

New Opportunities for Process Optimization in the Metal Industry using Laser Line Sensors for Thickness and Width Gauging

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Abstract. The use of laser line sensors in thickness and width gauges for the metal industry is the successful approach, to benefit from the advantages of laser triangulation measurement and to avoid the disadvantages of optical measurement in harsh conditions. Furthermore enables the high density of the acquired data a clever implementation of new applications.

Introduction

Thickness and width are important characteristics in the production of strip-like semi-finished products such as slabs, coils or sheets. Therefore it is worth to invest in R&D to improve used or develop new, innovative techniques, to satisfy the request for constant optimization of the processes in the metal industry, driven by increasing raw material costs, stricter tolerances or more complex products. In this discussion two different approaches have to be considered. On the one hand, technologies are applied, which determine the thickness indirectly via the use of material constants such as equipment based on isotope or X-ray radiation. These are increasingly confronted with the progression of the recycling in all fields of metal manufacture. In addition to the costs for radiation protection and safety, complex calibration with regard to the material is needed whereby the knowledge about its composition is declining more and more due to the globalized recycling supply chain. Therefore, the importance of the second approach is increasing, namely those techniques which measure thickness geometrically using displacement sensors. These systems have to be subdivided in two groups once again, the contacting and non-contacting ones. For sure the contacting gauges have high precision; however they have weaknesses with respect to high conveyor speeds, material with high surface quality or profiled material as the sensors then lift off, scratch or fail completely. Thus, all the facts mentioned above motivate to put the focus of the discussion on non-contacting and alloy-independent principles. The use of laser line sensors, presented below has the previously mentioned characteristics and enables both the more efficient solution of existing applications as well as opening up new measurement tasks. The clarification of the basic technique and its advantages is followed by the discussion of the systemic approach including the method for compensation of parasitic effects. The presentation of exemplary applications which have already been successfully implemented in the industry and/or are close to being launched on the market finish the paper concludes the explanations.

Principles of Dimensional Thickness Gauging

Dimensional Thickness Measurement using Displacement Sensors. Irrespective of whether the thickness measurement is performed with electromagnetic or optical sensors, one displacement sensor in each case is arranged on both sides of the conveyor. This principle is called differential thickness measurement. The distance of the two sensors from each other (= operating range d_A) is determined by a calibration process using a master part, - usually a certified gauge block - whose thickness d_C is precisely known. In doing so, the sum of the sensors signals d_{M1} and d_{M2} is added to the thickness of the master part, so that the following applies:

$$d_A = d_C + d_{M1} + d_{M2} \quad (1)$$

During the measurement operation, the sum of the sensor signals is subtracted from the operation range and the current thickness d of the target is calculated by

$$d = d_A - (d_{M1} + d_{M2}) \quad (2)$$

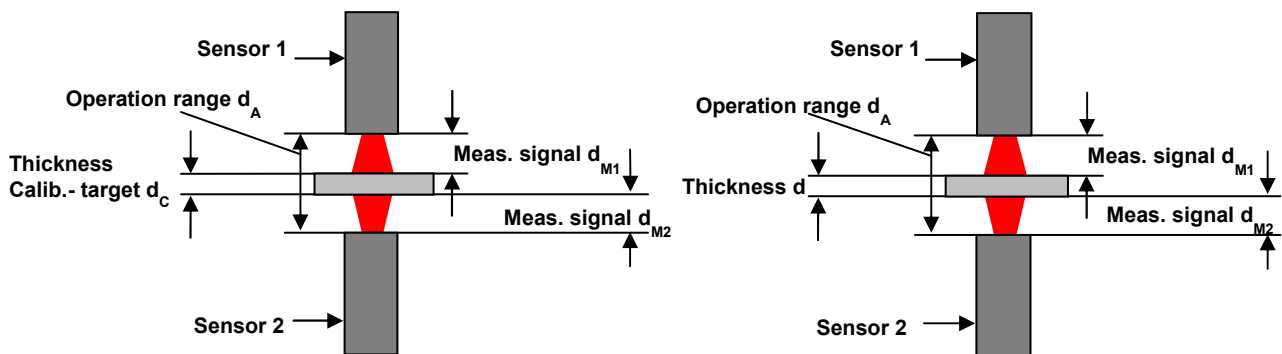


Fig. 1. Principle of calibration and thickness measurement using displacement sensors

