Measuring coating thickness is an important procedure when controlling the application of coatings to metal substrates for corrosion protection.

Portable, low-cost coating thickness gauges have made field measurement of coating thickness practical. Therefore, regular and routine checks of coating thickness can now be made during the preparation and construction of steel work and throughout the life of the structure.

This article explores reasons for measuring coating thickness, the types of equipment used, standards that apply to the use of coating thickness gauges, the keys to successful coating thickness measurement in the field, and practical hints for users of thickness gauges.

**Why Field Measurements are Necessary**

It is common practice to apply protective coatings to the components of a steel structure during their manufacture so that they are delivered to the site ready for assembly. Coating application should be monitored in the paint shop, but a site inspection is always useful to detect areas that are not coated correctly or that have been damaged in transit. Remedial action at this point can save considerable expense in future repairs during the life of the structure.

Measuring coating thickness during on-site application work is necessary to ensure that the coating system is fit for its intended purpose.

Routine measurement of coating thickness throughout the life of a structure can monitor the coating’s performance under prevailing exposure conditions. Data generated by regular inspections can be used to manage repair work and enable it to be performed conveniently and efficiently rather than in an emergency.

**Types of Gauges**

In the late 1940s, the first mechanical coating thickness gauges were developed for measuring coatings on steel. They are still available, but the gauges in common use today are electronic. Many are capable of measuring coatings on substrates made of either ferrous metal (mild steel, cast iron, etc.) or non-ferrous metal (aluminium, zinc, brass, etc.).

Mechanical gauges typically use the force required to remove a magnet from a coated steel surface as a measure of the non-magnetic coating thickness. The thicker the coating, the less the force that is required to remove the magnetic probe from the surface. They are limited to use on ferrous metals, since non-ferrous metals are not magnetic.

Electronic gauges use either electromagnetic induction or Hall-effect probes to measure non-magnetic coatings on ferrous substrates.

Electromagnetic induction probes have three coils, one powered by the gauge to create an alternating magnetic field and two search coils to detect the resulting magnetic field. The field is altered by the presence of the magnetic substrate under the coating, and these changes affect the output from the two search coils. The distortion of the magnetic field is maximised when the probe is in contact with uncoated steel. Therefore, the voltage output across the two search coils is also maximised. As the probe moves away from the steel surface, separated by the coating, the voltage output from the two search coils decreases until there is no detectable influence from the substrate. The voltage output from the two search coils, which changes with the coating thickness, is calibrated against known thickness values.

The Hall-effect probe contains a semiconductor device that is affected by magnetic fields and a permanent magnet to generate a field whose strength is influenced by the thickness of the coating. Hall-effect devices produce a voltage output that depends on the magnetic field strength, which in turn depends on the distance to the magnetic substrate. The output voltage from the Hall-effect device is calibrated against known values of thickness.

The maximum coating thickness that can be measured...
with both types of probes depends on their size and design. Typical thickness ranges are:
- 0–250 µm (0–10 mils) for small probes,
- 0–1,500 µm (0–60 mils) for standard-size probes with straight and right-angle configurations,
- 0–5 mm (0–200 mils) for probes used on fire-resistant coatings, and
- 0–13 mm (0–0.5 inch) for large probes used on foamed coatings.

To measure non-conductive coatings on non-ferrous metals, an eddy current gauge is used. It has a single coil with a high frequency signal that generates magnetic fields in non-ferrous metal substrates. These magnetic fields create eddy currents in the substrate that are detected by the probe. The strength of the eddy currents is affected by the coating thickness, which is how the measurement is determined.

Electronic coating thickness gauges might include various features such as:
- digital display of thickness readings,
- memory for calibration settings,
- dual operation for ferrous and non-ferrous substrates,
- integral probes for one-handed operation or separate probes for difficult access areas, and
- statistical calculations of mean (average) value to characterise a set of readings, standard deviation to assess the spread of a set of readings, highest and lowest readings to assess a range of values, and number of readings to determine the validity of a sample.

Other features might include multiple batch storage of readings to keep different sections of an inspection separate, data transfer to a printer or computer for record-keeping and further analysis, and date and time marking of readings.

**Relevant Standards**
There are a number of standards that apply to the use of coating thickness gauges. ISO, ASTM, SSPC, and recently CEN have all contributed to the information that controls the use of portable coating thickness gauges.

**ISO Standards**
The relevant ISO standards are:
- ISO 2178, Non-magnetic Coatings on Magnetic Substrates—Measurement of Coating Thickness—Magnetic Method;
- ISO 2360, Non-conductive Coatings on Non-magnetic Basis Metals—Measurement of Coating Thickness—Eddy Current Method; and
- ISO 2808, Paints and Varnishes—Determination of Film Thickness.
This last standard relates to several
film thickness measurement methods, including the two-point calibration method for use on blast-cleaned (roughened) steel surfaces. ISO 2178 describes the limitations of coating thickness gauges based on the magnetic principle, including the effects of changes in the magnetic properties of the substrate, of the component shape and thickness, and of surface finish.
CEN Standard
A CEN draft standard titled Measurement and Acceptance Criteria of Dry Film Thickness is currently undergoing review and voting for possible acceptance as a full standard.

