Advances in On-Line Measurement and Control for Optimizing Coating and Converting Applications

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Abstract

The accurate control of various critical dimensional properties of paper, film, and foil during production has become increasingly important to converters. Manufacturers across the globe have widely adopted non-nuclear measurement technologies such as Near Infra-Red in preference to Beta, Gamma, and X-Ray for a variety of production applications including the measurement and control of coat weight, coating thickness, lamination, and moisture. In conjunction with these methods, manufacturers are also implementing non-contact laser technology to precisely measure the length and speed of products. This paper reveals how these proven technologies work, how they are widely replacing error-prone gauging methods, and enabling manufacturers to increase productivity, improve quality, and realize significant production savings.

Why Gauging?

In today's competitive environment, Coat Weight and Length and Speed measurements are critical. With a properly selected and applied gauging system, you can reduce or eliminate:

- Quality issues (30 - 70% variability reduction)
- Off-grade product
- Material usage (2 to 5% typical)
- Energy Usage
- Drying / Curing time
- Scrap
- Lost machine time
- Customer returns

Investing in a properly designed gauging system can put you several steps ahead of your competition in both the quality of product that you provide to your customers and the cost for you to provide it.

Defining the Need

Before you can select the correct gauging system, first define which product parameters you need to measure to satisfy your customers and meet their end-use requirements. Do you need to reduce waste, such as start-up, edge trim, rejects, etc.? Is your need to improve quality, such as roll structure, flatness, edge structure, curl, gauge bands, adhesion, etc.? Is uniform and correct coat weight or moisture critical? These factors are important because they determine which parameters must be measured. For example, if roll structure and gauge bands are your primary concerns, then perhaps you don't need to measure coat weight, but rather total weight measurement with an emphasis on CD profile resolution, which infers a unique gauging system configuration.

This thought process leads logically to question which parameters must be measured by the gauging system: Coating weight? Substrate weight? Substrate moisture? Total product weight? Length and speed?

Beyond this, it is important to define the quality of measurement required. This includes issues such as gauge accuracy, CD resolution, insensitivity to the environment, and insensitivity to coating or substrate formulation. If the gauge is to be used by your operators, it must be repeatable, believable, and of adequate speed to get on spec quickly. For example, on extrusion or slot die coaters, CD resolution is critical to provide adequate profile detail for manual or automatic die adjustment.

Sensor Types and Configurations for Web Gauging

Two primary parameters dictate the function of a gauging sensor: the energy source used (e.g. infrared, x-ray, gamma radiation, laser, etc.) and whether the sensor is configured in transmission or backscatter mode. In a transmission configuration, the energy source is placed on one side of the web, the energy interacts with the web, and then a detector on the other side of the web receives and converts the remaining transmitted energy into information used to calculate the measured parameter (thickness, moisture, etc.). In a backscatter configuration, the energy source and detector are placed on the same side of the web; the energy interacts with the web, and then the detector receives and converts the backscattered energy into information used to calculate the measured parameter.

Figure 1. Beta Transmission Sensor ***Figure 2. X-Ray Backscatter Sensor***

Which is better: transmission or backscatter? It depends on what your needs are. Transmission sensors are generally more precise and have better resolution because they have better signal-to-noise ratio and can be focused to measure a smaller spot on the web. However, the sensor is slightly more expensive, and must be kept in near-perfect register in order to prevent measurement errors. This means that to scan a transmission sensor requires a rugged robust scanner called an O-frame to keep the sensor’s emitter and detector in register as the pair moves across the web. This adds significant cost and installation space. A backscatter sensor requires only a single beam scanner to traverse the web, making it easier to install and fit, and more cost-effective.

Typical transmission gauge advantages include higher accuracy and resolution, faster response, and better edge measurement. Typical backscatter gauge advantages include lower cost (sensor and scanner cheaper), requires less space, and no issues with head alignment.

To Scan or not to Scan?

