

In-Process Measurement of Organic Coating Thickness Using a Full-Spectrum Infrared Sensor

Coil coaters have tried on-line measurement techniques in the past to eliminate costly time delays between obtaining off-line lab information and making changes to the process to improve coat weight uniformity. Challenges with variations in the metal surface finish, volume/weight solids of paint, specific gravity of paint and the pigment/binder ratio of the paint have limited the success of earlier measurement techniques. Technology now exists that addresses the limitations and provides reliable measurement of organic coating thickness in real time. This measurement information can be used to control the primer and paint coating heads to improve coating uniformity, reduce paint usage and eliminate scrap/rework.

Introduction

Sheet steel is used in every aspect of our lives, from the cars we drive, to the buildings we work and live in, to the containers that hold and transport our food. With its strength and flexibility, it is the ideal material for so many applications. It can be recycled over and over again, helping to reduce landfill waste. One of the only negative properties of steel is that it corrodes, or rusts. To prevent corrosion, sheet steel producers use metallic (zinc, tin) and non-metallic (paint, acrylics) coatings. These coatings, when properly applied, improve the lifetime of the end product and add to its aesthetic quality. The coating material and the application process can be expensive, so coating weight instruments are used to verify that the thickness meets customer requirements but does not exceed them to the point of wasting material. Often these instruments are located in quality control laboratories near the line. However, this is not the ideal location, as the measurement takes place after the product is made, and any required changes to the process variables are made minutes or hours later. When deficiencies are discovered, entire coils must be scrapped or downgraded, and new coils produced. The ideal location for a coating weight instrument is on-line, where it can scan across the entire strip, head to tail, and provide reliable feedback to the coating line operators.

The on-line environment brings its own challenges, as the sensor must be non-contact, fast and insensitive to environmental changes.

Technology that provides reliable measurement of organic coating thickness in real time now exists. This measurement information can be used to control the primer and paint coating heads to improve coating uniformity, reduce paint usage and eliminate scrap/rework.

On-Line Measurements

When a manufacturing system has the benefit of independent sensors providing feedback on the product outcome, process engineers can tune process variables to optimize raw material, energy consumption and yield. In the typical coil coating application (Figure 1), the logical location for a coating sensor is directly after the process or at the cooling zone directly after the ovens. One of the first practical considerations in selecting a sensor is that it must be non-contact. The coating applied has a primary job to inhibit corrosion, but in many cases its secondary task, aesthetic appeal, is equally important. If the sensor touches the strip at all, it would make marks, and the product would lose much of its appeal to consumers.