Functional Principle and Advantages of Laser Line Sensors. Triangulation sensors operating according to the point-shaped approach have been used for optical thickness measurement to date. Thereby, a single spot is projected onto the surface of the target using a laser light source. Its diffuse

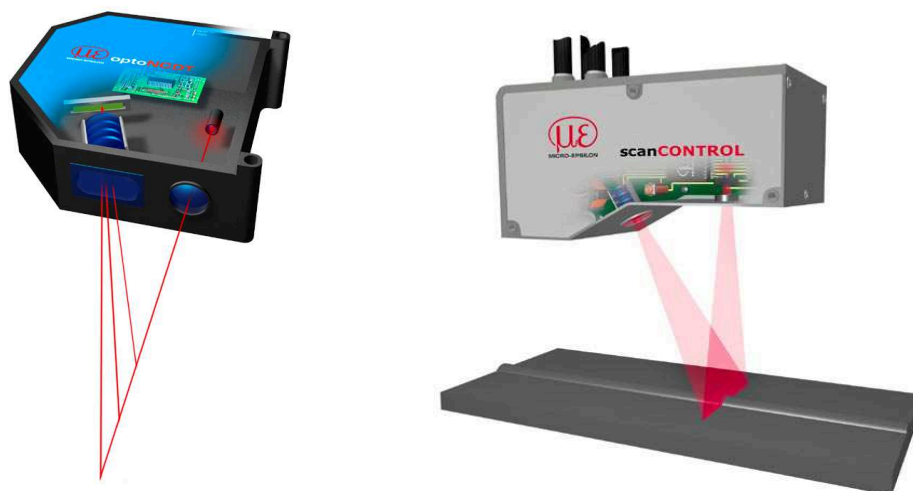


Fig. 2. Functional principle of the punctiform and linear triangulation

reflection is mapped onto a detector via a focusing lens and converted to a distance by a signal processor. To avoid the interference caused by surface roughness in the sub-micrometer range -

particularly predominant in shiny metal targets - the laser beam was widened using a special cylindrical lens. This technique improved the situation, but is not as performant as using laser line sensors working discrete.

For a discrete laser line sensor (= profile sensor or laser scanner), the laser spot is widened to a line using a special lens and projected onto the measurement surface (see Fig. 2). The diffuse reflected light of this line is mapped on a sensor matrix using a high quality lens. Both the distance information (= z-axis) as well as the position along the line (= x-axis) are evaluated in the controller and output to a two-dimensional coordinates system. A 3D evaluation is also possible using the movement information of the target and the positioning of the sensor.

Thickness gauging with displacement sensors is always in the area of conflict that the accuracy of the sensor reduces with increasing distance from the product and increasing measuring range; these are the factors desired for a robust measurement process. When using an appropriately precise point sensor that can monitor the tolerance of the produced strip, the measuring distance is so small that the strip leaves the measuring range, i.e. no measured value are available, or even touches the sensor and possibly damages it in doing so. With the high information density of the point cloud one gets from the laser line scanner it is possible to calculate a "best fit straight line", which is used as one measurement value (see Fig. 3). Thus the distance to resolution relation of the line sensor is significantly better than that of the point sensor as the change of this straight line is calculated from the interaction of many partial resolutions. This means the resolution of any individual point is permitted to be worse than that of the point sensor. Due to the "best fit straight lines", this feature is enhanced in the sum so that the resolution of the line sensor is better at the end for a larger measuring distance than that of the point sensor.

