

Non-contacting, non-nuclear caliper sensor for online direct thickness gauging

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ABSTRACT

Sensors that measure basis weight and use the web density to infer thickness are not accurate on variable density products. Traditional contacting and floating caliper sensors for thickness measurement require constant maintenance, are easily damaged and do not measure well on porous or heavily textured webs. Shadow-style caliper sensors contact one side of the web with a significant wrap on a roller and will stretch an elastic web, causing thickness changes. A new caliper sensor introduced to the foam, extruded and coated sheet, nonwovens and paperboard markets is completely non-contact and uses a combination of Triangulation Laser and Eddy Current (RF) sensor measurements to provide 0.2-mil (5-micron) repeatability with no color, density or web flutter sensitivity. This new sensor maintains its published accuracy without requiring any intensive maintenance or calibration. Technical details of the sensor design, as well as long-term field results, are presented.

Introduction

Legacy online web caliper measurement sensors must contact or nearly contact the web from one or both sides. Contacting the moving web with a scanning sensor causes rapid wear and contamination, and it can cause damage to the web and the sensor in the case of holes, sticking components both in the web and in the sensor, or web breaks. Shadow-style caliper sensors cannot measure webs with any degree of elasticity as stretching of the web due to the gauging technique results in a thickness change. Sensors that measure basis weight (beta and X-ray gauges, IR sensors) must know continuously the density of the web so as to calculate thickness. A solution for the online caliper measurement of foam, sheet, nonwovens and paperboard is presented that eliminates the continuous inaccuracy and maintenance difficulties and downtime of traditional contacting caliper sensors and provides accurate thickness profile measurement of variable density materials.

Legacy caliper sensors

Contacting Caliper Sensors: Contacting or near-contacting (air-bearing) sensors either touch both sides or often just the bottom of the web and float on a known thickness of air cushion on the top side of the web. The amount of maintenance required to keep

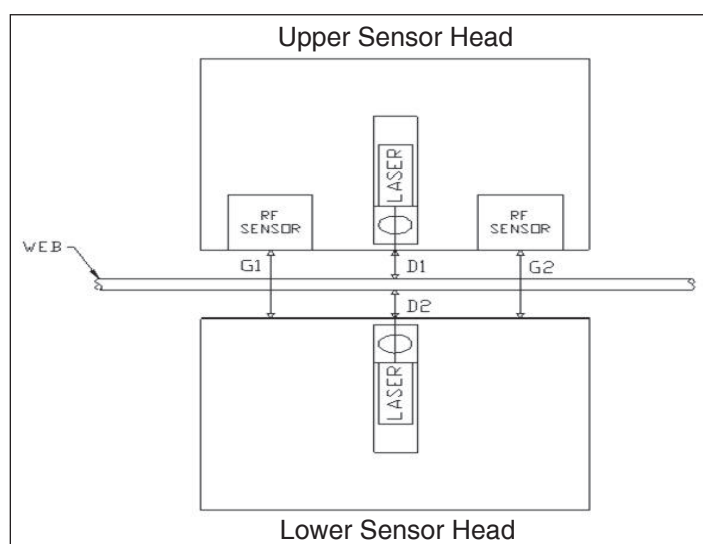


FIGURE 1. Dual-sided compensated laser caliper schematic

the air orifices and the low-clearance bearing components clean are very difficult in factory environments. These types of sensors often jam, crash into the web or chatter uncontrollably, resulting in a useless measurement and damage to the web and the sensor. Any of these near-contacting caliper sensors suffer from a problem with surface texture, impurities and porosity in the web causing erroneous measurement, web breaks and sensor damage.

Another type of contacting caliper wraps the web around a small diameter roller and uses a laser array to cast a shadow across the curved web onto a detector. These do work well with textured materials, except where the web is elastic or very rigid. Most variable density materials, such as foam, sponge, nonwovens, etc., are elastic, and the required tight wrap around a roller causes the web to stretch and change thickness. This thickness change then becomes dependent on the line tension, which cannot be maintained consistently enough for a repeatable, true thickness measurement. Rigid webs cannot conform to the necessarily tight web wrap.