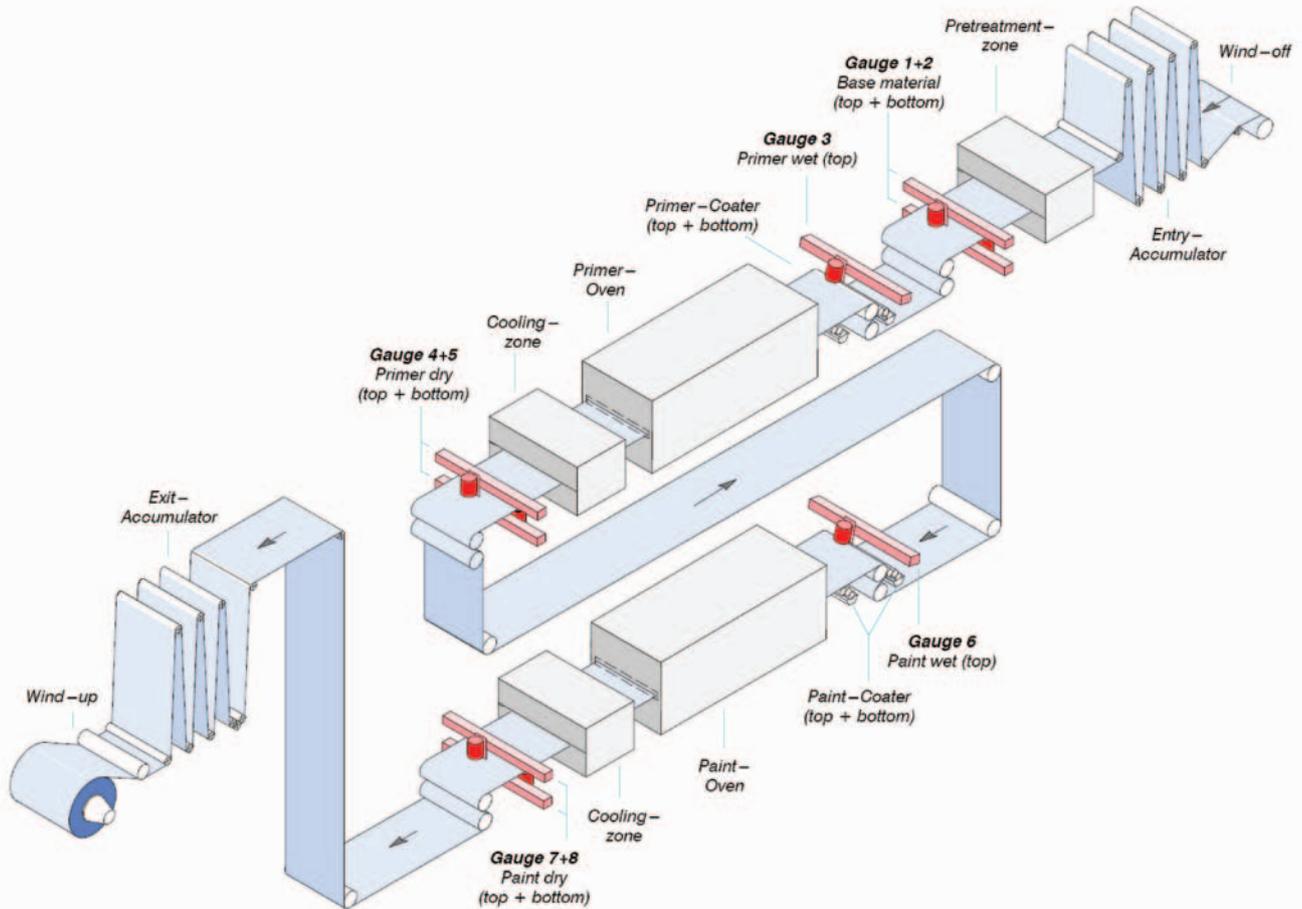
Sensor Overview: Radiation Sensors, Beta Backscatter — Radiation gauges are well-established as non-contact sensors in the flat metal production process. The use of beta radiation to measure organic coatings dates back more than 50 years. With the advent of computer data storage, beta backscatter coating gauges have produced measurement results on both primer and finish coatings that rival off-line testing. The sensor technology is possible thanks to the physical property that beta particles

Authors

Christopher Burnett (left), technical product manager, Thermo Fisher Scientific, Mount Airy, Md. (christopher.burnett@thermofisher.com); **Andreas Quick** (center), R&D manager — gauging, and **Bernd Harand** (right), measurement engineering, Thermo Fisher Scientific, Erlangen, Germany (andreas.quick@thermofisher.com, bernd.harand@thermofisher.com)



Figure 1



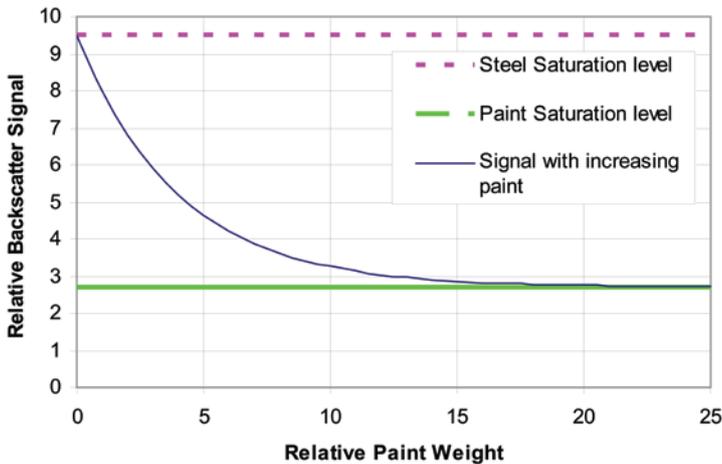
Typical coil coating line.