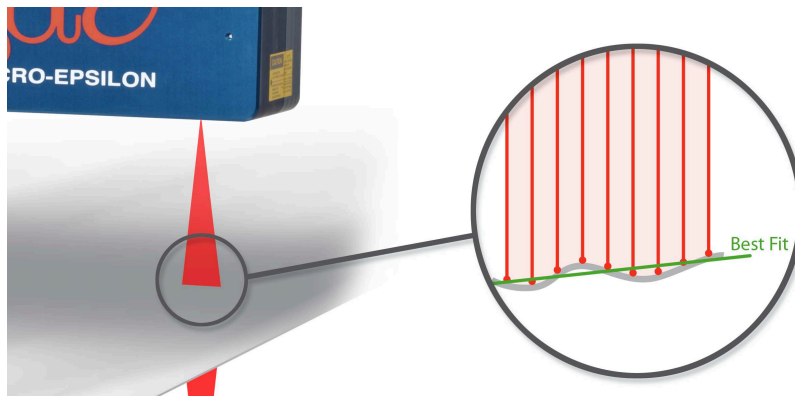


Fig. 3. Best fit straight line as distance value

The robustness with regard to the surface characteristics of the target material as well as the environmental conditions like steam or emulsion is also significantly better due to the high information density for profile sensors than for point sensors. Even if 30 – 40 % of the potential amount of points is not valid because of these effects, the best fit straight line is still very stable. This fact makes the gauges easy to use and very robust, without the necessity of detailed adjustment of the sensor settings.

A further challenge in connection with position changes of the strip in the process is the tilt of material; these also arise, for example, due to the forces of the cutter in slitting shears for the individual strips after the slitting process in the production direction. Even with ideal mechanical conditions, the measurement always has an error d_T of

$$d_T = d - \frac{d}{\cos(\alpha)}, \text{ where } d \text{ is the real thickness of the material and } \alpha \text{ is the tilt angle} \quad (3)$$

The tilt angle can be determined very precisely with the laser line scanner to compensate for the error (see Fig. 4).

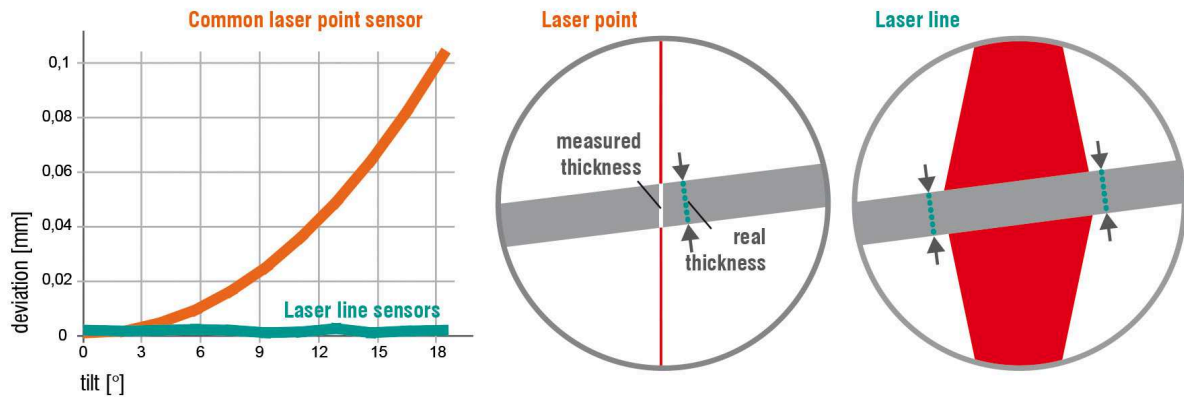


Fig. 4. Detection and compensation of the tilt angle

Constancy of the Operation Range. Two different mechanical design types are usually used; these are designated as C-frame or O-frame due to their mechanical form [1]. Here the technology for keeping the operation range constant of an O-frame (see Fig. 6) should be discussed.

There are basically two philosophies for the design of a dimensional thickness measurement system to keep the operation range constant. One approach is to design the mechanical equipment so that temperature changes do not have any influence. This approach may be appropriate for smaller arrangements; however, it is also quite cost-intensive. For large systems existing influences are too complex to design a precise machine in this way. The temperature changes due to environment or material influences make themselves noticeable very differently in the frame. Measures such as the acclimatization of a frame for the purpose of mechanical stability must therefore also be critically considered. Another point which must not be neglected in this context is the temperature drift of the sensor electronics which can have more severe adverse impacts than those of the mechanical equipment if it is not taken into account. For these reasons, the monitoring of the measuring gap with additional displacement sensors and iterative calibration at times not critical for the process is the basically more promising philosophy.

