Using Laser Gauges in Hot Rolling Mills

Digital technologies are transforming industry at all levels. Steel has the opportunity to lead all heavy industries as an early adopter of specific digital technologies to improve our sustainability and competitiveness. This column is part of AIST's strategy to become the epicenter for steel's digital transformation, by providing a variety of platforms to showcase and disseminate Industry 4.0 knowledge specific for steel manufacturing, from big-picture concepts to specific processes.

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The demand to use laser gauges in hot rolling mills has existed for years. Especially for thick plates, where the state-of-the-art method using x-ray is extremely cost-intensive, an alternative would be welcome. But a hot rolling steel mill is still one of the most uncomfortable places for an optical gauge. Up to 1,200°C material temperature and steam generate a real challenge for the gauge from an environmental point of view. Also, the fact that the system has to work with the highest precision in the worst area of the measurement range regarding its linearity makes it difficult to fulfill the needs of the application. Several phases of development and testing were necessary to provide such equipment successful to the industry.

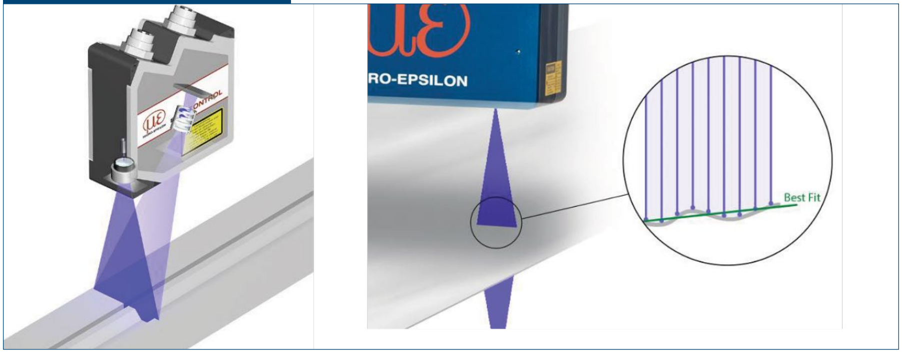
Besides a mechanical concept, which is controllable as far as the thermal impacts, sufficient cooling to protect the electronic components and a sensor design was realized to master the task of supplying a huge measurement range with the highest precision in the most critical area — the end of the range near the passline, where the material with the smallest tolerance has to be measured.

The first part of this paper describes the basic technology of laser line sensors, optical thickness gauges working with laser line triangulation and its advantages. The second part introduces a design that allows even thinner material to be measured very precisely despite a large distance between the upper sensor and the passline and a huge measuring range. The paper concludes with an explanation of the mechanics and its performance to compensate the thermal impact, which is really significant in the environment of a hot rolling mill.

Optical Laser Gauges Based on Discrete Laser Line Triangulation

Principle of Laser Line Triangulation and Its Use in Thickness Gauges — Triangulation is a general principle in which an object is observed from two different viewing positions. By replacing one position with a point-projecting laser beam with known direction and observing the projection with an optical device from the other position, an optical displacement sensor can

Figure 1



Laser line sensor and value from best-fit line principle.

be realized. By calculating the observation angles from the two viewing positions, the object position can be determined. If instead of the point-projecting beam a line-projecting fan of light is used and the linear array is replaced by a matrix sensor, one will be able to measure an array of distance points simultaneously and evaluate a two-dimensional profile. An often-used arrangement is to integrate the laser source, the optical components and the camera matrix in a housing. This integrated arrangement is finally calibrated and for the thickness gauging a "best-fit straight line" is calculated regarding this profile, which is used as one measurement value (see Fig. 1).[1]

Using the profile sensor with this procedure generates several advantages.