Maintenance of these contacting and near-contacting caliper sensors is quite frequent and includes cleaning of deposits and

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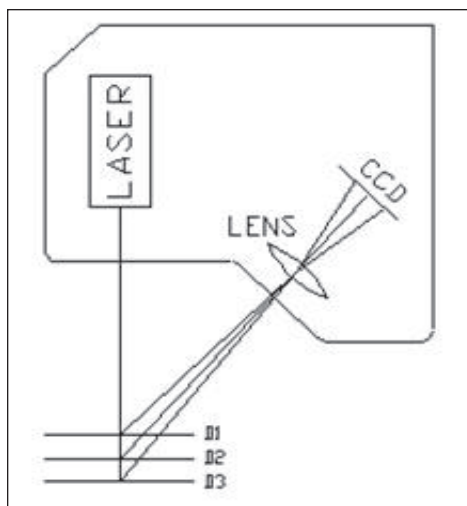


FIGURE 2. Laser triangulation

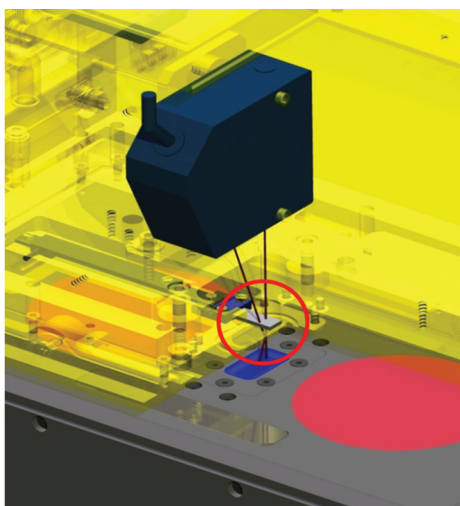


FIGURE 3. Laser caliper standardization method and caliper ceramic detail

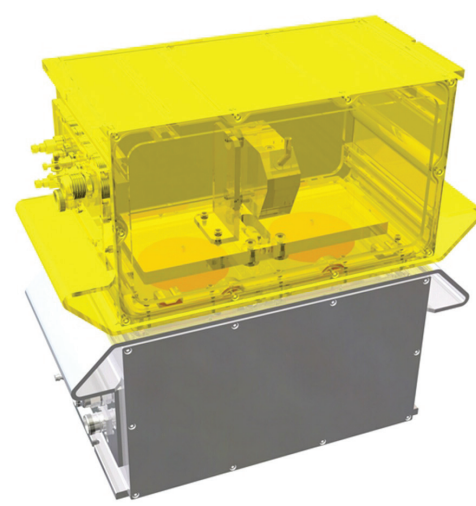


FIGURE 4. Compensated laser caliper sensor rendering

impurities on the sensor and roller. Hot webs cause a particular problem with the shadow-style sensor as its distance to the roller must be kept small to maintain linearity of measurement. Drifting and sensor failures increase with increasing web temperature.

Basis Weight Sensors for Inferring Thickness: Sensors such as beta, gamma and X-ray gauges, as well as IR absorption sensors, measure basis weight, mass per area, in units of grams per square meter, ounces per square yard or pounds per ream, for example. To infer thickness, the basis weight measurement (mass/area) must be divided by the density of the web (mass/volume), and the resulting calculation is in units of thickness – mils or mm. These basis weight sensors work well to determine the thickness of cast and extruded films in which the density is constant, but in the case of foams, laminates, nonwovens, thick and expanded sheet and paperboard, the density will vary from lot to lot, from run to run and even within a run of product. For these variable density products, a basis weight sensor cannot be used to infer thickness without continuous calibration and adjustment.