Another question that needs answering is whether the measurement sensors can be left fixed in place, or whether they should be placed on a scanner and scan across the whole web. A scanning sensor offers the advantages of seeing the whole cross-web profile, not just one or two points of the web. This gives a far more accurate representation of profile. On slot die coaters, a scanning system is highly recommended. To measure moisture, or to measure the coating on a blade or roll coater, one or two static sensors may suffice.

As mentioned earlier, there are two common scanner types: the O-Frame, which supports transmission sensors, and the single-beam scanner that only supports backscatter sensors. See Figures 3 and 4.

Figure 3. Typical O-Frame scanner

Figure 4. Typical single-beam scanner

The O-frame is a higher cost scanner that can sometimes be difficult to fit on small lines. It has a small chance of being susceptible to alignment issues. But if high measurement performance is required, it may be needed. A single-beam scanner is lower cost, and more easily fits in tight spaces. It also has no issues with sensor alignment as the backscatter sensor is a single self-contained unit. However, backscatter sensors tend to deliver less precise measurements.

Two Types of Measurement Capabilities: Selective and Total Weight

Depending on the type of energy source used, a measurement sensor may only be able to provide a reading of the total mass in the sensor gap. Other energy sources can provide a greater detail of information. For example, an infrared gauge is able to measure preferential absorptions at specific wavelengths, allowing it to make what we call “selective measurements”. This is accomplished by providing the gauge with special filters that monitor energy at the wavelengths where energy is preferentially absorbed by the material we want to measure. For example in Figure 5 to measure the weight of the PE, we could use filters at 2.32 microns wavelength, and to measure the water-based coating, we could monitor energy absorption at 1.45 microns wavelength. This gives infrared unique advantages for measuring both coating weight and substrate moisture with a single sensor / scanner. And the infrared measurement is usually more accurate, costs less to implement, and does not employ ionizing radiation.

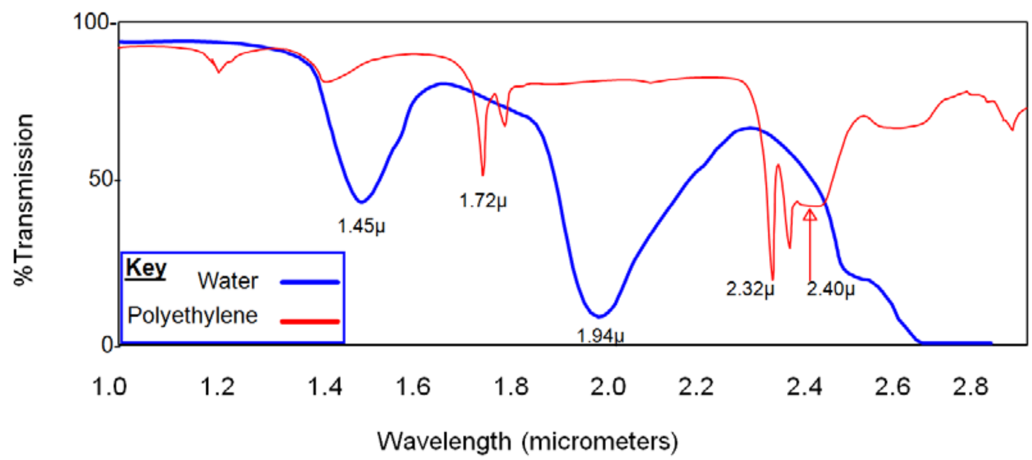

Figure 5. A single infrared sensor can measure both the PE substrate thickness and the water-based coating weight

The following provides typical IR backscatter gauge performance for coating applications.

- Moisture: Range: 0 – 90% moisture; Accuracy: 0.1%
- Coating Weight: Range: 0 – 1000 gsm; Accuracy: 0.1 gsm

Note that these values are product / substrate dependent.

With infrared, measuring the solvent/water can accurately infer coating weight, assuming that the solids content in the solution is accurately controlled.