The method in this draft standard includes the concept of correction values to allow for the effect of a roughened surface on a gauge that has been adjusted to read on a smooth surface. The correction values are linked to the profile assessment described in ISO 8503–1 (Preparation of Steel Substrates Before Application of Paints and Related Products—Surface Roughness Characteristics of Blast-Cleaned Steel Substrates—Part 1: Specifications and Definitions for ISO Surface Profile Comparators for the Assessment of Abrasive Blast-Cleaned Surfaces). The value is subtracted from the coating thickness value obtained using a gauge adjusted to read correctly on a smooth surface.

This methodology is designed to provide a consistent way of assessing coating thickness despite the use of different gauges or the same type of gauge by different operators.

The CEN draft standard is also undergoing a parallel voting procedure within ISO. If it is accepted by ISO, it would become the accepted standard within the ISO 12944 series (Paints and Varnishes—Corrosion Protection of Steel Structures by Protective Paint Systems), which currently does not define a method of determining dry film thickness on blast-cleaned steel.

SSPC Standard
SSPC-PA 2 (Measurement of Dry Coating Thickness with Magnetic Gages) describes the use of pull-off magnetic gauges (Type I) and constant pressure probe electromagnetic gauges (Type II) for measuring coatings on steel.

This standard describes the way in which readings are collected and provides an analytical technique to allow for the statistical variation encountered on roughened surfaces.

It uses the concepts of target values for the thickness of the coating and spot values that are the mean of three readings at any point on the surface. Individual spot values are allowed to be as low as 80% of the target, but the average of the spot readings must be at or above the target value. SSPC-PA 2 also includes a correction for profile called the base metal reading, which applies to pull-off magnetic gauges.

ASTM Standards
ASTM D1186 (Standard Test Methods for Nondestructive Measurement of Dry Film Thickness of Nonmagnetic Coatings Applied to a Ferrous Base)
and ASTM D1400 (Standard Test Method for Nondestructive Measurement of Dry Film Thickness of Nonconductive Coatings Applied to a Nonferrous Metal Base) describe the use of magnetic gauges and eddy current gauges, respectively. They both include the use of either measured foils or coated thickness standards for checking and adjusting the calibration settings of the gauges. They also describe the limitations of coating thickness gauges as determined by magnetic properties of the substrate, component shape, etc.

**Field Measurement**
The two keys to successful field measurement of coating thickness are a clear understanding of what is intended by the coating thickness application and a correct coating thickness gauge calibration adjustment.

**Understanding the Limitations**
Many coating thickness specifications are written without an appreciation of the limitations of coating thickness measurement. For example, a specification that says a minimum thickness of 100 µm (4 mils) is required may lead to over-coating in some areas to ensure that this “minimum” figure is achieved. With some coatings, this can be counter-productive, since the thicker areas can be prone to cracking. In other cases, a major coating project may be “rejected” for a single reading below the minimum value.

Specifications of coating thickness are best expressed as a nominal or target value with a range of acceptable values above and below the nominal value (e.g., 100 µm ± 20 µm). This should be accompanied by a description of how the thickness is to be tested.

**Adjusting the Calibration**
There are two aspects to calibration.

1. The calibration condition of a gauge should be checked before an inspection. The probes of coating
thickness gauges will eventually wear, as characterised by a loss of ability to read accurately across the full range of the gauge. It may measure accurately at zero and at the calibration foil value, since the gauge has been adjusted to these values, but intermediate readings may show an unacceptable error due to wear on the probe tip. A regular assessment of the gauge performance against a full set of calibration foils is not only good practice but also can predict when probes should be replaced.

2. Adjusting the calibration of the gauge to the work at hand can ensure maximum accuracy and repeatability of the measurement. Since different substrate materials, different shapes, and different surface finishes can all influence the accuracy of the measurement, these effects can either be “calibrated out” by adjusting the
gauge to the uncoated substrate or corrected for in cases when the substrate is already coated and not available for calibration adjustment.

**PRACTICAL HINTS**

The most obvious advice to users of coating thickness gauges is to agree on the method of operation and the acceptance/rejection criteria for the job before it starts. For example, when measuring thin-film primers on profiled surfaces, it might be more realistic to use an alternative method, such as spraying a smooth test panel at the same time and measuring the dry film thickness on this rather than on the blast-cleaned surface.

The acceptance/rejection criteria are a cause of many problems. On a surface that varies from point to point as a result of blast-cleaning, the significance of a single reading must not be allowed to govern the management of the whole project. It will be practically impossible to repeat such a measurement if the coating is applied correctly, but areas of low coating thickness can be identified if sufficient readings are taken.

How many readings are sufficient? Follow the standard being used. SSPC-PA 2 specifies a required number of measurements, while ASTM D1400 includes a recommended sampling procedure. The new CEN draft standard details a sampling plan based on inspection areas, which may be the whole structure or sections of the whole structure, depending on its size.

An inspector should always carry spare batteries. They are easily available for most instruments, but the inconvenience of having to get new batteries half way through an inspection can be considerable on some sites.

Also, the calibration foils should be replaced regularly, since they can be damaged by creasing if not stored and used with care.

If measuring the thickness of a soft coating, a foil of known thickness (e.g., 250 µm [10 mils]) can be used to spread the load of the probe to prevent indentation and incorrect readings.

Finally, inspectors should always have access to a good quality sample substrate so the condition of the gauge can be checked on site.

**CONCLUSION**

Measuring coating thickness on site is an effective way to control a coating process and to ensure that the applied coating is fit for purpose. Modern coating thickness gauges are robust and intended for use in the field, but they must be treated with care.