Legacy Non-Contacting Caliper Sensors: Older-style laser triangulation sensors suffered from significant sensitivity to web color and surface reflectivity, low resolution due to limitations in their displacement sensor and web flutter due to measurement processing speeds. These issues limited their use to rigid, thick materials with smooth surfaces and consistent light color.

New non-contacting, laser caliper sensor

This firm's new dual-sided laser caliper sensor does not contact either side of the web. It is compensated for thermal expansion and any systematic scanner runout; is very insensitive to web color, surface conditions, density or web flutter; and provides long-term dynamic measurement repeatability of five micrometers (0.2 mils, 2 sigma).

Operating Principle: The dual-sided compensated laser caliper sensor employs laser triangulation distance sensors in both the

top and bottom sensor housing and two Eddy Current (RF) sensors on either side of the laser in one of the sensor housings (see Figure 1).

The lasers measure their distance to the top and bottom surfaces of the web, respectively, and the RF sensors measure their distances to the closest electrically conductive surface, which is the machined face of the opposite sensor housing. The averaged distance measurements of the two RF sensors are used to eliminate the effects of any small change in sensor separation and parallelism as it scans across the web.

The calculation of web thickness with the new compensated laser caliper sensor is the average of the two distance measurements from the RF Sensors, G1 and G2, minus the distance of the top laser to the top surface of the web, D1, minus the distance of the bottom sensor to the bottom surface of the web, D2: thus $\text{Thickness} = [(G1 + G2) \div 2] - D1 - D2$. The laser and RF sensors are optimized for a relatively wide non-contacting measurement gap of 15 mm (0.6 in.).

Maintaining high accuracy

As the relatively long-distance measurements from the two lasers and two RF sensors are summed to achieve a very small thickness measurement, these distance measurements must be of very high resolution and remain very stable through temperature changes, vibration, etc. To provide temperature isolation and control of all internal components subject to thermal expansion, the internal components of the caliper sensor are designed to make extensive use of very low coefficient of thermal expansion (CTE) materials. Temperature sensors are strategically positioned within the sensor housing and used to compensate for any residual thermal influences. Further, the sensor internal volume is thermally insulated to slow the effects of ambient changes.

Eliminating color/gloss sensitivity

The fundamental distance measurement repeatability of each

TABLE 1. Compensated laser caliper sensor (Type 2) specifications

Configuration	Type 1 Single Sided	Type 2 Dual-Sided	Type 3 Single-Sided	Type 4 Dual-Sided
	Continuous Active Gap Compensation		Precision Stored Gap Profile	
Measurement Principle	Laser Triangulation <i>plus</i> RF Sensors, against precision reference roller	Laser Triangulation <i>plus</i> RF Sensors, against precision reference roller	Laser Triangulation, against precision reference roller	Laser Triangulation, sensors above and below web
Measuring Range	0.05 - 10 mm (0.002 - 0.40 in.)		Dependent on material	0.25 - 45 mm (0.01 - 1.8 in.) (Larger range available on request)
Measurement Gap	15 mm (0.6 in.)		50 mm (2.0 in.) (Larger gap available on request)	
Repeatability (Dependent on material)	Typically $\pm 5\mu$ (± 0.0002 in.)		Typically $\pm 25\mu$ (± 0.001 in.)*	Typically $\pm 2\mu$ (± 0.001 in.)
Laser Wavelength	650 nm			
Ambient limits	60° C (140° F), 0 - 95% relative humidity (non-condensing)			
Options	Air purging, air or water cooling			

laser is 0.2 microns (0.008 mils) due to the high resolution of the linear charge coupled device (CCD) used to detect the reflected beam from the web to triangulate the distance. To render the caliper sensor insensitive to web flutter, distance measurements from each laser are synchronized and acquired 50,000 times per second (see Figure 2).

In addition to using the CCD for determining position, a measurement of the total received laser beam intensity is made. This information is used to closed-loop modulate the intensity of the laser beam so sufficient light is reflected to the CCD not only to maintain a low-noise measurement in the case of dark-colored or matte targets but also so the CCD does not saturate from strong laser reflections from a highly reflective target. This utility significantly reduces any sensitivity to web color, gloss or surface reflectivity.