Tests in a temperature chamber have shown that a change of the operation range of $\Delta d_A = 400 \mu m$ occurs for systems of this type with a width of approx. 2 m and any temperature change of $\pm 10^\circ$. This test which was performed over 26 hours is shown in Fig. 5. The concept of the "compensation frame" patented by Micro-Epsilon provides assistance here. An additional frame which does not vary with temperature is integrated in the system parallel to the lower and upper boom and the mounting of every measuring sensor is enhanced with a so-called compensation sensor. The compensation sensors measure the distance of the mounting from the compensation frame. Any change of the measuring gap is thus transmitted 100 % to the distances of the compensation sensors from the compensation frame. Using the measurement results of the compensation run, the measuring gap can be virtually kept constant at a non-critical level for the measurement task of $\Delta d_A = \pm 2 \mu m$. This can also be observed in the visualization of the test mentioned above in Fig. 5.

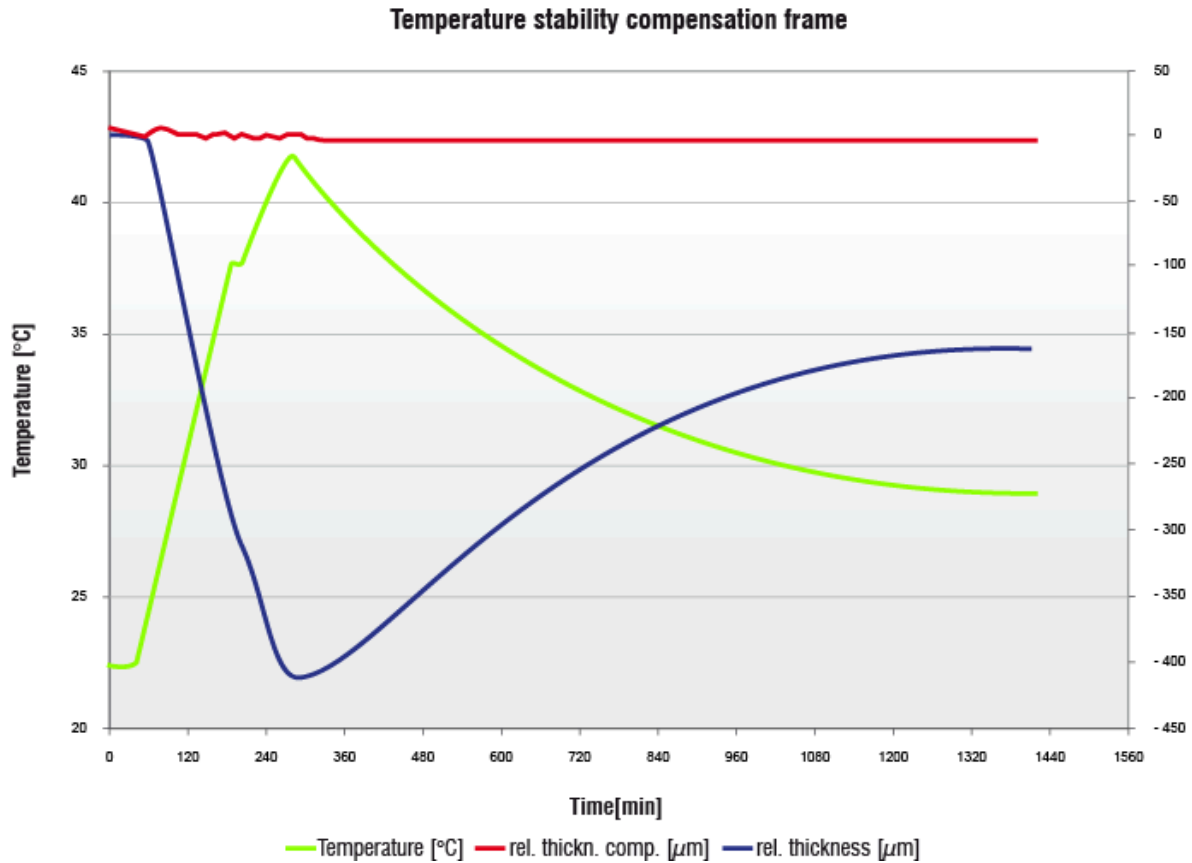


Fig. 5. Uncompensated and compensated change of the measuring gap

Iterative calibration is also performed to compensate for the modification of the sensor mounting and the electronics. The system for this innovative form of temperature compensation is outlined in Figure 8. The operation range is thus calculated by

$$d_A = d_{AK} - (d_{K1} + d_{K2}) - C, \quad (4)$$

with $C = d_{AK} - (d_{K1} + d_{K2} + d_A)$ from the calibration for each measuring point.

