The following article provides definitions, explanations, limitations and practical examples of metrology terminology as it relates to DeFelsko coating thickness measurement gauges. While many of these terms and definitions also apply to other instruments, consult the manufacturer for details specific to your individual instrument.

**TYPE 1: PULL-OFF GAUGES**

In Type 1 pull-off gauges 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 gauge. The magnetic force holding the magnet to the surface varies inversely as a non-linear function of the distance between magnet and steel, i.e., the thickness of the dry coating. Less force is required to remove the magnet from a thick coating (Figure 1).

**TYPE 2: ELECTRONIC GAUGES**

A Type 2 electronic gauge uses electronic circuitry to convert a reference signal into coating thickness (Figure 2).

- Electronic ferrous gauges operate on one of two different magnetic principles. (Some ferrous gauges use the principle of magnetic induction.) When a permanent magnet is brought near steel, the magnetic flux density at the pole face of the magnet increases. Coating thickness is determined by measuring this change in flux density, which varies inversely to the distance between the magnet and the steel substrate. Hall elements and magnet resistance elements positioned at the pole face are the most common ways this change in magnetic flux density is measured.
- Other ferrous electronic gauges operate on the principle of electromagnetic induction. A coil containing a soft iron rod is energized with an AC current, thereby producing a changing magnetic field at the probe. As with a permanent magnet, the magnetic flux density within the rod increases when the probe is brought near the steel substrate. A second coil detects this change. The output of the second coil is related to the coating thickness. Many gauges also need temperature compensation due to the temperature dependence of the coil parameters, although some gauges utilize a balanced secondary coil configuration to help improve temperature independence.
- Non-ferrous electronic gauges also operate on a principle of electromagnetic induction. A coil conducting an alternating current sets up an alternating magnetic field at the surface of the probe. As the probe is brought near a conductive surface, the magnetic field creates eddy currents on the surface. A second coil, the output of which is related to the coating thickness, detects these eddy currents. Some gauges utilize only one coil to both set up the magnetic field and to detect the opposing magnetic field produced by the eddy currents.

**REFERENCE STANDARDS**

A reference standard is a sample of known thickness against which users may verify the accuracy of their gauge. Reference standards are typically coating thickness standards or shims. They may or may not be traceable to a national or international registry. If agreed to by the contracting parties, a sample part of known (or acceptable) thickness may be used as a reference standard for a particular job.

**COATING THICKNESS STANDARDS**

For most instruments, a coating thickness standard is typically a smooth, metallic sub-
strate with a nonmagnetic (epoxy) coating of known thickness that is traceable to national standards (NIST). The substrate is ferrous (steel) for magnetic gauges or non-ferrous (aluminum) for eddy current and ultrasonic gauges. High-accuracy coating thickness standards are used to calibrate gauges as part of the manufacturing process. The same standards are available for purchase by customers to be used as calibration standards in a calibration lab or as check standards in the field or on the factory floor.

Coating thickness standards to be used with ultrasonic gauges can also be solid plastic (polystyrene) blocks that have been machined to a flat smooth surface. In addition to a known thickness traceable to national standards, these standards also have a known sound velocity.

Calibration Standards are purchased as accessories to help meet the increasing customer need to fulfill ISO/QS-9000 and in-house Quality Control requirements. Many customers find it more practical to verify accuracy of their own gauges in-house, rather than utilize vendor services. To assist these customers, sets of calibration standards are available with nominal values selected to cover the range of each gauge. Standards usually come with a Calibration Certificate showing traceability to NIST. In addition, some vendors make calibration procedures available to their customers.

SHIMS
A shim is a thin strip of non-magnetic plastic, metal, or other material of known uniform thickness used to verify the operation and make adjustments to dry film thickness gauges (Figure 3). While a plastic shim is able to take the form of most substrates to be measured, the accuracy of the shim is more limited than coating thickness standards. Therefore, when using a shim to make adjustments with Type 2 (electronic) gauges, it is important to combine the tolerance of the shim with the tolerance of the gauge before determining the accuracy of measurements.

Plastic shims are often used to adjust a gauge in the intended range of use over the surface of the representative substrate material.

We do not recommend shims be used with Type 1 (mechanical pull-off) gauges. Shims are usually fairly rigid and curved and do not lie perfectly flat, even on a smooth steel test surface. Near the pull-off point of the measurement with a mechanical gauge, the shim frequently springs back from the steel surface, raising the magnet too soon and causing an erroneous reading.

THREE STEPS TO ENSURE BEST ACCURACY
When using a coating thickness gauge, there are three basic procedures to ensure measurement accuracy: calibration, verification, and adjustment. Following is a breakdown in detail:

Calibration
Calibration is the high-level, controlled, and documented process of measuring traceable calibration standards over the full operating range of the gauge and verifying that the results are within the stated accuracy of the gauge. If necessary, gauge adjustments are made to correct any out-of-tolerance conditions.

Calibrations are typically performed by the gauge manufacturer or by a qualified laboratory in a controlled environment using a documented process. The coating thickness standards used in the calibration must be such that the combined uncertainties of the resultant measurement are less than the stated accuracy of the gauge. Typically, a 4:1 ratio between the accuracy of the standard and the accuracy of the gauge is sufficient. The outcome of the calibration process is to restore/realign the gauge to meet/exceed the manufacturer’s stated accuracy.

Calibration Interval: A calibration interval is the established period between recalibrations (recertifications) of an instrument. As per the requirements of ISO 17025, some vendors do not include calibration intervals as part of Calibration Certificates issued with their coating thickness gauges.