are scattered differently based on the atomic number (or average atomic number) of the scattering media. Generally, the higher the atomic number, the more scattered beta particles will be detected. In the case of paint on steel, the steel scatters about three times the amount of beta particles that an “infinite” thickness of paint

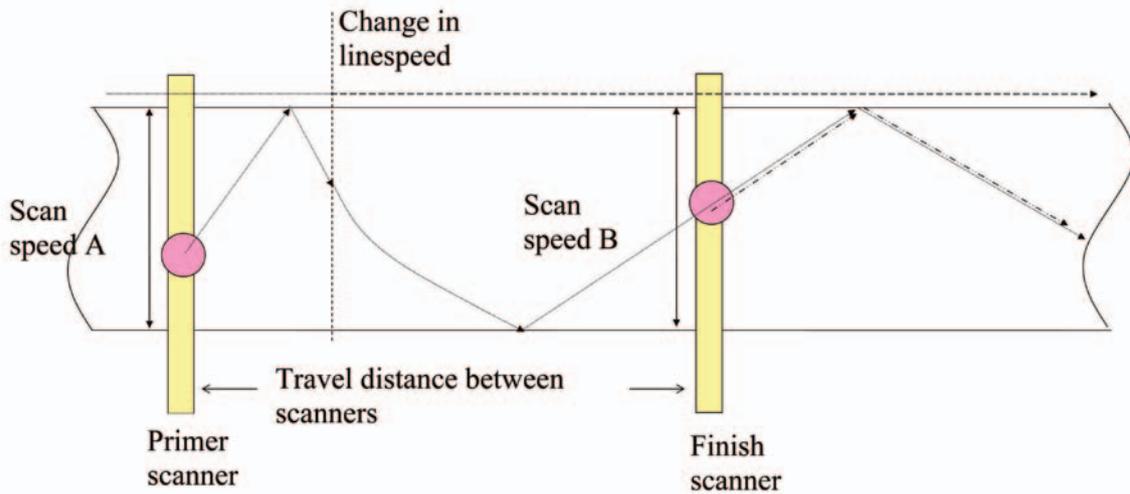
would scatter. Therefore, as paint is applied, the signal would drop (Figure 2). The rate of change for the signal drop may differ based on the coating composition, but the raw measurement can be compensated to most paint types by the use of a simple multiplier.

Promethium-147 and Krypton-85 are the two practical radioisotopes used for on-line paint measurement. They both have sufficient half-lives to provide a useful measurement for years. Promethium has a much lower energy and is used primarily on very thin coatings. Krypton-85 has a higher energy, and a longer half-life is more common. The measurement technology is best employed when measuring a single coating layer. As subsequent layers are added, the measurement from the previous sensor is used as a reference. In order to properly correct for any variations in the substrate and primer layer, precise head positioning from one measuring point to the next is essential. A multi-scanner system requires motion control software known as “same spot” to manage the scanning. Process parameters, including accurate line speed and exact travel distance between scanners, govern when each sensor begins its scan and at what cross-strip scan speed (Figure 3). Off-line, post-process analysis of coating thickness has seen measurable coating variations over distances on the order of 1 m or less, so the

Figure 2



Relative paint signal levels with bare steel, maximum paint and increasing paint.

Figure 3

Overview of “same spot” scanning routine.

