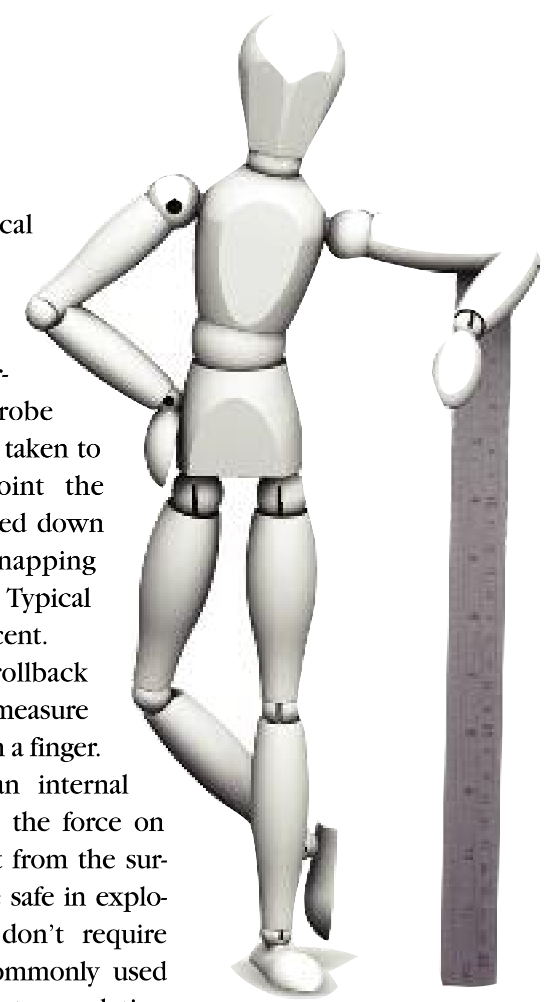
Coating Thickness MEASUREMENT



By David Beamish

Coatings perform a variety of important functions including protecting and beautifying outdoor structures and manufactured goods. Accurately measuring the thickness of these coatings helps maintain product quality and control production costs.

Several types of instruments are available to measure coatings in their uncured (wet) or cured (dry) state. Proper instrument selection is crucial to obtaining accurate, meaningful results. Instrument selection is dependant upon the type and thickness range of the coating, the substrate material, the shape of the part, and the need for statistical analysis. To make this choice, one must understand the different technologies available for coating thickness measurement.

Measuring techniques are either destructive or non-destructive. Non-destructive methods include magnetic, eddy current, ultrasonic, and micrometer measurement. Destructive methods include cross-sectioning and gravimetric (mass) measurement. Methods are also available for pre-cured liquid and coating powder measurement.

Figure 1

An inspector non-destructively measures paint thickness on steel drums with an electronic magnetic instrument.

MAGNETIC GAGES

Dry-film magnetic coating thickness gages non-destructively measure the thickness of non-magnetic coatings on ferrous substrates such as paint over steel. Most coatings on steel are measured with instruments using one of two principles of operation: magnetic pull-off (mechanical operation) or magnetic/electromagnetic induction (electronic operation).

MAGNETIC PULL-OFF

Magnetic pull-off gages, sometimes referred to as Type I gages, are rugged, simple and inexpensive. They are a good, low-cost solution in situations where quality goals require only a few readings during production or inspection.

A permanent magnet, a calibrated spring, and a graduated scale are key elements to these mechanical gages. The attraction between the magnet and magnetic steel decreases as the coating thickness separating the two increases. The thicker the coating the easier it becomes to pull the magnet away. Coating thickness is determined by measuring this pull-off force.

Pencil-type models use a magnet mounted to a helical spring that works by pulling the gage perpendicularly away from the coated surface until the probe releases. Thickness is taken to be the furthest point the gage's indicator moved down the scale before snapping back upon release. Typical accuracy is ±10 per cent.

More common rollback dial models (Fig.2) measure by rotating a dial with a finger. This action turns an internal spring and increases the force on the magnet to pull it from the surface. These gages are safe in explosive environments, don't require batteries, and are commonly used by painting contractors, plating shops, and small powder coating operations. Typical accuracy is ±5 per cent.