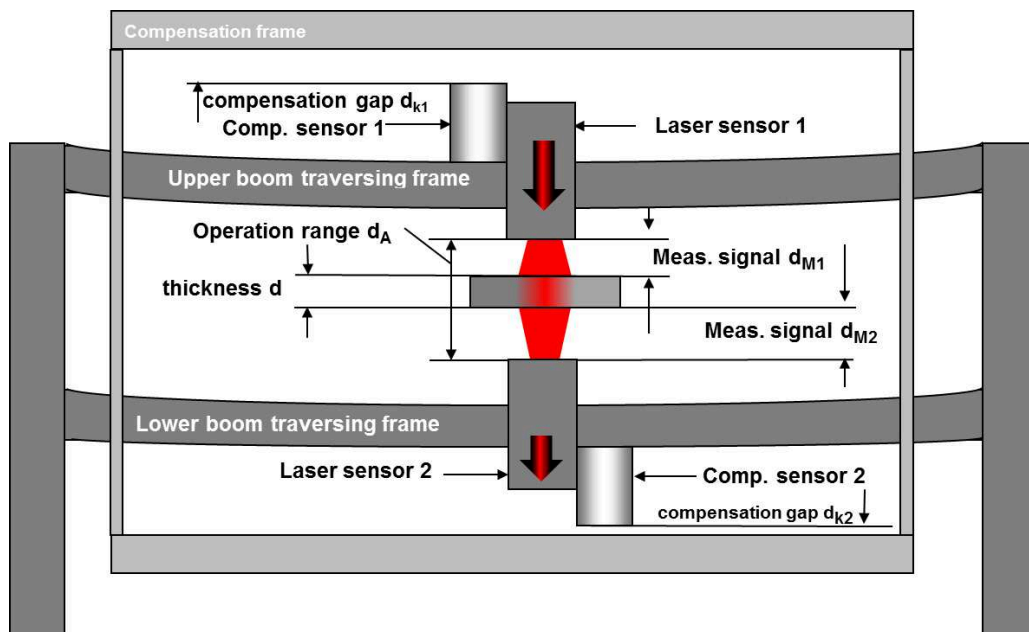


Fig. 6. Principle of O-frame gauge with compensation frame

After discussing the thickness gauging, the width gauging should be explained in the next section.

Width Measurement with Laser Line Sensors

Fundamental Functionality. The width gauging is based on the high lateral resolution of the profile sensors. It enables the precise recognition of the edges of a target so that in combination with an incremental encoder the measurement is realized in form of a gantry (see Fig. 7).

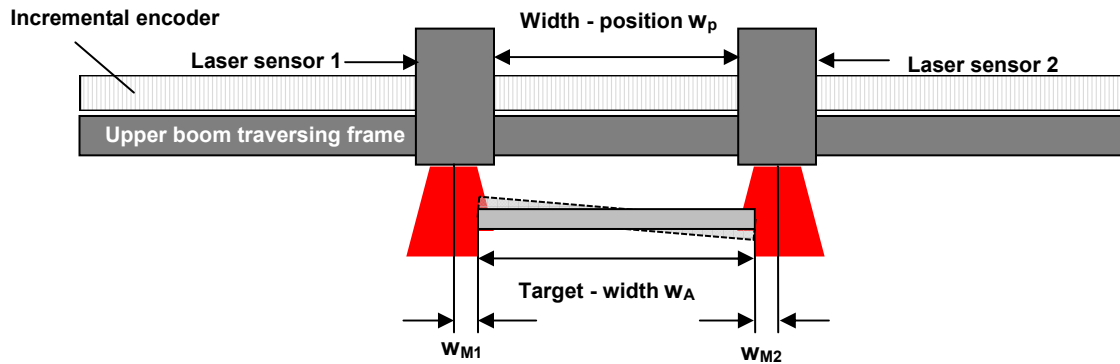


Fig. 7. Width measurement with laser line sensors (inclusive tilt detection)