Ensuring true peak-to-peak thickness

The laser beam footprint is small compared to the surface texture in some webs. To obtain good correlation to TAPPI T 411 and ASTM D 645/D 645M Thickness Test Methods, a sophisticated peak-picking algorithm is used in the gauging console to provide true peak-to-peak thickness over the desired integration distance. Even though the laser caliper sensor applies no pressure to the web during measurement, reporting the data in Peak mode has been shown to provide a very repeatable correlation to QC Lab calipers, which are inherently peak-picking measurement techniques.

Long-term stability

To maintain the long-term measurement repeatability required of the compensated laser caliper sensor, an internal precision ceramic standard is employed. When the sensors standardize in the offsheet position, the ceramic standard is projected by an electrical solenoid into the beam path of both lasers just inside one of the caliper sensor heads behind the protective lens. The

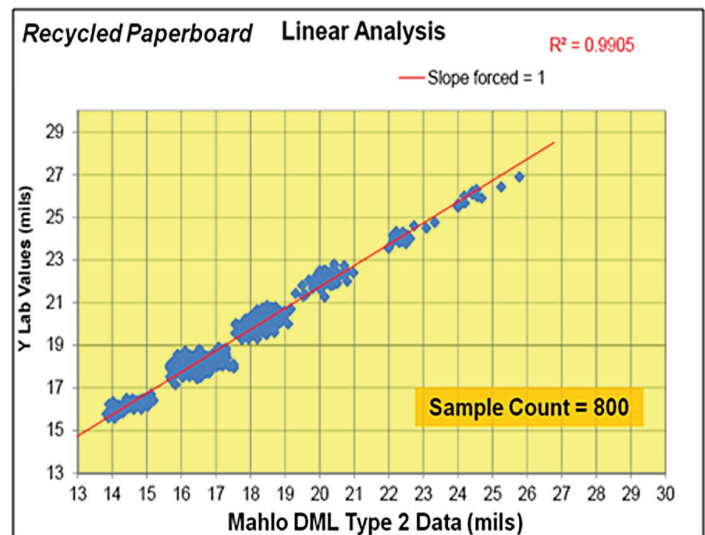


FIGURE 5. Linear regression of laser caliper vs. T411 lab data

thickness of the ceramic standard is measured and used to correct for any residual measurement changes between standardization intervals (see Figures 3-4). The ceramic standard is contained completely within the sealed sensor head so it cannot be contaminated by dirt or debris. The standardization process is fully automated.

Dynamic specifications

With the addition of the precision gap measurement from the RF sensors, the tight internal temperature control and the use of very low CTE components, the new compensated laser caliper sensor (Type 2 in Table 1) provides a dynamic repeatability of $\pm 5\mu$ (0.2 mils, 0.0002 in.) in harsh factory environments *without contacting the web*.

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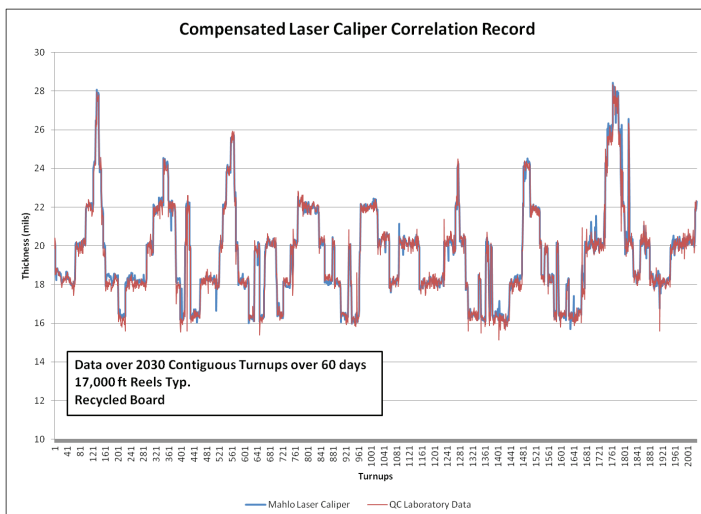