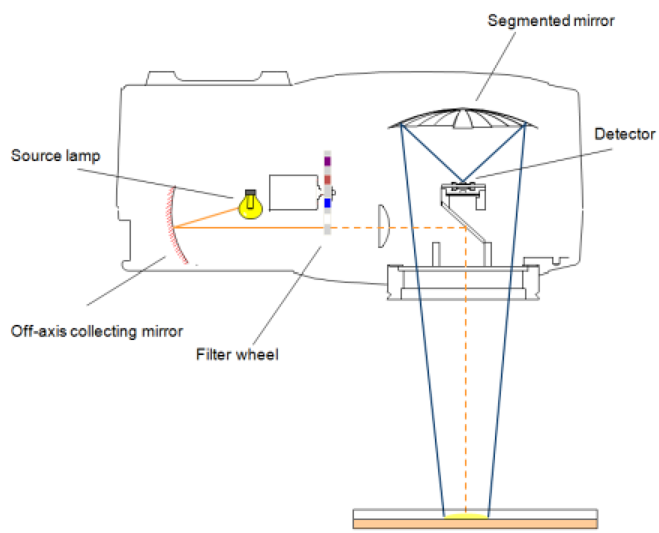

Figure 6. IR backscatter gauge schematic. IR light source is focused onto a spinning filter wheel that allows pulses of light through at specific wavelengths. These light pulses interact with the web, where the energy is preferentially absorbed. The detector converts the remaining light energy to a useable signal for data processing.

Challenges with Infrared Measurement

The substrate being coated will directly affect the behavior of the Infrared signal. As show in Figure 7, there are three types of IR energy behavior when interacting with various substrate types: direct transmission (clear substrates), scattering reflection or diffusion (diffusive substrates), and direct or specular reflection (shiny substrates).

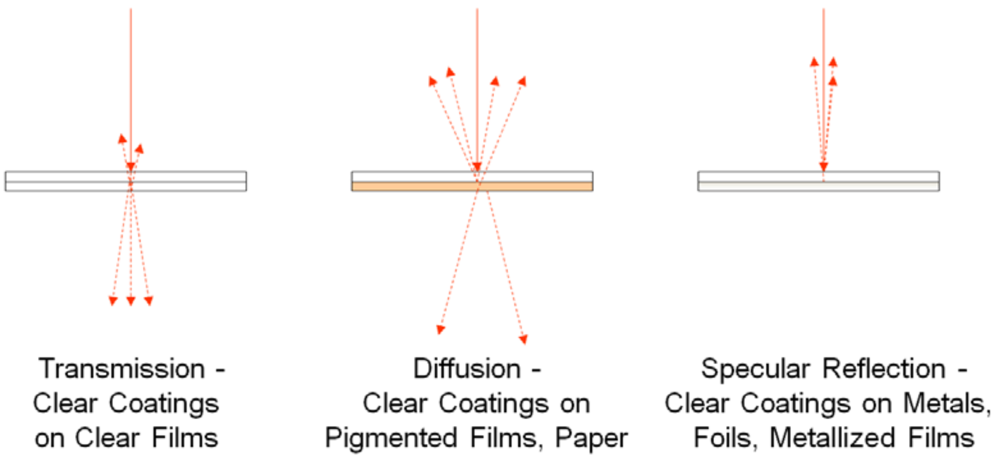

Figure 7. Types of IR energy behavior on substrates

When employing multiple substrate types with an infrared backscatter gauge, one can use a diffuse or passive reflector. A diffuse reflector will backscatter the IR light when clear substrates are used, enabling measurement of coating and film. With diffusive substrates like paper, the reflector will remain passive and have no effect.

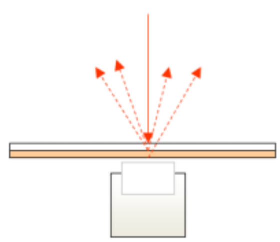

Figure 8. Example of diffuse or passive reflector

When trying to use infrared to measure thin organic coatings applied to foil or metalized film substrates, a phenomenon called optical interference can occur. This can create significant errors in the gauge's reported coating weight. Special IR gauge designs that provide optical interference suppression are available and should be employed if shiny foil-type substrates are processed a significant percentage of the time.

For some applications, IR measurement is not possible. For example, IR cannot measure opaque coatings. IR may also have issues when the substrate and coating are similar in composition. There is also the possibility that no absorption band is available that measures just the coating. In these situations, a differential measurement may be the only solution.