The position displacement w_p of the laser sensors 1 and 2 is read in via an incremental encoder. The center of the sensor lines are defined in each case as zero points and the value between the edge of the object and the zero point of the sensor is measured as w_{M1} and w_{M2} . In a calibration process with a well-known target having the width w_C , the offset w_o between the incremental measuring system and the zero points of the laser lines is determined as follows:

$$w_o = (w_C + w_{M1} + w_{M2}) - w_p \quad (5)$$

This offset must be taken into account for every measurement of the incremental position value. The width w_A of an individual strip can now be calculated through:

$$w_A = w_p + w_o - (w_{M1} + w_{M2}) \quad (6)$$

The triangulation laser line sensors are not only able to detect the edge. As in section **“Functional Principle and Advantages of Laser Line Sensors.”** explained it is also possible, to identify the tilting of the target (see Fig. 7). This is very important for a precise width measurement and is in contrast to a solution with Thru Beam sensors or non-Stereo vision systems a big advantage. Particular in the use in slitting lines, which is one of the applications, where the machine demonstrates its advantages most impressively tilting of the single strips is the normality of the industrial process.

Special Applications for Thickness and Width with Profile Sensors

Combined Thickness and Width for Slitting Lines. In many processes of the metal industry, particularly in process lines and service centers the inspection of the thickness and width are two central features. The use of laser line sensors allows an efficient solution of these two applications in one machine.

In addition to the sensors for the thickness measurement like described in Fig. 1, a third laser line sensor which can be positioned independently (see Fig. 8) is integrated in the system for this. Thus sensor 1 and sensor 3 are working like described in section **Width measurement with laser line sensors**. Both edges of each strip can be measured synchronously and any weaknesses have no

influence on the measurement result. While the thickness sensor moves continuously across the width of the complete material, which can be one single or many different strips, the width sensor is positioned in each case at the next cutting gap.

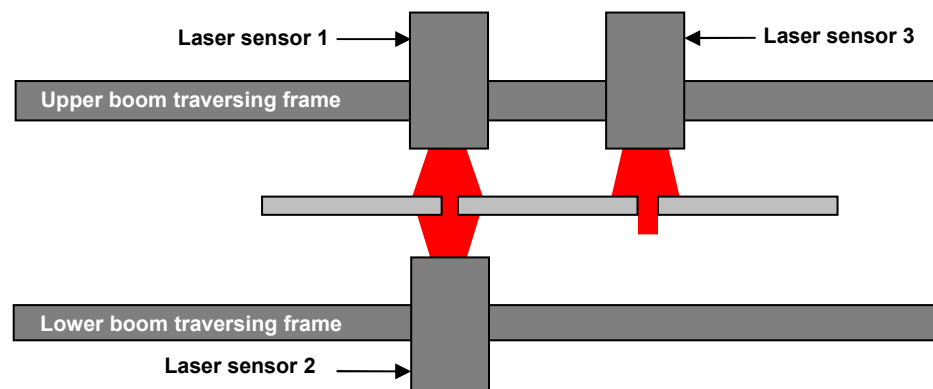


Fig. 8. Thickness measurement with integrated width measurement

An impressive number of installations in different processes in the metal industry prove the potential of the approach.

Summary

The use of laser line sensors opens up new perspectives for optimization and quality control in many metalworking processes. On the one hand, existing problems such as alloy-dependency, surface problems and inadequate process robustness can be rectified. On the other hand, further measurement tasks in addition to the discussed applications will become apparent. For example, in a new aluminum hot rolling mill, the X-ray thickness measurement directly next to the roll stand will be calibrated completely automatically to compensate for the problem of alloy dependency which occurs when using recycling material. The philosophy of compensating for changes in measuring systems attributable to thermal effects using additional sensors and iterative calibration has proved itself as very successful in many realized projects in the meantime. Furthermore it is obvious, that precise thickness measurement is not only assembling to sensors. It needs experience and innovation to compensate the parasitic effects of temperature, vibrating and tilting of the product, to get a precise and robust result that ensures the precise non contacting inspection of metal sheet processes.

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