Description of Potential Errors in Laser Thickness Measurement Systems

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Introduction

Since 1998, Advanced Gauging Technologies (A.G.T.) has been the market leader in isotope thickness gauging for steel service centers throughout North America. In 2012 the company began development of a laser thickness gauge with countless hours of testing and development. The AGT800 Laser Thickness Gauge & S.P.C. Reporting System is the result, and was introduced in 2013. The first system was commissioned in 2014, and later that year the gauging system was an American Metals Market top five finalist for Best Innovation Product. In 2015, the company was awarded U.S. Patent #9,151,595 for laser thickness gauge and method including passline angle correction. Since its introduction, the AGT800 has steadily gained market acceptance and popularity.

AGT800 Laser Thickness Gauge

The AGT800 Laser Thickness Gauge & S.P.C. Reporting System is a complete thickness profile measurement system developed to measure any opaque material in strip, coil or sheet form. New versions are currently being designed to gauge cold and hot steel and aluminum plate, along with wall thickness of pipe and pole.

Customized C-frames are manufactured with two (or three*) Keyence LK-G/H series Class 2 laser sensors. Each sensor has individual adjustability in order to retain collinearity. Ultra high speed, high accuracy CCD sensors are used to measure distance and the thickness is interpolated. Built-in air knives protect glass sensor windows and ensure repeatability by keeping them free of oil and debris.

Our proprietary S.P.C. reporting system provides fast and reliable thickness measurements and data storage. Direct benefits include documented compliance with ISO and various other quality specifications, improved process control, increased productivity and scrap reduction.

*Two laser sensors are used to measure flat rolled material. One sensor is mounted below the strip, and the other above. Optionally, an additional sensor can be mounted above the strip. This allows the top two sensor readings to compare readings and determine material passline angle. A Passline Angle Correction factor is then applied.

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Issues that Affect Overall Measurement Accuracy

Following is a list of issues that can affect the overall measurement accuracy of laser thickness gauging systems in general.

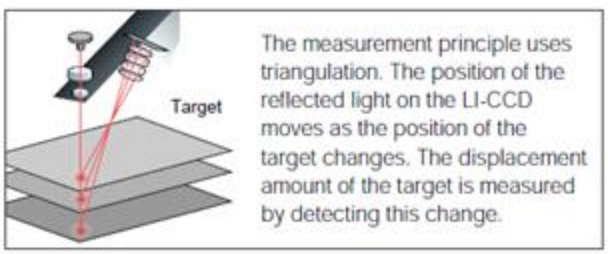
1. Design of laser sensors
2. Shape of the laser beam spot
3. Linearity of laser sensors
4. Alignment of the lasers sensors, and collinearity of the laser beams
5. Perpendicularity of the laser sensors to the material to be measured or material passline angle changes
6. Cleanliness of laser sensors and laser sensor covers
7. Thermal expansion of C-frame, accuracy of C-frame temperature monitoring and accuracy of temperature correction routine/algorithm
8. Tuning fork effect of C-frame design
9. Surface cleanliness of material to be measured
10. Electronic noise
11. Filtering

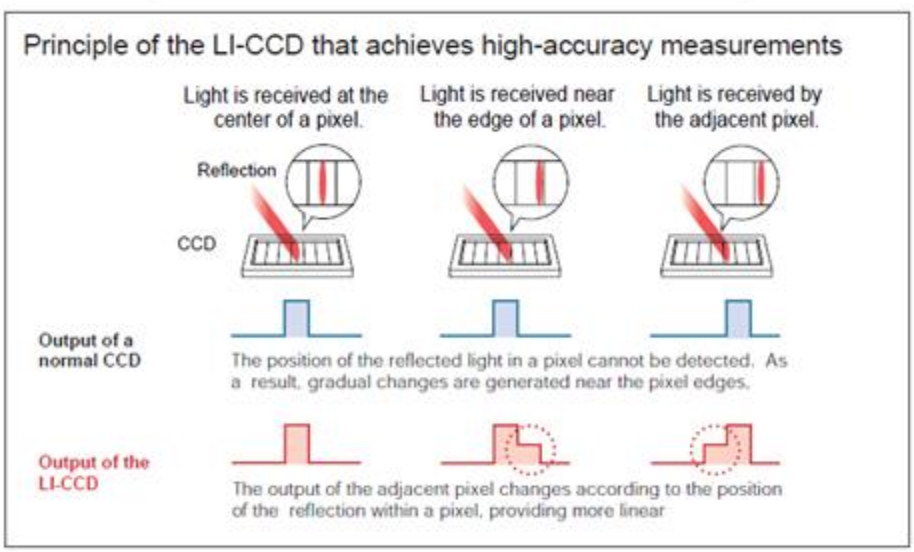
Ways These Factors Are Minimized in the AGT800 System

Here are the design elements incorporated into the AGT800 thickness gauging system that serve to reduce the measurement errors as much as possible.