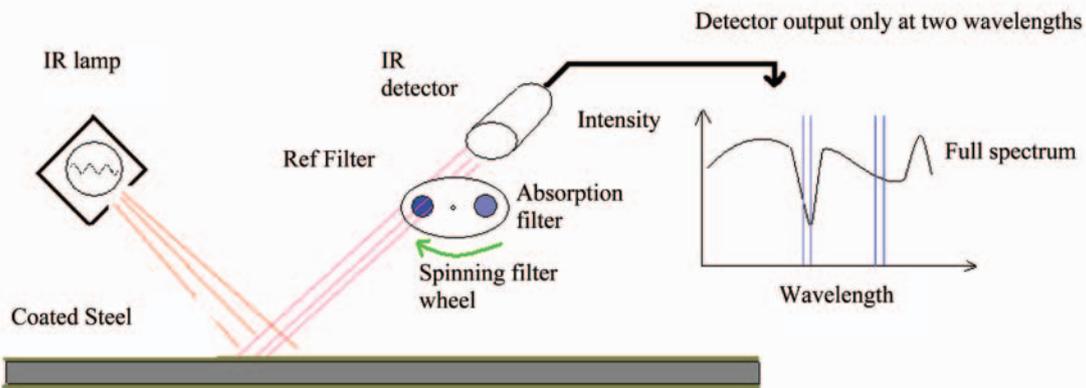
same-spot software must be accurate to less than 50 mm. Additional challenges arise from changes in air temperature and pressure, which influence the sensor measurement but can be compensated. Finally, the distance between the metal surface and the sensor must be carefully maintained, as passline changes of ± 1 mm can cause measurable changes in sensor output.

Overall, the use of beta backscatter is well-established. The technology provides an accurate measurement of coating thickness and has proved itself a valuable tool in quality control and documented material savings for process engineers.

Sensor Overview: Standard, Two-Wavelength Infrared — Another common method to measure non-metallic coatings is with infrared (IR) light. Just below the energy of visible light, IR light is defined as light with wavelengths between 0.7 and 1,000 microns. Subdivided into three sections based on wavelength, IR light has many practical applications outside of the coil coating line. Coil coaters use light primarily in the near-IR range to take advantage of the fact that the molecular bonds of most hydrocarbons absorb specific wavelengths of infrared light. By positioning an IR light source and detector

on the same side of the coated product, a system of optics can be used to measure the intensity of a specific wavelength of reflected light relative to a reference wavelength. By comparing the ratio of the two intensities, a relative measurement of the coating thickness can be made. In general terms, the thicker the coating, the more absorption will occur at the measured wavelength and the larger the observed ratio.

Two methods have been developed into practical on-line IR sensors. The first is interferometry. It provides a tight window for the measured and reference wavelengths, but it tends to be expensive and sensitive to light-scattering pigments and mechanical shock. The second approach is to use a spinning filter wheel that exposes a single detector to alternating wavelengths of light (Figure 4). The primary filter on the wheel is selected based on the coating type to be measured, while the second filter passes the reference wavelength. Both methods have the benefit of reduced sensitivity to passline, and both are virtually unaffected by changes in air pressure or temperature. There are limitations to their effectiveness, as the measurement can be influenced by spectral changes coming from variations in the surface finish of the substrate or moisture in the air or

Figure 4

General arrangement of two-wavelength IR sensor.

Figure 5



Thermo Scientific RM 320 FSIR measuring head.

the coating. Additionally, in the case of the filter wheel, the operator must physically change the wheel to measure paint compositions that are dramatically different from the standard filter.

In summary, the standard IR sensor can be a practical on-line measuring instrument for coil coaters that produce the identical product repeatedly in their production schedule.

Sensor Overview: Full-Spectrum Infrared — For those production situations that involve multiple coating types, the most appropriate sensor is one that measures the full spectrum of infrared light (FSIR). Configured to measure wavelengths associated with an entire range of hydrocarbon bonds, a FSIR sensor can accurately measure coating weights for nearly every type of paint. A proprietary sensor design eliminates background interference due to air temperature changes between the sensor and the strip, background light variations and sheet flutter. As an added benefit over the filter wheel design, there are no moving parts, therefore increasing the overall reliability (Figure 5).

The sensor response is virtually immune to variations in passline, maintaining accurate measurements over a span of ± 8 mm (Figure 6). The intensity of the incident IR lamp will vary by a factor of 3 across this range, but by considering the relative absorption of wavelengths across the whole spectrum, the system is still able to provide accurate measurements.