Total Weight Gauges

Most gauges are what we call total weight gauges. They measure the total amount of "stuff" in the measurement gap. This includes Beta transmission, Gamma backscatter, and X-Ray transmission and backscatter sensors. For these sensors, determining coat weight requires a differential measurement: the first sensor, located prior to the coating station, measures the weight of the base stock; then a second sensor, mounted after the coating station, measures the total weight of coating plus substrate. Special software subtracts the two readings and "nets out" the coating weight. This requires at least two sensors / scanners, and hence is normally a more expensive solution.

Here are some well-accepted total weight sensor technologies that are commonly used to make coating weight measurements on coating lines by subtraction:

Gamma Backscatter (GBS) Sensor

- Small and simple in design (see Figure 9)
- Weighs only 1 Kg and is the size of a flashlight
- Very accurate; insensitive to material composition
- Wide measurement range (up to 25000 gsm)
- Uses a low-cost, single-beam scanner
- Can be used in a static position
- Typical repeatability of 0.5%

Figure 9. GBS sensor

Beta Transmission Sensor

- Common Beta isotopes: Pm-147, Kr-85 and Sr-90
- Pm-147 upper measurement limit of 150 gsm
- Kr-85 operating range of 15 to 1200 gsm
- Sr-90 suitable for thick products (100 – 5500 gsm)
- Beta gauges require frequent standardization
- Some sensitivity to composition
- Typical repeatability is 0.15% with an accuracy of 0.25%.

Figure 10. Beta sensor

X-Ray Transmission

- Non-nuclear; but still emits ionizing radiation
- Requires a larger size sensor
- Requires frequent standardization
- Measurement range can be quite wide
    - 5 Kev device – up to 1000 gsm
    - With higher voltage tubes, the range increases and can exceed 10,000 gsm

- Typical repeatability of 0.1gsm
- Excellent spatial resolution; relative insensitivity to head alignment and sheet flutter
- Highly sensitive to composition variation, particularly any presence of mineral / metal additives, like TiO_2 or $CaCO_3$ or aluminum foil
- This sensor requires careful consideration before being employed on a coating line

X-Ray Backscatter (XRB)

- Total mass measurement gauge (see Figure 12)
- Single-sided measurement; emits ionizing radiation in use
- Range of 10 – 25000 gsm
- Less sensitivity to composition than XRT
- Typical repeatability is 0.3 to 0.4%
- Larger spot size than Beta or XRT gaug

Figure 12. XRB sensor

Calculating Potential Coat Weight Error with Differential Measurement

One problem with a differential (subtractive) gauge approach: the accuracy is a root mean squared (RMS) function of the total mass measured by each gauge, meaning that the differential technique is normally only viable when coat weight is a significant percentage of base weight. Otherwise, cumulative errors render this gauging approach useless. The heavier the substrate, or the lighter the coating, the more significant the gauge reading error becomes. Here's an example calculation of the potential error with a differential measurement, using beta gauges with 0.25% accuracy:

- Substrate = 100 gsm
- Coating = 3 gsm
- Coat error = $\sqrt{(100 * .0025)^2 + (103 * .0025)^2}$
- Coat error = $\sqrt{(0.0625\ +\ 0.0663)}$
- Coat weight error = 0.36 gsm or **12%** (0.36 gsm on 3 gsm)

An industry rule of thumb regarding differential gauging systems: for acceptable coat weight accuracy with differential gauging systems, the coating weight must be at least 10% of the substrate weight.

Other Challenges with a Differential Gauging Technique

Same Spot

One consideration is that the substrate has basis weight variation; this can be significant. We need to prevent this variability from creating coat weight measurement errors. The accepted solution is to provide accurate "Same Spot" measurement so that both sensors are synchronized to see the same area of base material when making the associated coat weight measurement (see Figure 13). The best Same Spot measurement solution is length driven, not speed driven. Early same spot designs assumed a constant machine speed, and knowing the distance between scanners, simply counted off a clock before launching the second scanner. Today, same spot algorithms are more sophisticated, with digital servo's tracking the scanner speeds to maintain a constant ratio to line speed, and using a distance based launch scheme with high resolution encoders to precisely map the two scanner paths independent of changes in machine speed.