Improvement of the Relationship Range to Precision: By using the technology described earlier, the resolution improves significantly, since the smallest change in the position of the best-fit straight line is obviously smaller than that of a single point. Thus, in the thickness measurement, a larger optical measuring range can be realized with the same accuracy of a point solution.[3]

Precise Even in the Harshest Conditions: The use of laser line sensors creates a powerful point cloud, which provides another advantage. Even though parts of the cloud will become invalid when used in difficult conditions due to steam and the residues of rolling emulsion, the resulting best-fit straight line remains extremely stable and repeatable.[5]

Performance of a Profile Scanner: In order to protect the closer environment of the gauge from rolling emulsion, air knives are used. In any case, smaller or larger accumulations of drops remain on the plate or coil. If the capabilities of the laser line sensor are used as a 2.5D profile sensor, such a drop accumulation is a geometric object like a target in any other scanner application. Thus, residues of emulsion can be detected, filtered and have no influence on the measurement result.[5]

With understanding the basic technology and advantages of the use of discrete laser line sensors, the next section deals with the principle of thickness measurement based on displacement sensors. This principle is independent of the type of sensors. It is valid for optical and electromagnetic displacement sensors as well.

Performing thickness measurement with displacement sensors, one sensor is arranged over and one below the material. There are two typical mechanical forms for doing this. One is the O-frame, where only the sensors are moving to get a cross-profile or to place the sensors at a position. More popular is the C-frame, where the complete frame is moved to the measurement and respective parking position (see Fig. 2). The distance of the two sensors from each other (= measuring range d_A, in the figure it's shown without standoff) is determined by a calibration process using a certified gauge block with a precisely known thickness d_C.[3]

In doing so, the signals of the sensors d_{M1} and d_{M2} for the thickness of the gauge block are added so that:

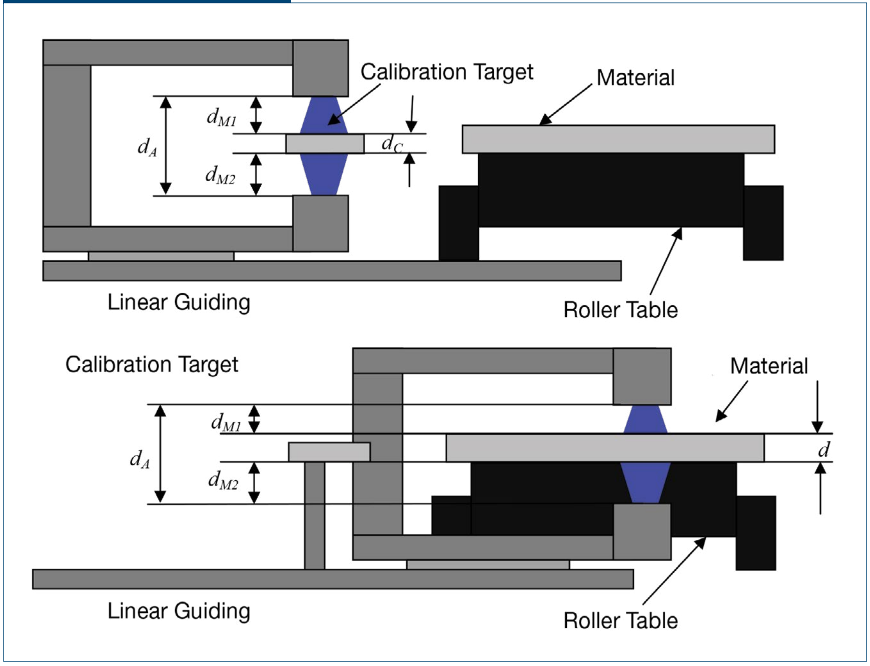
$$d_A = d_C + d_{M1} + d_{M2}$$

During the measurement operation, the two sensor signals are subtracted from the measuring range and the current thickness, d, of the target is calculated by:

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

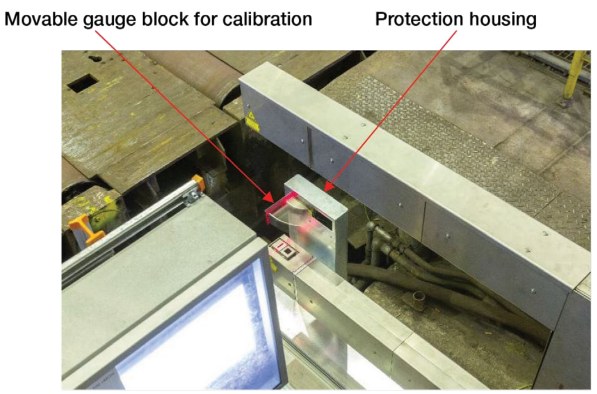
This process for the calibration described above is normally fully automated. Such a calibration station is placed in the parking position of the C-frame. The gauge block is protected in a housing and is moved, for example, by a pneumatic cylinder in the measurement area of the C-frame (see Fig. 3), where the size of the operating range is determined. Due to the fact that this procedure needs only a few seconds of time, it can be

Figure 2



Calibration procedure and measurement process.

Figure 3



Calibration station with gauge block.

activated before each measurement so that there is no long-term drift on the measurement result.

After this introduction of laser optical thickness gauges, the discussion about the development has reached a point where it's possible to manufacture a precise and robust gauge for processes, where the thickness and its variation are in a small range. But still the operation area, which means the distance from the lower to the upper bar, or what's even more important, the distance from the passline to the upper bar, is limited. Even when it's better than with a laser point sensor, the people in production are afraid of a collision between the target and the gauge in case of a so-called "crocodile" (when an excess of material at the beginning or end of a slab, plate or coil is formed in the shape of a crocodile's mouth) or "ski" (when an excess of material forms only on the upper side). An additional issue is the fact that for a roughing or a plate mill, the thickness range of the rolled material is huge. This is a special challenge for optical sensors in particular.[5]

Extending The Range With a Modified Sensor Approach

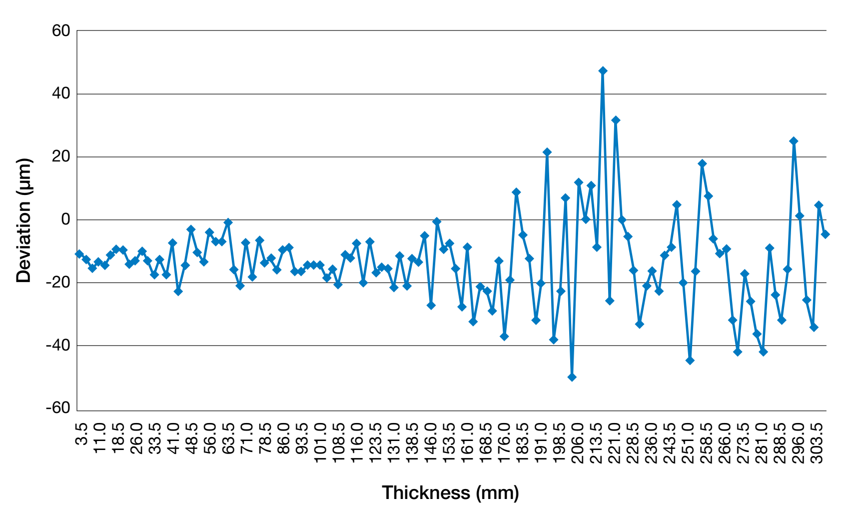
Limits of the Laser Line Triangulation — To cover the application mentioned above and to reduce the risk of a crash between gauge and material, a sensor with a large measuring range has to be introduced in the upper arm of the frame. By reducing the thickness of the plate pass by pass, the distance from the sensor to the upper surface of the plate increases. Unfortunately, the behavior of accuracy and operating range are in contrast. This leads to a situation for thin plates in which the need for precision is the highest because the tolerances are the smallest. The sensor is used where the quality of the signal is the worst. This fact limits the advantage that the thick plates can be measured quite easily and cost-effectively compared to an x-ray gauge. If one takes a look at the linearity of a 300-mm laser line sensor, it's noticed that in the last 30% of the measuring range, the deviation can be in the worst case and without signal processing up to ±50 µm (Fig. 4).