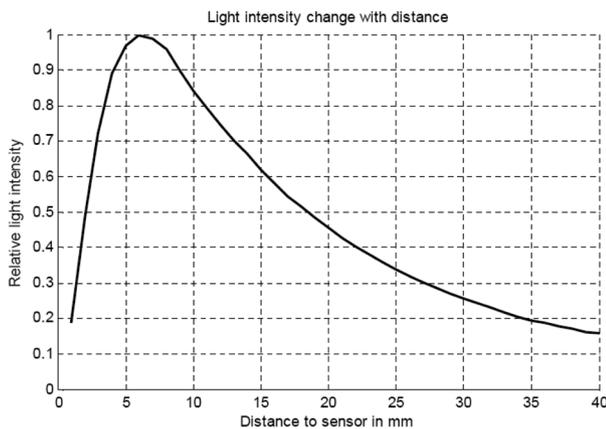
By collecting the signals over a complete spectrum of wavelengths, the calibration process results in a measurement that is independent of colorant/additive effects, moisture changes and substrate effects. While each of those factors influences the spectrum in different ways, the FSIR breaks the spectrum into its constituent elements, extracting the coating weight portion, and calculates a measured thickness (Figure 7). Additionally, in some applications, the sensor can simultaneously measure the thickness of the primer layer.

Since various government health agencies have eliminated the use of hexavalent chromium in industry, coated steel producers have researched a number of chrome-free options to passivate the metal. Several of these alternatives include suspending metal powder or flakes in an acrylic binder (Figure 8). For these coating types, the beta backscatter measurement approach is unable to sense the coating, as the relative atomic number of the coating is now much closer to the atomic number of the substrate. In these applications, the only practical choice is the FSIR sensor. The full spectrum, as compared to the two-wavelength IR approach, is able to measure the coating without the influence of the normal spangle variations in the zinc coatings. As the light intensity varies across the spangle, the two-wavelength IR sensor would falsely interpret that as a coating change, whereas the FSIR monitors the influence on the entire spectrum and ignores the effect.

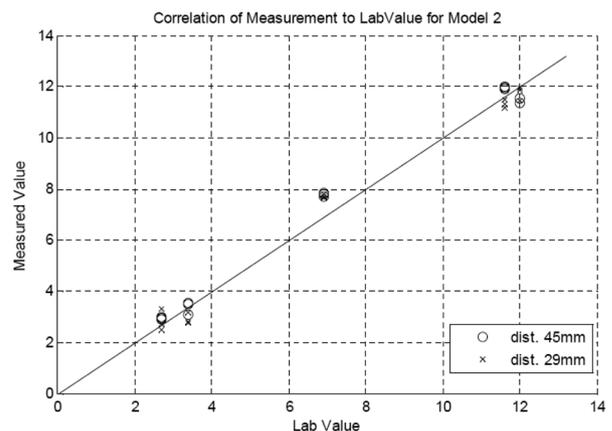
Potential Savings

The projected cost savings from the FSIR sensor are significant. Aside from the intangible benefits of brand

Figure 6



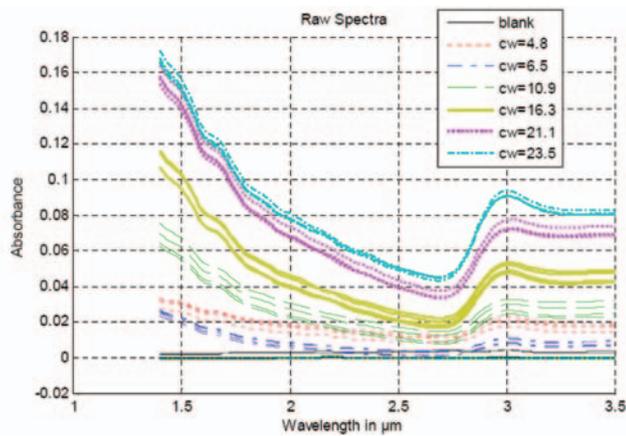
(a)



