FEATURE

Ultrasonic Thickness Measurement of UV-Cured Coatings on Rigid Substrates

By David Beamish

Handheld instruments can now measure coating thickness ultrasonically, making non-destructive testing available to industries using UV/EB curing technology. This article describes the working principle and benefits of ultrasonic testing.

Coating thickness gages that use ultrasonic measurement techniques are becoming increasingly popular in industries that work with rigid substrates, such as wood, plastic and composites. These instruments support or replace destructive methods for measuring the thickness of UV/EB-cured coatings greater than 15 microns (0.5 mil) thickness in a variety of industries, including automotive, aerospace, wood products manufacturing and industrial finishing.

FIGURE 1

A UV-cured coating on hickory

Coatings serve a variety of functions. Some are designed to resist scratching, abrasion, moisture and other chemicals. Some restore, protect, waterproof and beautify structures. Others are specifically formulated to seal and fill pores and to provide an aesthetically pleasing surface texture.

Why Measure Thickness?

Coatings are designed to perform their intended function best when applied within a tight thickness range as specified by the manufacturer. This ensures optimum product performance. Examples of situations where thickness measurement is important:

- Conversion varnishes are harder than other coatings and should not be used in excess of five mils dry thickness in order to prevent cracking or other finish failures.
- Nitrocellulose lacquer should usually be kept lower than three mils.
- UV cure primer surfaces on plastic should be between one and six mils before sanding.
- A consistent mil thickness is paramount when applying lacquer base coats.
- Stress becomes a problem in UV-cured adhesives applied too thick because cure happens so quickly that neither the adhesive nor the surface can equilibrate fast enough to prevent stress from occurring.

- On medium-density fiberboard (MDF), powder coating thickness typically ranges between three to nine mils. Usually the thicker the mil coverage, the more durable the finish. Factory specifications often call for a stated ±1 mil tolerance. This level of quality cannot be determined just by looking at it.

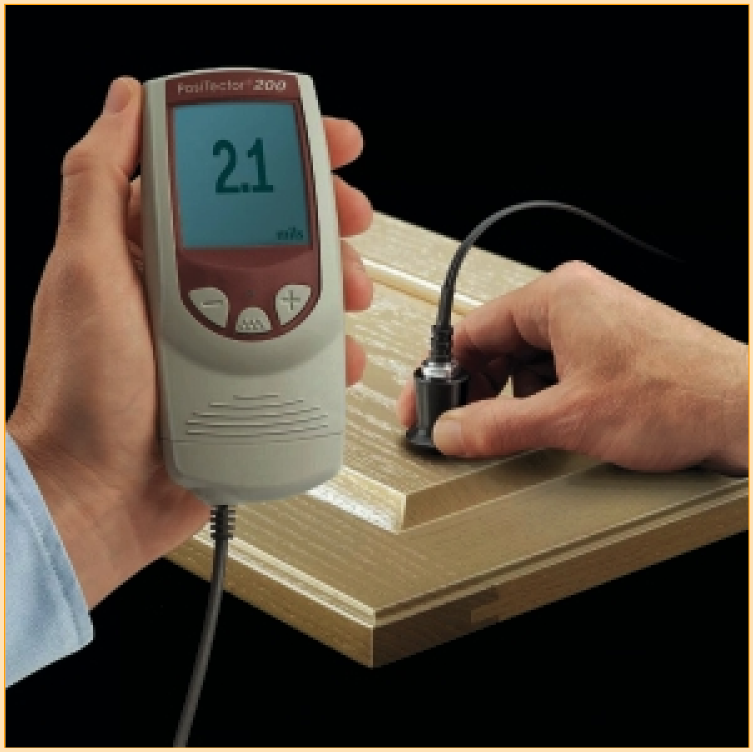
There are other benefits to precisely measuring finish thickness—whether to meet ISO, quality and customer requirements for process control or to control costs. When companies fail to check and verify coating quality of incoming material, they waste money reworking product. By checking their application equipment, they ensure the coating is being applied in compliance with the manufacturer's recommendations. Additionally, applying excessive film thickness risks the possibility of incomplete cure and can drastically reduce overall efficiency. Finally, regular testing can reduce the number of internal reworks and customer returns due to finishing defects.

How Best to Test?

Over metal, testing the thickness of coatings is commonplace for quality control and inspection purposes. When the base metal is carbon steel, a magnetic method is used. Eddy current devices are used for the other metals, such as copper and aluminum. Among these handheld instruments, there are many models to choose from. Some have the probe built in for easy one-handed measurement of large surfaces. Others have a small probe located at the end of a short cable to allow the operator to measure on small parts or on hard-to-reach areas. Many instruments have optional features to make the job of measurement easier, such as running average calculations and memory to download stored measurements to a printer or computer.

Figure 2

An ultrasonic, coating-thickness gage measuring coating thickness on wood cabinets



As popular as they are, however, magnetic and eddy current instruments cannot measure the thickness of finishes over non-metal substrates. Therefore, industries have been using alternate techniques to measure thickness, including:

- Optical cross-sectioning (cutting the coated part and viewing the cut microscopically).
- Height measurement (measuring before and after with a micrometer).
- Gravimetric (measuring the mass and area of the coating to calculate thickness).
- Dipping a wet film thickness gage into the uncured coating.
- Substitution (placing a steel coupon alongside the part and coating it at the same time).

These tests are time consuming, difficult to perform and are subject to operator interpretation and other measurement errors. Applicators find destructive methods impractical. To get a statistically representative sample, several products from a lot might need to be scrapped as part of the destructive testing process. The Gravimetric method will provide an average film build on the part, but will not provide a film thickness profile over specific areas.

With the arrival of ultrasonic instruments, many finishers have switched to non-destructive inspection for thick UV/EB-cured coatings.