1. **Design of laser sensors**

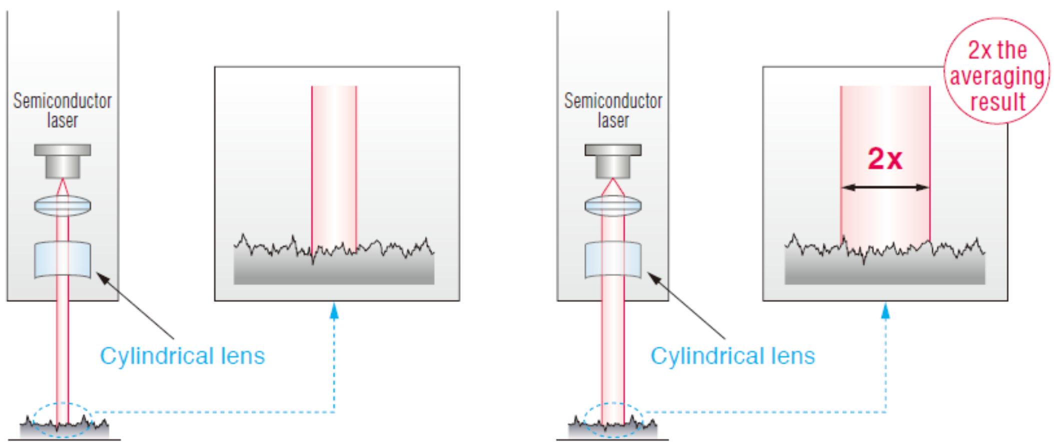
   Since a charge coupled device (CCD) has digital output characteristics for each pixel, the errors caused by gradual outputs generated at the edge of pixels was a barrier to higher accuracy. As a countermeasure, Keyence developed a linearized CCD (LI-CCD) that outputs the position of reflected light in a pixel, achieving excellent accuracy that is two times higher than conventional models. In addition, the dedicated design of the sensor has achieved a speed that is 25 times faster and sensitivity ten times better than conventional models. Refer to the following image from Keyence for more details.





2. Shape of the laser beam spot

Surfaces such as aluminum slabs that appear flat, will often contain minute projections and depressions once magnified. This microscopic surface roughness can often cause measurement errors with conventional narrow spot sensors. By using sensor heads with wider beam spots, the effect of the uneven surface is averaged and stable measurements of coarse targets are possible. For this reason, the AGT800 incorporates these wide beam laser spots. The difference in beam widths is illustrated in the following graphic from Keyence.



3. Linearity of laser sensors

All laser sensors have some degree of linearity, meaning their accuracy will be dependent on the position of material within the measurement window. The AGT800 utilizes Keyence LK-H series CCD laser displacement sensors. These are the highest quality sensors available in the industry, and boast linearity specifications of 0.02% of full scale. For this reason, minor vertical movement of the slab within the measurement range will have negligible effect on the measurement accuracy.

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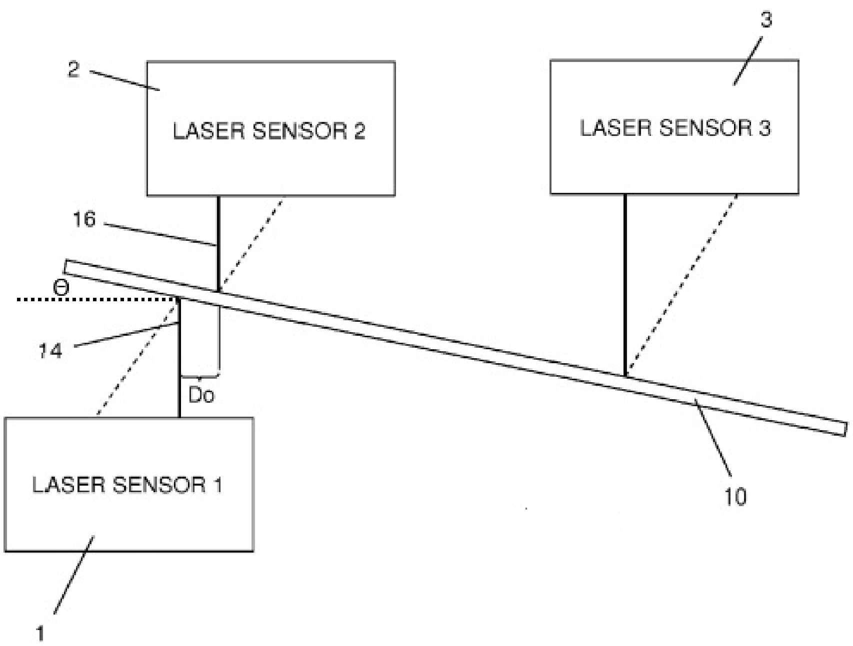
4. Alignment of the laser sensors, and collinearity of the laser beams.