FIGURE 6. Plot of laser caliper data and T411 lab data over 2,030 turns

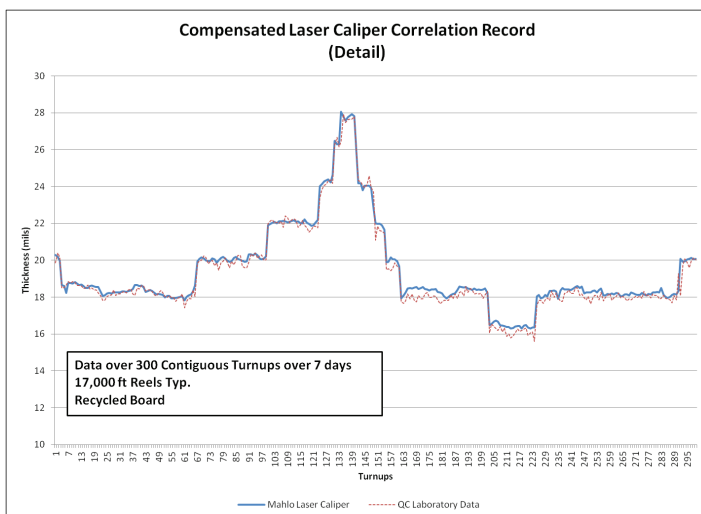


FIGURE 7. Detail plot of laser caliper data and T411 lab data over 300 turns

Field results

Both laser caliper and lab caliper data were recorded by the mill's QCS system. Figure 5 is a regression analysis of 800 data points over six grades of clay-coated paperboard. The quality of fit (R^2) is 0.99.

Figure 6 shows an overlay of the laser caliper CD profile averages and the QC lab manual caliper measurements over 60 days and 2,030 (turnups) reels. The average correlation over the 60 days was better than 0.08 mils. Figure 7 shows plot of laser caliper data over 300 turns.

Please note that other than an occasional cleaning (typically once per month) of the laser caliper sensor windows using a soft cloth and window cleaner, no additional maintenance was performed during the testing periods.

Discussion

Even though the individual laser and RF sensors have measurement resolutions on the order of 0.1 micron (0.004 mils), summing the many relatively long distance measurements to yield a very small thickness, even with advanced temperature control and data processing tools, results in a published compensated laser caliper sensor repeatability of measurement of 5 microns (0.2 mils). Our experience is that this is a valid long-term specification day-in and day-out in the harsh environment of a manufacturing line. The measurement range is thus stated as 0.05-10 mm (2-400 mils), but for a two-mil web, the measurement variability calculates to 10%, which typically will make this sensor unsuitable for thicknesses below 50 microns (2 mils).

Conclusion

The new compensated laser caliper sensor is proving to be an extremely low-maintenance, accurate and reliable sensor for the measurement of true thickness of variable density products and of any opaque web thicker than 0.002 in. where a non-nuclear, non-contact sensor is desired. ■

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Eric J. Reber, technical sales mgr. for Mahlo America, Inc. (Spartanburg, SC), holds advanced degrees in Physics and Mathematics from Marquette University (Milwaukee, WI). His web-gauging sensor development work began with Barber-Colman's purchase of Indev Gauging. He set up a sensor development center for web gauging for Eurotherm International (now Thermo-Fischer Gauging) in Newberry, England, and headed up sensor development for NDC Systems (Irwindale, CA) and was responsible for the development of NDC's original beta transmission sensor and laser caliper sensor and O-frame scanner. Reber has numerous publications in the web-gauging industry and holds three sensor patents. He can be reached at 864-576-6288, etc. 125; fax: 864-576-0009, email: eric.reber@mahloamerica.net, www.mahloamerica.com.