Ultrasonic Breakthrough

Quality professionals are already familiar with various aspects of ultrasonic testing wherein high-frequency sound energy is used to conduct examinations and make

FIGURE 3

An ultrasonic gage measuring the individual layer thicknesses in a two-coat system

measurements. Ultrasonic testing can detect and evaluate flaws in metal, measure dimensions, ascertain material characterization and more.

Wall-thickness measurement is perhaps the most common and simple of ultrasonic tests. Precision ultrasonic wall-thickness gages permit quick thickness measurement of objects without requiring access to both sides. For coating measurement, however, these gages are not ideal. They do not have sufficient sensitivity to measure the thickness of acrylic fillers, factory primers, lacquers, UV finishes, powder coatings and other materials used over non-metal products.

The first handheld instrument designed specifically for coating thickness measurement appeared on the market 14 years ago and is now in its fourth generation. It uses a single-element transducer and advanced numerical techniques to filter and enhance digitized echoes. Today's handheld ultrasonic coating thickness gages are simple to operate, affordable and reliable (Figure 3).

A Sound Measurement 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 or perhaps a different coating layer. The vibration, partially reflected at this interface, travels back to the transducer. Meanwhile, a portion of the transmitted vibration continues to travel beyond that interface and experiences further reflections at any material interfaces it encounters (Figure 4).

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 multilayer 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.

Measurement Accuracy

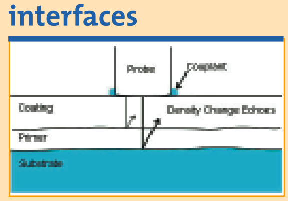
The accuracy of any ultrasonic measurement directly corresponds to the sound velocity of the finish being measured. Because ultrasonic instruments measure the transit time of an ultrasonic pulse, they must be calibrated for the "speed of sound" in that particular material.

From a practical standpoint, sound velocity values do not vary greatly among UV/EB coating materials. Therefore, ultrasonic coating thickness gages usually require no adjustment to factory calibration settings.

Ultrasonic coating thickness measurement is now an accepted and

FIGURE 4

Ultrasonic vibrations reflect off coating interfaces



reliable testing routine for UV/EB-cured coatings. To verify gage calibration, epoxy-coated thickness standards are available with certification traceable to national standards organizations.

Where the Coating Meets the Substrate

A factor influencing the accuracy and repeatability of ultrasonic measurement is how these coatings interface with the substrate. Wood products, for example, can have both smooth and rough surfaces on which to test coating thickness. Figure 5 shows an example of coated wood. This photo, taken at higher resolution than most field destructive tests are capable of, shows the boundary between the finish and the wood. The finish coating may look smooth on top, but thickness may be inconsistent. Wood substrates often are grainy with varying degrees of surface roughness and primer penetration. Such porosity and roughness may promote adhesion but they increase the difficulty of attaining repeatable thickness measurements by any means.

Ultrasonic gages are designed to average small irregularities to produce a meaningful result. On particularly rough surfaces or substrates where individual readings may not seem repeatable, comparing a series of averaged results often provides acceptable repeatability.

A Final Echo

A standard test method for this technology is described in ASTM D6132-04 "Standard Test Method for Nondestructive Measurement of Dry Film Thickness of Applied Organic Coatings Using an Ultrasonic Gage" (2004, ASTM). In a recent effort to update this standard, eight companies completed a round-robin study in which a variety of coated wood panels were measured ultrasonically. Panels included UV-cured coatings on hickory and maple. Results, which will be published later this year, show good repeatability and reproducibility with small standard deviations.

Quick, non-destructive thickness measurements can now be taken on materials that previously required destructive testing, lab analysis or expensive non-destructive equipment.

This new technology improves consistency and throughput in the finishing room. Potential cost reductions include:

- Minimizing waste from overcoating by controlling the thickness of the coating being applied.
- Minimizing rework and repair through direct feedback to the operator and improved process control.
- Eliminating the need to destroy or repair objects by taking destructive coating thickness measurements.

Today, these instruments are simple to operate, affordable and reliable.

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FIGURE 5

High-powered magnification reveals surface roughness of both the coating and the wood substrate

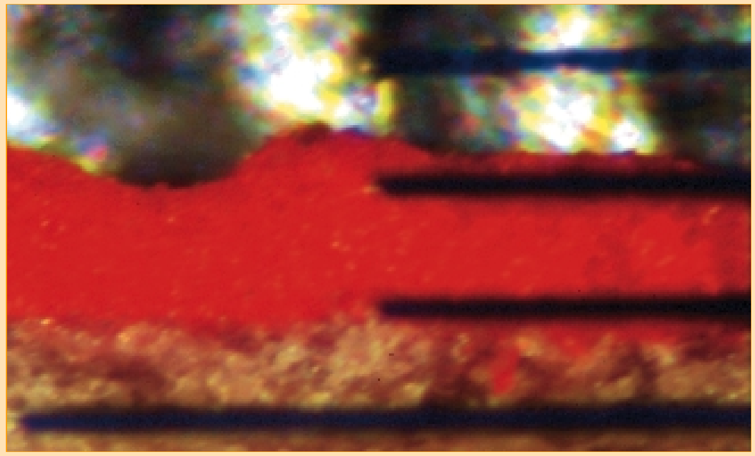
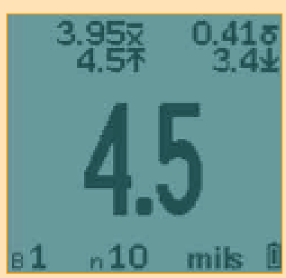


FIGURE 6



Some instruments provide statistical analysis. In this example, 10 measurements have been taken. The last measurement of 4.5 mils is displayed along with the average, standard deviation and max/min values of all 10 readings.