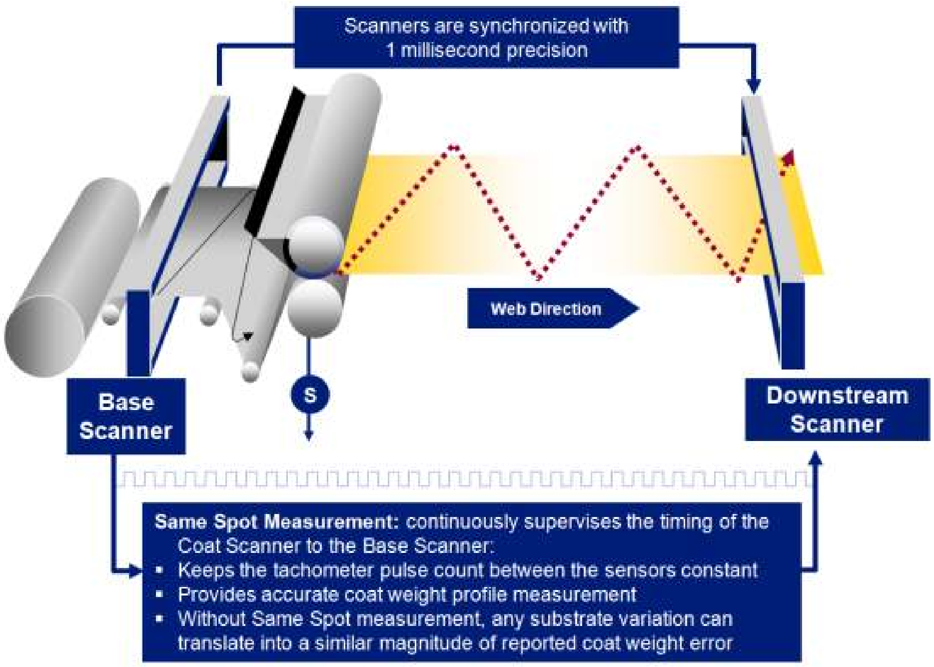

Figure 13 – Same Spot Measurement logic

Non-Contact Laser Technology for Accurately Measuring Length and Speed

Over the years, the non-contact laser measurement technique has gained wider acceptance in a broad spectrum of industries, including converting. It uses a long-established non-contact Laser Doppler Velocimetry (LDV) technology to provide highly accurate and repeatable product length and speed measurements (see Figure 14). This method eliminates the length and speed measurement errors associated with mechanical contact types of encoders. Because of the unique LDV technology, the non-contact laser gauges can measure the length and speed of products with better than +/-0.05% accuracy and +/-0.02% repeatability.

Figure 14. Non-contact laser measurements are performed optically, so there are no moving parts to wear out and need for calibration

How Non-Contact Laser Measurement Works

The non-contact laser gauge projects a unique pattern on the surface of the surface of the product to be measured (see figure 15 on the next page). This pattern is created when the two laser light beams that exit the gauge converge and overlap at a specific distance called the "standoff" distance. The intersection of the two beams creates a measurement region referred to as the "depth of field." As the product moves through the depth of field, light is scattered back to the gauge at a frequency proportional to the speed of the material. The frequency is measured and converted to velocity and pulses are generated at a rate proportional to the speed. External counters or PLCs count the pulse to determine product length.