For an x-ray gauge, the exact the opposite is the case. It has an increasing accuracy with decreasing thickness, so it's able to measure thinner plates with high accuracy.

Dual-Range Laser Line Triangulation Sensor — A first solution to improve the limitations described in the last section was the development of a C-frame with a vertical moving sensor on the top. Although this procedure provided the required accuracy, the assembly was very expensive. It was necessary to integrate many moving parts and flexible cooling components in the measuring head. Ultimately, concerns about the robustness regarding this design motivated the decision to take a different route. The next step of development was a special sensor armed with two detecting units (see Fig. 5).

Thus the area above the passline for this device is not divided into two zones, standoff and measuring range, it is divided now into three zones: standoff, measuring range 1 and measuring range 2. The standoff from the sensor housing to the beginning of the first measuring range is 300 mm. Measuring

Figure 4



Linearity of a laser line sensor used for thickness measurement.

range 1 is 300 mm wide and has an accuracy of 40 microns. Measuring range 2 starts after a 600-mm standoff. It covers 100 mm and provides an accuracy of 10 microns (see Fig. 6). Considering the accuracy of an x-ray gauge, which is mostly specified with 0.1% of the thickness to be measured, the laser gauge is now highly competitive in plate mill and roughing mill applications (see Fig. 7).[6]

This type of sensor increases the advantages of laser gauges significantly, which can be summarized as:

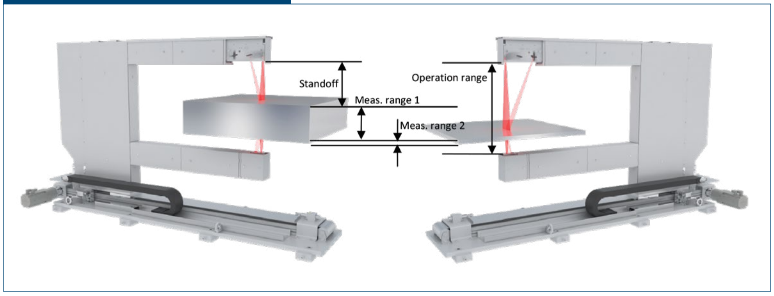
- The laser gauge is also highly accurate for thin plates and is still very cost-effective for the whole thickness range.
- It provides a big standoff and, respectively, a large operating range of 1,200 mm. That makes the gauge quite robust for the milling process, in particular when the beginning or the end of the plate shows a so-called crocodile or ski form.
- The measurement is independent to alloys; no alloy-specific compensation or calibration is necessary.
- The installation is easily performed. There is no further need for a safety zone, for paperwork with authorities or for specially trained employees.

After discussing in detail how to improve the sensor's suitability for the rolling process, the next section explains the steps that were necessary in using a laser optical gauge in the hot rolling area.

Figure 5

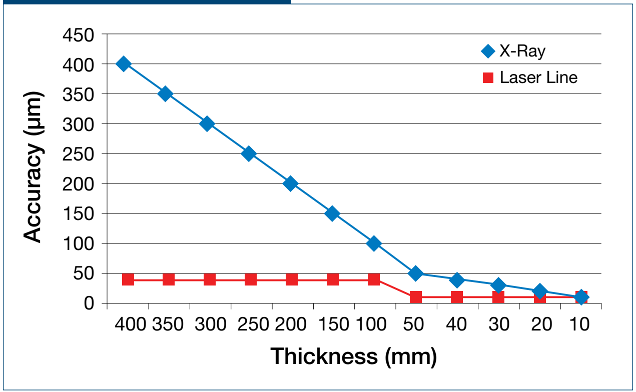
Sensor with two detection units.

