Implementing an Accurate, Reliable Measurement System for Improving Mass Flow Automatic Gauge Control in Rolling Mills and Related Processes

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Key Words: non-contact gauge, laser measurement, length and speed, high accuracy

INTRODUCTION

Cold rolling mills in steel production plants take hot band material from the hot mill and roll it to the correct thickness and flatness. Most cold rolling mills use Mass Flow Automatic Gauge Control (MFAGC) to control the mill’s rolling force and speed to obtain high-quality steel within the thickness specifications. It is critical to control the gauge or thickness of the cold-rolled steel strip for end-user requirements. Automobile manufacturers stamping car body parts depend on the steel to be within specified thickness tolerances when making high-quality parts. The steel might tear or have less than the specified strength if the steel is too thin, and the mold used to stamp out body parts will have premature wear if the steel is too thick. Stamping molds are very expensive to replace. Obtaining accurate gauge control in cold rolling mills has become more and more difficult as mill speeds increase and manufacturers work to reduce the thickness of metals, and tolerance get tighter.

Traditionally, mechanical contact measurement devices (also known as mechanical contact encoders) have been used to measure the strip speed. But, mechanical contact measurement devices indirectly measure the speed of the strip and are subject to measurement errors due to slippage. Today, modern rolling mills are adopting non-contact laser gauges, such as the LaserSpeed™ length and speed gauge, to directly measure the strip speed in MFAGC applications. This new generation of laser-based gauge provides high measurement accuracy and high performance, and eliminates those measurement errors associated with mechanical-based contact measurement devices. This non-contact technology can measure strip speeds with ±0.05% accuracy and +/-0.02% repeatability, and without making contact with the product. It has no moving parts, eliminates all slippage errors, and is permanently calibrated.

This paper describes a proven method to accurately, consistently capture strip speed measurements in MFAGC applications, and discusses the process improvements and production benefits that can be achieved.
DISCUSSION

Problems with Mechanical Contact Measurement
Mechanical contact measurement devices indirectly measure the strip speed in MFAGC and other mill processes. They perform these measurements by using a tachometer connected to a roller or wheel in contact with the product or a driven roller. These mechanical systems are subject to slippage and debris buildup on the rotating measurement wheel, causing measurement inaccuracies. From a service standpoint, mechanical contact measurement devices are also prone to wear and mechanical failure, requiring operators to perform frequent calibrations, maintenance, and production line adjustments.

As seen in Figure 1, a large amount of coolant is used to keep the rollers cooled during the rolling process. This results in an excess of coolant on the strip. The excess of coolant causes slippage between the mechanical tachometer roller and the strip. Contact measurement devices attached to a driven roller will always lead the true strip speed changes. Also, contact measurement devices attached to a non-drive roller will always lag speed changes during speed acceleration and deceleration because of slippage errors.

Employing a non-contact measurement method, such as the LaserSpeed gauge, eliminates slippage errors and significantly improve the mill performance.

Using Non-Contact Laser Measurement in MFAGC Application
Using MFAGC to achieve better gauge control during the rolling process in cold rolling mills requires the speed and thickness of the strip to be measured at the entry and exit of each mill stand. Figure 2 shows non-contact length and speed gauges installed at the entry side of each stand in a four-stand, tandem cold rolling mill. Figure 3 shows a close-up of a LaserSpeed gauge at the entry side of stand 2. For MFAGC, a non-contact laser gauge is used in conjunction with a thickness gauge to perform the control application.
Overview of MFAGC Calculation

Figure 4 illustrates the basic mass flow principle for MFAGC applications. The mass of the steel strip flowing into the rolling stand equals the mass of the strip exiting the stand.

![Figure 4: Mass Entry = Mass Exit](image)

The MFAGC is calculated as follows:

\[ \text{Mass}_{\text{Entry}} = \text{Mass}_{\text{Exit}} \]  
\[ \text{Mass} = \text{Thickness (T)} \times \text{Width (W)} \times \text{Density (D)} \times \text{Length (L)} \]  
\[ \text{Length} = \text{Speed (S)} \times \text{Time (T)} \]

Width, Density, and Time are constant.

Therefore, substituting in the Mass formula:

\[ T_{\text{Entry}} \times S_{\text{Entry}} = T_{\text{Exit}} \times S_{\text{Exit}} \]  
\[ T_{\text{Entry}} \times \left( \frac{S_{\text{Entry}}}{S_{\text{Exit}}} \right) = T_{\text{Exit}} \]

In summary, a production plant using this process setup can effectively control the thickness out of a mill stand if the entry side thickness and speed as well as exit speed are known.

Improvements in Gauge Control

Field data has shown that the use of a non-contact laser gauge greatly improves the gauge control of a rolling mill. The graph in Figure 5 shows the gauge of the strip at the entry of stand one and exit of each mill stand in a four-stand, Tandem cold rolling mill without using a non-contact laser gauge to measure the speed. The speed reference is obtained from the drive rolls of the mill. The graph shows slippage between the strip and roll with driven and non-driven rolls. The strip always lags the driven roll and the strip always leads a non-driven roller due to slippage.