MAGNETIC AND ELECTROMAGNETIC INDUCTION

Electronic instruments are the most popular type of magnetic gage used in the steel coatings industry. Sometimes referred to as Type II gages, they use one of two principles of operation – magnetic induction or electromagnetic induction. Both measure the change in magnetic flux density at the surface of a magnetic probe as it nears a steel surface. The magnitude of the flux density at the probe surface is directly related to the distance from the steel substrate. By measuring flux density the coating thickness can be determined.

Magnetic induction instruments use a permanent magnet and a Hall-effect generator or magneto-resistor to sense the magnetic flux density at a pole of this magnet. Electromagnetic induction instruments use a soft, ferromagnetic rod wound with a coil of fine wire to produce an alternating magnetic field. A second coil of wire detects changes in magnetic flux.

Electronic magnetic gages (Fig.3) come in different shapes and sizes with a selection of optional features. Different probes are available; each optimized for specific shapes and thickness ranges.

Figure 2

A rollback dial-type magnetic coating thickness gage.

Figure 3

Electronic coating thickness gages for metals.

Measurement is fast and readings are easy-to-read on a digital liquid crystal display (LCD). Smart user-interfaces make operation simple with optional features such as measurement averaging, analysis of reading trends, printouts for permanent record, and user-selectable languages and units of measurement. Typical accuracies are between ±1 per cent and ±3 per cent.

EDDY CURRENT GAGES

Eddy current coating thickness gages (Fig.3) often look and operate just like their magnetic cousins. They employ an eddy current technique to non-destructively measure the thickness of non-conductive coatings on non-ferrous metal substrates such as paint on aluminum.

Similar to the electromagnetic induction principle, a coil of fine wire is used. This time a higher-frequency alternating current (above 1 MHz) is used to set up an alternating magnetic field at the surface of the instrument's probe. When the probe is brought near a conductive surface, the alternating magnetic field sets up eddy currents on the surface. The substrate characteristics and the distance of the probe from the substrate (the coating thickness) affect the magnitude of the eddy currents. The eddy currents create their own opposing electromagnetic field that is sensed by the exciting coil or by a second, adjacent coil.

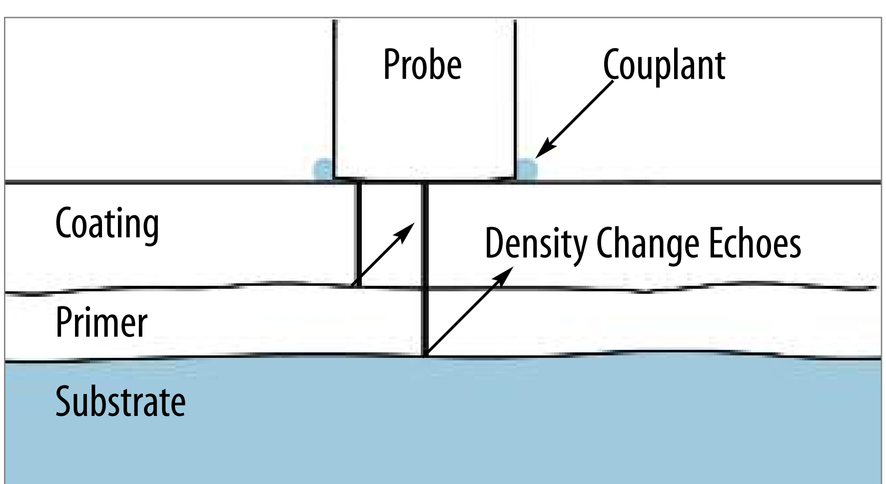


Figure 4

Ultrasonic vibrations reflect off coating interfaces

Some instruments incorporate both magnetic and eddy current principles into one unit. Most simplify the task of measuring by switching automatically from one principle of operation to the other depending upon the substrate. These combination units are popular with painters and powder coaters.