Figure 6



C-Frame with integrated dual-range sensor.

Figure 7



Linearity of a laser line sensor used for thickness measurement.

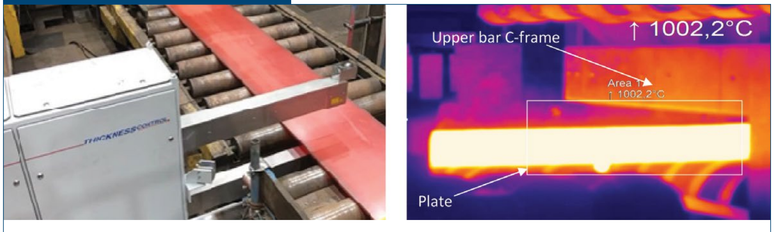
Design of the Mechanics for a Laser Gauge Used in a Hot Rolling Mill

The temperature of red-hot steel is certainly the biggest challenge when measuring with an optical gauge in a hot rolling steel mill. The design of the frame for an application where the material temperature is higher than 1,000°C (see Fig. 8) must first of all take into account two things:

- Most electronic components used in the gauge can take only temperatures up to 45°C or 50°C. To ensure a long service life, around 30°C should be reached, so it is necessary to develop an efficient cooling concept.
- Furthermore, the precision of the geometric thickness measurement depends on the constancy of the operating and, respectively, the measuring range. As any temperature gradient leads to a change of the mechanical structure and so to a potential modification of the operating range, this fact has to be considered very carefully.[6]

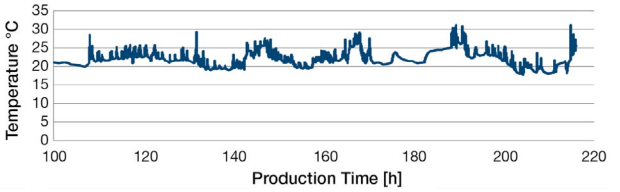
To fulfill these requirements, a package of measurements is implemented in the gauge. First, the frame is designed in several layers, starting with the shield layer. Here, the heat radiation is reflected, resulting in 85% of the energy being kept away from the next layers. Below the shield, a so-called cladding layer is installed. This layer is designed so that the frame is forced to change

Figure 8



Installed C-frame (a) and infrared image in a plate mill environment (b).

Figure 9



Temperature distribution at the cladding layer in 120 hours of production.

mechanically under the influence of temperature in such a way that its deformation can be compensated. Due to the fact that this layer is integrated into the cooling in order to keep the thermally induced changes small, the temperature at this point is already to a certain extent a constant low of around 25°C (see Fig. 9).[5]

Fig. 9 shows that the cooling system is highly efficient and the electronic components are protected enough against the temperature. Underneath the cladding layer is the actual measuring frame, which supports the sensors. A set of temperature sensors monitors the situation at multiple points in the gauge. These ensure that in case something is wrong with the cooling and there would be a dangerous situation for the sensors and the other electronics, the frame can be moved outside of the line. Furthermore, software routines to perform a virtual compensation of the resulting deviation regarding the operating range are controlled by the measurement results. These routines are trained during the commissioning because every frame is unique. Finally, an iteratively performed calibration procedure with a certified gauge block ensures that every component is working well.

Figure 10

Laser gauge in form of a C-frame, suitable to work in a hot rolling environment.

Conclusions

Gauges based on laser line triangulation sensors have found their way into the steel industry and have shown to be reliable and precise enough to improve product quality and process performance. The state of development has now reached a quality that allows the laser gauges to fully exploit their advantages in comparison with other technologies.

This paper showed that the gauges are not limited anymore to cold and clean applications. Numerous installations, which have since been carried out, prove in daily use in the rolling mills that laser measuring instruments are a real alternative in more and more applications.

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