with separate or remote probes. Type 2 gages are available with memory, measurement batching, statistical analysis packages and data download/print-out. The manufacturer's stated accuracy is typically 1 to 3 % of the reading.

5.5 Instruments using either a magnetic or eddy current principle measure total film thickness only. In multi-layer coating systems 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.

5.5.1 Some instruments employ both principles and may be capable of measuring the individual thickness of two layers such as paint over zinc (duplex coating) on steel.

5.6 Most electronic coating thickness measuring gages can be verified for accuracy using coating thickness standards. Gages that cannot be adjusted by the user should be returned to the manufacturer or their authorized agent for calibration if the readings obtained on the coating thickness standards are outside of the combined accuracy of the standard and the manufacturer's stated gage accuracy.

5.6.1 Gage operation should be verified on a prepared, uncoated substrate having the same composition, shape and surface profile to which the coating will be applied to, for the intended range of use. If necessary, the gage should be adjusted as described in 7.4.

5.7 Type 2 gages should not be used directly on soft or tacky coatings, unless expressly designed for this application, as the pressure on the probe can indent the coating yielding false low measurements, or coating materials may contaminate the probe yielding false high measurements. A shim of known thickness can be placed on top of the soft/tacky coating film and a measurement of the coating thickness obtained by subtracting the shim thickness from the total measurement of the shim and the coating. Note that some Type 2 gages can be programmed to automatically deduct the shim thickness (known as "zero offset"). Type 2 gages may be sensitive (to some degree) to substrate effects including, but not limited to edges, corners and holes in the substrate, as well as substrate thickness. The manufacturer's specifications will contain a temperature operating range. Use of the gage or the probe outside of this range may generate false coating thickness measurements and may damage the instrument.

5.8 Coating thickness measurement accuracy can also be affected by, but is not limited to, the factors listed below. Consult the instrument manufacturer for details on the specific effects of these factors and how they are addressed by the instrument.

5.8.1 *Curvature*—The influence of curvature varies considerably with the make and type of instrument but often becomes more pronounced as the radius of curvature decreases.