![Figure 5: Graph shows gauge of strip at entry of stand one and exit of each stand using a contact measurement method](image)
The graph in Figure 6 shows the same mill’s performance when a non-contact laser gauge is used for the speed measurement in the mass flow control system. The non-contact laser gauge measures the speed of the strip with +/-0.05% accuracy and +/-0.02% repeatability. This high level of measurement accuracy significantly improved the gauge control from +/- 3.0% to +/- 0.25%. In addition, more than 97% of the coil length is within gauge specification when using the non-contact laser gauge as compared to only about 85 to 87% of the coil being within specification when not using non-contact measurement for MFAGC.

The graph in Figure 7 shows the slippage between the driven roller and the strip in a cold rolling mill. The top graph shows the target speed for the control system. The bottom graph shows the speed measured by the driven roll (Blue line) matches the target speed of the control system but lags the actual strip speed by 500 milliseconds. The speed measured from the non-contact laser gauge (Red line) measures the true strip speed.

The biggest difference is seen during acceleration of the strip. Here the driven roll speed leads the actual strip speed by 500 milliseconds. Whereas the measured speed from the non-contact laser gauge follows the true strip speed exactly.
How Non-Contact Laser Gauges Perform Accurate, Direct Measurements

The LaserSpeed gauge will be used to describe the principle of operation for non-contact laser measurement. This non-contact laser gauge uses dual-beam interferometer technology to measure the product velocity. The non-contact laser gauge has one laser diode source but it is split into two beams that exit the gauge aperture at an angle. The two beams converge and overlap at the standoff distance. When the two laser beams intersect, an interference pattern of both light and dark fringes is created. This is called the measurement region and is illustrated below in Figure 8. As the strip passes through the measurement region, the frequency of the scattered light is directly proportional to the speed of the material. The scattered light is then collected by receiving optics within the gauge and is converted to an electrical signal. These electrical signals are then processed by digital signal processors (DSPs) to obtain frequency information, subsequently calculating speed and integrating it to determine the length. Pulses are generated at a rate proportional to the speed. This speed information is sent to a PLC to automate the mass flow gauge control.

![Non-contact laser measurement principle of operation](image)

Figure 8: Non-contact laser measurement principle of operation

The following illustrates the mathematics behind the measurement principle.

The distance \( (d) \) between the fringes is a function of the wavelength \( (\lambda) \) of light and the angle between the beams \( (2 \sin \kappa) \). It is represented in the following equation:

\[
d = \frac{\lambda}{2 \sin \kappa}
\]

The material velocity \( (v) \) is Distance / Time where the Distance is the distance between light fringes and Time is the time required to move from one fringe to the next.

\[
v = \frac{d}{t}
\]

Since the time is inversely proportional to the frequency of the signal, the material velocity can be obtained by multiplying the distance between fringes by the measured frequency.

Therefore, \( v = d \times f \)

Having measured the material velocity, the length can also be determined by integrating the velocity information over the total time.

\[
L = \int_0^T v \, dt
\]
Other Common Mill Applications
In addition to capturing accurate speed measurements for MFAGC, non-contact laser gauges are being used in a range of other demanding applications to improve process control and better control production costs. The following illustrates a few other common non-contact length and speed measurement applications.

Cut Control on a Slab Caster
Mills requiring cut length accuracy use the non-contact laser gauges to obtain precise and reliable slab length measurements for controlling a torch cutter. Once length is determined, a pulse output (e.g., pulses/unit) is sent to a control system, such as a PLC, to trigger the precise cuts. In some cases, the non-contact laser gauge performs measurements on a slab caster from the side. Because of the extreme heat conditions, the gauge is housed in a stainless-steel, heat-protected environmental housing and mounted up to 2.5 meters away from the slab. This helps reduce cooling requirements and premature failure risk due to excessive heat. In addition, the non-contact laser gauge eliminates the need for continual checks of cut length accuracy and constant tweaking of the control system. This results in significant money savings by producing the correct slab length required with minimal waste.

Elongation and Differential Speed Control at Temper/Skin Pass Mills
In order to produce quality products that meet exacting production specifications, it’s important for the temper mills and skin pass mills to accurately control the elongation ratio and speed measurements. Two non-contact laser gauges are used to control the entry speed and exit speed of the mill stand. Mills that have used contact tachometers have experienced huge errors in elongation ratio when the mill accelerates and decelerates. The main causes were due to slippage errors between the roller and the strip, and errors due to roller diameter wear. Since the non-contact laser gauges do not contact the product, measurement errors due to slippage were eliminated. The non-contact laser gauges obtained direct speed measurements of the steel strip with high reliability and high repeatability.

SUMMARY
The advantages of non-contact length and speed measurement systems, such as the LaserSpeed gauge, have been shown to improve gauge control during cold rolling processes. This non-contact, laser-based technology eliminates measurement errors associated with contact wheel tachometers and drive systems as a result of slippage and mechanical wear. In addition, non-contact laser gauges can be used in a variety of other mill applications to improve processes such as continuous length measurement of slab, billet and bloom casters; cutting control; elongation control in temper and skin pass mills; and other challenging applications. Take note that accurate length and speed measurements can effectively reduce scrap during production and increase capacity which ultimately improves productivity and product quality.