The manufacturer's instructions should be carefully followed for most accurate results. Standard test methods for magnetic and eddy-current instruments are available in ASTM D7091, ISO 2808 and SSPC-PA2.

ULTRASONIC GAGES

Instruments discussed to this point only measure coatings over metals. Non-metal applications such as coatings over plastic, wood and concrete require an ultrasonic pulse-echo technique.

Ultrasonic testing works by sending an ultrasonic vibration into a coating using a probe (transducer) with the assistance of a couplant applied to the surface.

The vibration travels through the coating until it encounters a material with different mechanical properties—typically the substrate but perhaps a different coating layer. The vibration, partially reflected at this interface, travels back to the transducer where it is converted into a high frequency electrical signal. The echo waveform is digitized and analyzed to determine a coating thickness value that is based upon the time of travel for the pulse. Meanwhile, a portion of the transmitted vibration continues to travel beyond that interface and experiences further reflections at any material interfaces it encounters Because a potentially large number of echoes could occur, the gage is designed to select the maximum or "loudest" echo from which to calculate a thickness measurement. Instruments that measure individual layers in a multi-layer application also favor the loudest echoes. The user simply enters the number of layers to measure, say three, and the gage measures the three loudest echoes. The gage ignores softer echoes from coating imperfections and substrate layers.

Ultrasonic instruments (Fig.5) measure the transit time of an ultrasonic pulse. Therefore they must be calibrated for the "speed of sound" in that particular material. From a practical standpoint, sound velocity values do not vary greatly among paints and therefore these gages usually require little or no adjustment to their factory calibration settings.

Typical accuracy is ±3 per cent. Standard methods for the application and performance of this test are available in ASTM D6132 and ISO 2808.

THICKNESS STANDARDS

Dry-film coating thickness gages are calibrated to known thickness standards. These standards are typically smooth, metal substrates with an epoxy coating of known thickness (Fig.6). There are many sources of thickness standards but it is best to ensure they are traceable to a national measurement institute such as NIST (National Institute of Standards & Technology).

Highly accurate coating thickness standards are used to calibrate gages as part of the manufacturing process. The same standards are available for purchase for use as calibration standards in a calibration lab or as check standards in the field or on the factory floor. A regular check against these standards verifies the gage is operating properly. When readings do not meet the accuracy specification of the gage, the gage must be adjusted or repaired.

HEIGHT MEASUREMENT

Micrometers are sometimes used to check coating thickness. They have the advantage of measuring any coating/substrate combination but the disadvantage of requiring access to the bare substrate. The requirement to touch both the surface of the coating and the underside of the substrate can be limiting and they are often not sensitive enough to measure thin coatings.