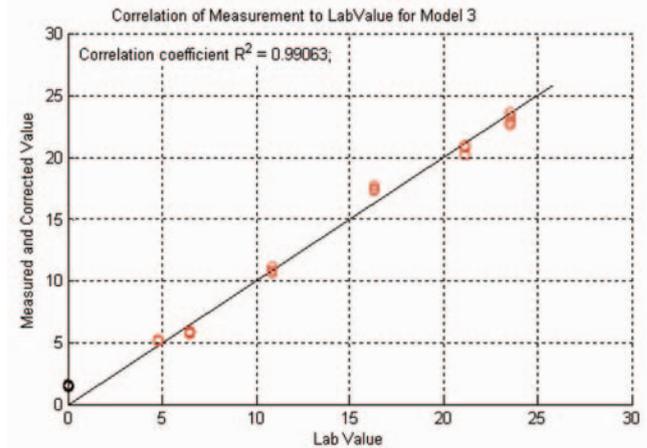
(b)

(a) IR light intensity as a function of sample position, and (b) accuracy at 29 mm and 45 mm high.

Figure 7



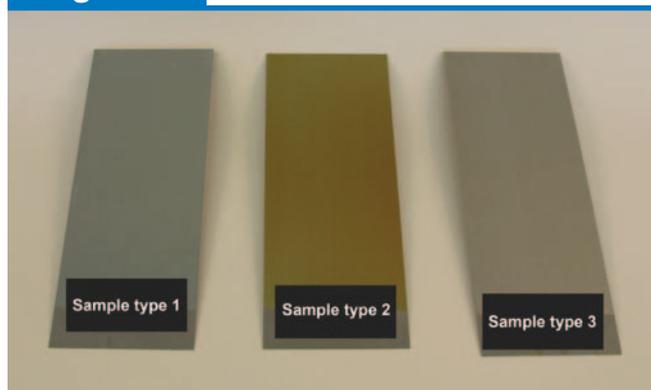
(a)



(b)

(a) Typical FSIR spectrum reading for multiple samples, and (b) predicted FSIR versus actual lab measurements.

Figure 8



Hexavalent chrome-free coated samples.

protection and customer retention, there are measurable benefits in the form of reduced head-end scrap, reduction in coating consumption, elimination of rework/re-rolling and substrate savings.

For those coil coaters without an on-line sensor, the payback is substantial (Table 1). These figures do not include the time saved when rolling a new coating type or color. The sensor includes a recording feature where the measurement is provided using a calibration from an older coating, but the raw spectra are stored in a data file that can be used later to make a calibration for the new coating type. In other systems, the new product would be rolled and then samples cut for off-line analysis. Older systems would then need to be pulled off-line to have these samples measured in the garage position, thereby preventing the system from being used to measure current production.

Table 1

Projected Cost Savings When Using On-Line Sensors

Benefit area	Conservative	Probable	Potential
Scrap reduction	0.27%	0.45%	0.75%
Reduced paint scrap	\$59,130	\$99,658	\$166,067
Reduced rework time	\$112,641	\$189,844	\$316,406
Reduced rework metal	\$72,090	\$121,500	\$202,500
Possible savings (annual)	\$243,861	\$411,002	\$684,973

Summary

On-line measurement of paint, acrylic and other non-metallic coatings is becoming essential as coil coaters work to eliminate costly delays in their process, save raw materials, reduce rework and improve product quality. Environmental and product changes, including air temperature changes and variations in metal surface finish, reduce the list of measurement sensors to consider. The full-spectrum infrared (FSIR) technology addresses the external influences and provides reliable measurements for organic coating thickness in real time. This results in significant savings associated with improved coating uniformity, reduced paint usage and elimination of scrap/rework. ♦

This paper was presented at AISTech 2010 — The Iron & Steel Technology Conference and Exposition, Pittsburgh, Pa., and published in the Conference Proceedings.



Did you find this article to be of significant relevance to the advancement of steel technology? If so, please consider nominating it for the AIST Hunt-Kelly Outstanding Paper Award at AIST.org/huntkelly.