It is paramount that the top and bottom laser beams be aimed at the same spot on the target material, and are installed so the beams are collinear. It is so important, in fact, that A.G.T. received a patent for the way we address collinearity issues with respect to floating material. The AGT800 incorporates specific design elements allowing simple laser sensor alignment adjustments to be made, assuring laser beam collinearity, and thereby eliminating this potential source of measurement error.



The above diagram from our U.S. Patent #9,151,595 shows the need to correct for lack of laser beam collinearity. The following formula is used in these cases.

$Ta = Tm \times \cos\theta - Do \times \sin\theta - Db$

- Ta is actual thickness
- Tm is measured thickness
- θ is the angle between the target material surface and an imaginary line drawn perpendicular to the laser beam
- Do is S1 versus S2 Collinearity Offset
- Db is S1 versus S2 Beam Dynamics Correction

5. **Perpendicularity of the laser sensors to the material to be measured or material passline angle changes**

   The laser sensor beams and the target material must be perpendicular for the most accurate measurements. In the AGT800 design, the laser sensors are mounted in an extremely rigid C-frame, maintaining the proper perpendicularity at all times. However, the angle of the material itself may change. In these cases a third laser sensor may be installed. The top two sensor readings can then be compared to determine material passline angle, and our patented Passline Angle Correction factor can be applied.

6. **Cleanliness of laser sensors and laser sensor covers**

   With any type of optical gauging system, cleanliness of the laser sensors is critical. To ensure accurate measurements, each of the laser sensors will be covered with an individual glass window. The AGT800 C-frames will also incorporate individual air knives to help keep the glass windows as clean as possible.

7. **Thermal expansion of C-frame, accuracy of C-frame temperature monitoring and accuracy of temperature correction routine/algorithm**

   The AGT800 C-frame design includes a temperature sensor to monitor C-frame temperature at all times. Any time the gauge is calibrated, the C-frame temperature is stored by the software. Going forward, the current temperature is compared to the calibration temperature and a temperature correction is made.

   $Ta = Tm - TCF * (TMPc - TMPn)$

   - Ta is actual thickness
   - Tm is measured thickness
   - TCF is Temperature Correction Factor
   - TMPn is C-frame temperature at last calibration
   - TMPc is C-frame temperature at current time

8. Tuning fork effect of C-frame design

The AGT800 C-frames are assembled from HSS (hollow structural section) 8 x 8 inch (top arm), 8 x 4 inch (bottom arm) and HSS 8 x 8 inch (double uprights). In addition, upper and lower gussets are incorporated into the design. No fasteners are used. Instead, all components are welded together. This extra rigid C-frame construction serves to minimize the tuning fork effect as much as possible.

9. Surface cleanliness of material to be measured

The most repeatable and accurate thickness readings will be maintained when the material to be measured is as clean as possible. Compressed air may be used to keep the sensors clear of debris, scale, mist, etc. Thin oil films are not an issue for this gauge design.

10. Electronic noise

The Keyence LK-H series laser sensors produce digital displacement measurements within the sensors themselves. This eliminates analog signals being transmitted through cables over long distances, which means there is no electronic noise present.

11. Filtering

The AGT800 design incorporates a combination of several types of data filtering.

a. Moving Average. The measurement values are set with a moving average in the range of 1 to 262,144 times. This number will be set for best possible performance in the AGT800 system.
b. Median Filter. This function applies a 7, 15 or 31-point median filter to prevent measurement fluctuations by ignoring sudden changes in the measured value. This function is useful when the target moves fast. This number will be set for the best possible performance in the AGT800 system.
c. High-Pass Filter. Abrupt changes are ignored and only moderate changes are detected, based on a specific cutoff frequency.
d. Low-Pass Filter. Moderate changes are ignored and only abrupt changes are detected, based on a specific cutoff frequency.