Two measurements must be taken: one with the coating in place

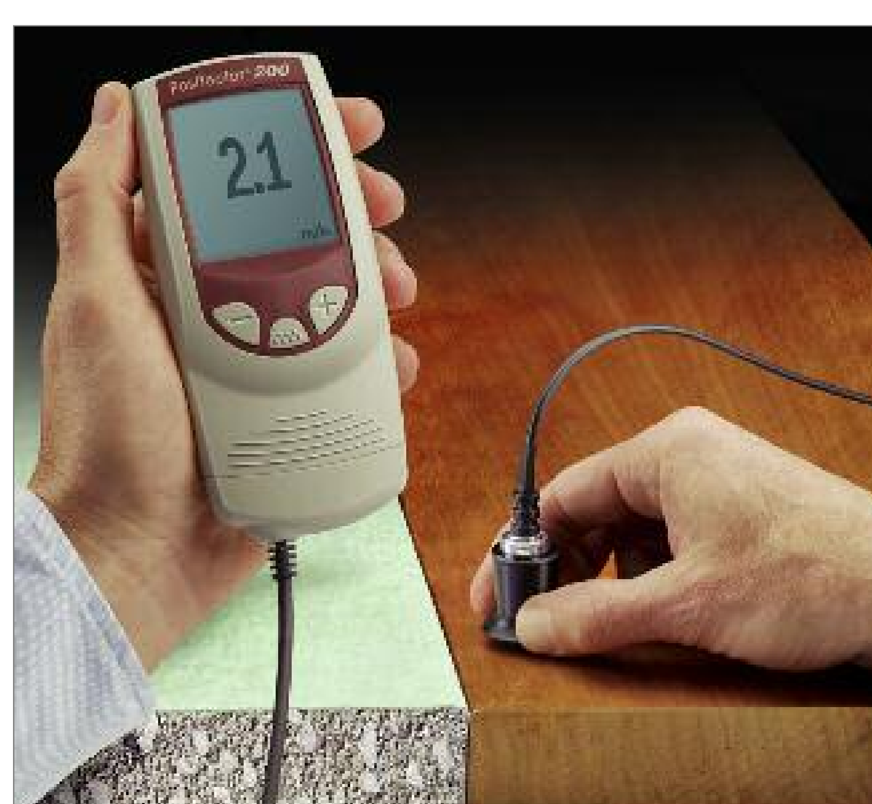


Figure 5

An ultrasonic coating thickness gage.

Figure 6

Coating thickness standards.

and the other without. The difference between the two readings, the height variation, is taken to be the coating thickness. On rough surfaces, micrometers measure coating thickness above the highest peaks.

Similarly, dial gages with a spring-loaded stylus can be affixed to a test stand. The part to be measured is placed under the instrument and film thickness is taken to be the difference between the reading obtained for the total thickness and that obtained for the substrate thickness only.

CROSS-SECTIONING

Coating thickness can be measured destructively by cutting the coated part and viewing the cut microscopically. This technique commonly uses a scaled microscope to view

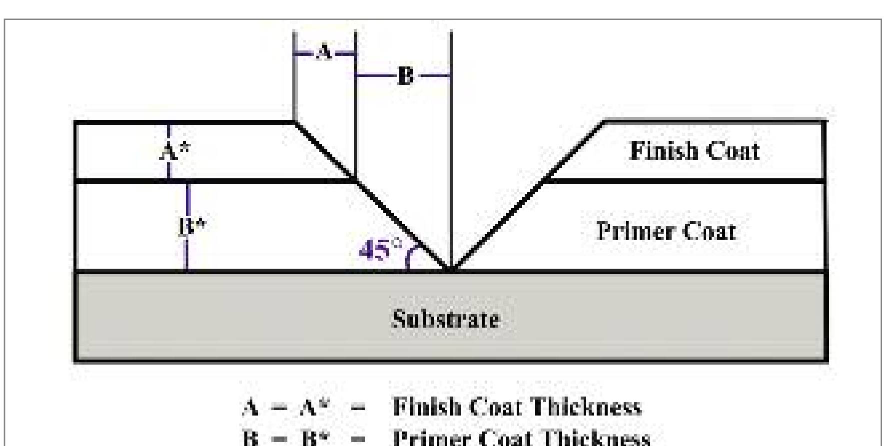


Figure 7

Cross-Sectional Coating Thickness Measurement

a geometric incision through the dry-film coating. A special cutting tool is used to make a small, precise V-groove through the coating and into the substrate (Fig.7). Instruments are available that come complete with cutting tips and illuminated scaled magnifier.

While the principles of this destructive method are easy to understand, there are opportunities for measuring error. It takes skill to prepare the sample and interpret the results. Adjusting the measurement reticule to a jagged or indistinct interface may create inaccuracies, particularly between different operators. This method is used when inexpensive, non-destructive methods are not possible, in some multiple layer applications, or as a way of confirming non-destructive results. ASTM D4138 outlines a standard method for this measurement method.

GRAVIMETRIC

By measuring the mass and area of the coating, thickness over the entire coated surface area can be determined. The simplest method is to weigh the part before and after coating. Once the mass and area have been determined, the thickness is calculated using the following equation:

$$T = \frac{m \times 10}{A \times d}$$

Where T is the thickness in microns, m is the mass of the coating in milligrams, A is the area tested in square centimeters, and d is the density in grams per cubic centimeter.

It is difficult to relate the mass of the coating to thickness when the substrate is rough or the coating uneven. Laboratories are best equipped to handle this time-consuming and often destructive method.