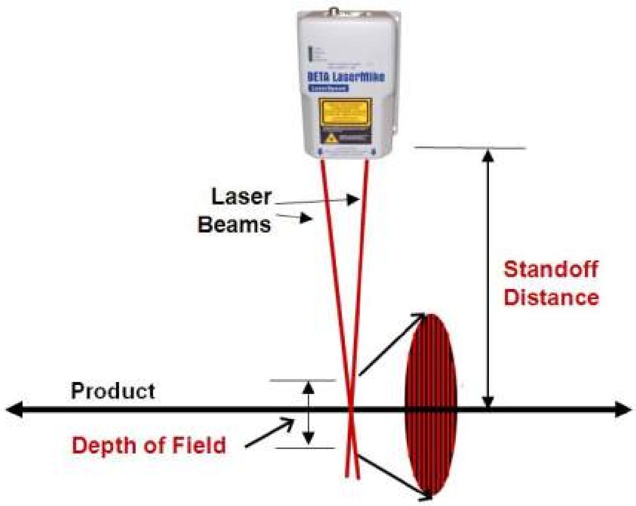

Figure 15. Non-contact gauge uses a dual-beam laser technology to measure product velocity and length

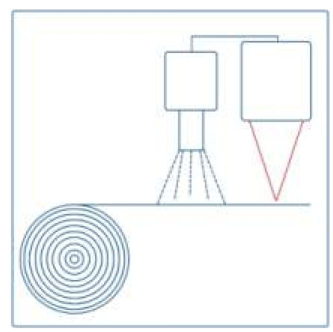

Figure 16. Coating control

Typical Length and Speed Measurement Applications

Continuous Length / Coating & Lamination / Stretch & Draw

Manufacturers of paper, film and foil products have applications where they need to control the length and speed of products in applications such as continuous length measurements at unwind and rewind/slitter stations, controlling coating and lamination processes and maintaining product thickness during stretch/draw operations. Most manufacturers depend on the accuracy of their drive speeds or contact encoders. Products typically exhibit a certain amount of slipping on the drive roller based on texture, product composition, or changes in tension at certain points on the line. A contact encoder on the drive roller attached to the drive roller exhibits the same problems. A contact encoder riding on the product reveals wheel wear, slippage, and calibration issues. Length and speed measurement inaccuracies can be as great as 2%. Placing non-contact laser gauges at critical measurement points along the line enable the manufacturer to directly measure the product length and speed with the highest degree of accuracy. For example in coating processes, label manufacturers depend on the accuracy of the line's drive speed and contact encoders to accurately apply the correct amount of coating such as adhesive coatings on the face stock and special coatings on the release liner (see Figure 16). In lamination processes, it's vitally important to accurately synchronize the speed of two or more converging materials. Speed inaccuracies create product quality issues and waste, and directly affect productivity.

Cut Control

Some manufacturers require their product to be cut to precise lengths via a cutting system. The knives of the cutter are controlled by a cut signal. It's critically important that the speed of the product is accurately controlled. Slippage from contact encoders and "out of calibration" pull rolls create variances in the cut which ultimately result in material scrap. By installing a non-contact laser gauge to directly measure the actual product speed as it enters the knives, the speed signal from the unit controls the system with precise pulse counts to control the cutting knives (see Figure 17). The gauge's +/-0.05% accuracy helps eliminate scrap and increases product quality.

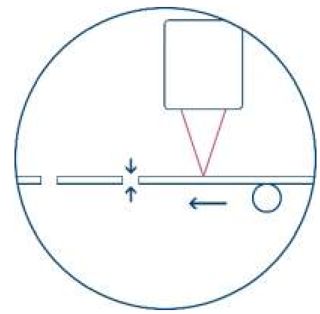

Figure 17. Cut control

SUMMARY

In the face of global competition, it's imperative that manufacturers look at proven and more efficient ways to increase productivity, improve product value, and boost the bottom line. Manufacturers across various converting sectors face numerous challenges resulting from rapidly evolving technologies, continually expanding markets, increasing customer requirements, limited production resources and quality control demands. To meet those challenges, manufacturers need to implement highly accurate, non-contact gauging systems to reliably measure and control coat weight, coating thickness, lamination, moisture, and product length and speed. Non-nuclear measurement technologies such as Near Infra-Red, Beta, Gamma, X-Ray, and Laser gauges have been proven across a wide range of converting applications involving paper, film, foil, and other converted products. The highly accurate and repeatable measurements from these proven technologies enable manufacturers to meet today's ever-growing market demands. The result is a fast ROI with long-term savings and numerous operational benefits for today's quality-driven manufacturers.