For customers seeking assistance in developing their own calibration intervals, we share the following experience: Non-age related factors have shown to be more critical in determining calibration intervals. These factors are primarily the frequency of use, the application in question, as well as the level of care taken during use, handling and storage. For example, a customer that uses the gauge frequently, measures on abrasive surfaces, or uses the gauge roughly (i.e. drops the gauge, fails to replace the cover on the probe tip for storage, or routinely tosses the gauge into a tool box for storage) may require a relatively shorter calibration interval.

Note: We recommend that customers establish gauge calibration intervals based upon their own experience and work environment. Customer feedback suggests one year as a typical starting point. Furthermore, our experience suggests that customers purchasing a new instrument can safely utilize the...
instrument purchase date as the beginning of their first calibration interval. The limited effect of age minimizes the importance of the actual calibration certificate date.

**Calibration Certificate:** A Calibration Certificate is a document that records actual measurement results and all other relevant information to a successful instrument calibration. Calibration Certificates clearly showing the traceability to a national standard are included with most new calibrated or repaired instruments. Note: Some manufacturers charge extra for this document.

**Traceability:** Traceability is the ability to follow the result of a measurement through an unbroken chain of comparisons, all the way back to a fixed international or national standard that is commonly accepted as correct. The chain typically consists of several appropriate measurement standards, the value of each having greater accuracy and less uncertainty than its subsequent standards.

**Recalibration (Recertification):** Recalibration, also referred to as recertification, is the process of performing a calibration on a used instrument. Recalibrations are periodically required throughout the life cycle of an instrument since some probe surfaces are subject to wear that may affect the linearity of measurements.

**Verification of Accuracy**

Verification is an accuracy check performed by the instrument user on known reference standards prior to gauge use for the purpose of determining the ability of the coating thickness gauge to produce reliable values compared to the combined gauge manufacturer's stated accuracy and the stated accuracy of the reference standards. The process is intended to verify that the gauge is still functioning as expected.

Verification is typically performed to guard against measuring with an inaccurate gauge at the start or end of a shift, before taking critical measurements, when an instrument has been dropped or damaged— or whenever erroneous readings are suspected. If deemed appropriate by the contracting parties, initial agreement can be reached on the details and frequency of verifying gauge accuracy.

If readings do not agree with the reference standard, all measurements made since the last accuracy check are suspect. In the event of physical damage, wear, high usage, or after an established calibration interval, the gauge should be removed from service and returned to the manufacturer for repair or calibration.

The use of a checking measurement standard is not intended as a substitute for regular calibration and confirmation of the instrument, but its use may prevent the use of an instrument, which, within the interval between two formal confirmations, ceases to conform to specification.

**Adjustment (Optimization, Calibration Adjustment)**

Adjustment is the physical act of aligning a gauge's thickness readings (removal of bias) to match those of a known sample in order to improve the accuracy of the gauge on a specific surface or within a specific portion of its measurement range.

In most instances it should only be necessary to check zero on an uncoated substrate and begin measuring. However, the effects of properties such as substrate (composition, magnetic properties, shape, roughness, edge effects) and coating (composition, mass, surface roughness), as well as ambient and surface temperatures, may require adjustments to be made to the instrument.

Most Type 2 gauges can be adjusted on known reference standards, such as coated parts or shims. However, Type 1 “pull-off” gauges have nonlinear scales. Since their adjustment features are linear no adjustments should be made. Instead, the user should take a base metal reading (BMR) and subtract that value from the coating thickness reading.

With a Type 2 gauge where an adjustment method has not been specified, a 1-pt adjustment is typically made first. If inaccuracies are encountered then a 2-Pt Adjustment should be made.

**1-Pt Adjustment (Offset, Correction Value):** 1-pt adjustments involve fixing the instrument's calibration curve at one point after taking several readings on a known sample or reference standard. If required, a shim can be placed over the bare substrate to establish such a thickness. This adjustment point can be anywhere within the instrument's measurement range, though for best results should be selected near the expected thickness to be measured.

Zeroing is the simplest form of 1-pt adjustment. It involves the measurement of an uncoated sample or plate. In a simple zero adjustment, a single measurement is taken and then the reading is adjusted to read zero. In an average zero adjustment, multiple measurements are taken, then the gauge calculates an average reading and automatically adjusts that value to zero.

**2-Pt Adjustment:** This method is preferred for very unusual substrate materials, shapes, or conditions. It provides greater accuracy within a limited, defined range. Two-pt adjustments are similar to 1-pt except the instrument's calibration curve is fixed at two known points after taking several readings on known

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**ORGANIC FINISHING: CASE STUDY**

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samples or reference standards. The two thicknesses must be within the instrument’s measurement range. Typically, points are selected on either side of the expected coating thickness (Figure 4).

**BASE METAL READING**

The base metal reading (BMR) is the measured effect of substrate roughness on a coating thickness gauge 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.

A BMR is a zeroing technique typically used with Type 1 (mechanical pull-off) gauges on rough surfaces. Adjustments to a Type 1 gauge are linear in nature; however, the scale of the gauge is nonlinear. Therefore, it is important not to adjust the gauge to read zero on the bare substrate.

The BMR is calculated as a representative value (average) of several measurements taken from several locations across a bare substrate.

**REPEATABILITY**

Coating thickness gauges are necessarily sensitive to very small irregularities of the coating surface or of the steel surface directly below the probe center. Repeated gauge 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.

**ROUGHNESS**

If a 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 gauge senses is an imaginary plane located between the peaks and valleys of the surface profile (Figure 5). Gauges read thickness above the imaginary magnetic plane. If a Type 1 gauge is used, the coating thickness above the peaks is obtained by subtracting the BMR. With a correctly adjusted Type 2 gauge, the reading obtained directly indicates the coating thickness.

**REFERENCES**


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