WET-FILM MEASUREMENT

Wet-film thickness gages help determine how much material to apply wet to achieve a specified dry-film thickness provided that the percent of solids by volume is known. They measure all types of wet organic coatings such as paint, varnish and lacquer on flat or curved smooth surfaces.

Measuring wet film thickness during application identifies the need for immediate correction and adjustment by the applicator. Correction of the film after it has dried or chemically cured requires costly extra labor time, may lead to contamination of the film, and may introduce problems of adhesion and integrity of the coating system.

The equations for determining the correct wet-film thickness (WFT), both with and without thinner, are as follows:

Without thinner:

$$WFT = \frac{\text{desired dry-film thickness}}{\text{\% of solids by volume}}$$

With thinner:

$$WFT = \frac{\text{desired dry-film thickness} \ / \ \text{\% of solids by volume}}{100\% + \text{\% of thinner added}}$$

Wet coatings are most often measured with a wet film comb or wheel. The wet-film comb is a flat aluminum, plastic or stainless steel plate with calibrated notches on the edge of each face. The gage is placed squarely and firmly onto the surface to be measured immediately after coating application and then removed. The wet-film thickness lies between the highest coated notch and the next uncoated notch. Notched gage measurements are neither accurate nor sensitive, but they are useful in determining approximate wet-film thickness of coatings on articles where size and shape prohibit the use of more precise methods such as described in ASTM D1212.

The gage should be used on smooth surfaces, free from irregularities and should be used along the length, not the width, of curved surfaces. Using a wet-film gage on quick-drying coatings will yield inaccurate measurements. ASTM D4414 outlines a standard practice for measurement of wet-film thickness by notch gages.

DRY POWDER MEASUREMENT

Powder coatings can be measured prior to curing with a simple hand-held comb, a modified magnetic gage, or an ultrasonic gage. A recently published ASTM D7378 practice describes these methods of coating powder measurement.

The inexpensive powder film comb (Fig.8) works much the same way as a wet film gage. The comb is dragged through the uncured powder and the thickness is considered to be a range value between the highest numbered tooth that made a mark and has powder clinging to it, and the next highest tooth that left no mark and has no powder clinging to it.

A special magnetic probe is available to achieve the same objective. Three pins integrated into the probe penetrate the coating powder down to the substrate. The probe tip touches slightly onto a pressure-reducing foil that is bent onto the powder coating.

Because both these gages produce a height measurement of the uncured coating powder, a reduction factor must be used to predict the cured powder thickness for each particular powder. This reduction factor is obtained by measuring the cured powder thickness at the same location where the uncured powder thickness measurement was taken. Marks left by both these gages may affect the characteristics of the cured film.

Finally, an ultrasonic device can be used non-destructively on uncured powder on smooth metal-

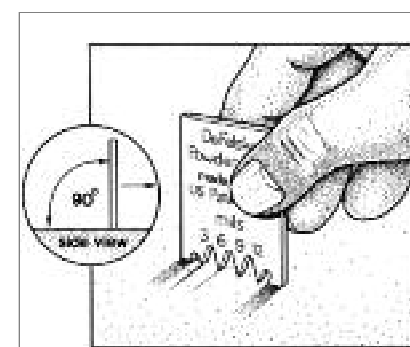


Figure 8

A powder coating comb.

lic surfaces to predict the thickness of the cured film. The user first makes a calibration adjustment to the instrument by measuring the cured powder thickness at the same location where the uncured powder thickness measurement was taken and aligns the gage readings with the cured coating readings. The probe is positioned a short distance from the surface to be measured and a reading is displayed on the LCD of the device.

SUMMARY

Accurately determining the thickness of coatings helps control costs and quality. Measurement of film thickness should therefore be a routine event for all coaters. A variety of recognized methods can be used and the selection decision should be based upon an understanding of the different technologies available. ■

David Beamish is general manager of DeFelsko Corporation, a New York-based manufacturer of hand-held coating test instruments. He has a degree in civil engineering and has more than 20 years' experience in the design, manufacture and marketing of these instruments.