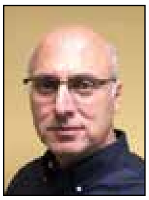
Optimizing Strip Speed Measurement for AGC/Mass Flow and Elongation Control With Laser Surface Velocimeters



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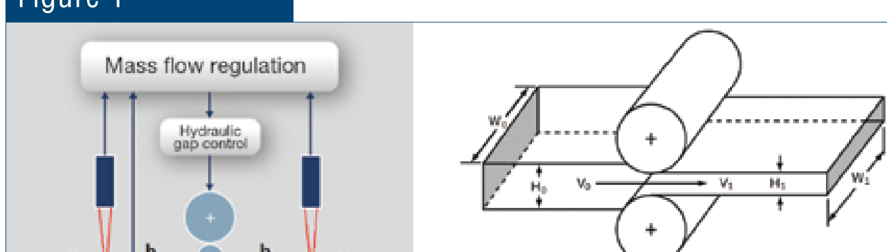
Leading manufacturers are constantly seeking out ways to increase yield, improve quality and reduce operating costs. Automatic gauge control using mass flow and elongation control has become a standard controls technique used in cold rolling to achieve these goals. Within these techniques, laser velocimeters are well known for improving control by offering a more accurate strip speed measurement as compared to contact methods, especially during acceleration/deceleration transition events in mill speed. This paper discusses differences between the two measurement techniques, as well as best practices for configuring, installing, integrating and optimizing a laser velocimeter measurement signal.

Automatic gauge control (AGC)/mass flow and elongation control are techniques used to manage strip thickness, surface quality, mechanical specifications and other strip parameters in tandem, temper and skinpass cold rolling mills. These techniques enable tighter control of strip thickness or elongation by providing faster and more accurate control of the roll gap. Not only have these techniques resulted in better control of critical process parameters, in recent years they have enabled manufacturers to accurately and reliably produce coil with variable thickness along various sections of the total coil length. Utilizing these control techniques has permitted roll mills to achieve specified thickness requirements over a greater percentage of the coil length, thus greatly improving the final yield.

Mass Flow Using AGC/Elongation Concept

The mass flow technique (Fig. 1) states that the strip thickness and speed entering the stand must equal the strip thickness and speed exiting the stand, while the width remains constant. Since the response time of a speed measurement is significantly

Figure 1



$v_0 \cdot h_0 = v_1 \cdot h_1$ (where $w_0 = w_1$)

where:
v_0 = velocity in,
h_0 = thickness in,
v_1 = velocity out,
h_1 = thickness out,
w_0 = width in and
w_1 = width out.

Concept of mass flow technique.

faster than that of the thickness gauge measurement, it enables better tracking of a specific point through the process. The exit thickness can then be predicted and controlled by measuring the thickness and speed entering the stand and the speed exiting the stand. The exit thickness gauge then confirms the strip thickness in a feedback loop.

Elongation is achieved through the temper/skinpass mill. Unlike tandem mills, which are designed for major reduction, temper/skinpass mills are designed to achieve the desired specifications for flatness, surface finish and quality, as well as final mechanical properties of the strip. Elongation control can range from roughly 0.25% to 4% depending on specifications and is controlled, similarly, by measuring and comparing the entry speed and exit speed of the mill using the following formula:

$$\frac{v_0 - v_1}{v_0} \times 100\% = \text{Elongation}$$

Methods of Measuring Strip Speed

Contact methods of measuring strip speed for mass flow/elongation calculations utilize encoders or tachometers on drive rolls or deflector rolls at the entrance and exit to the mill stand. These contact techniques measure the speed of the spinning roll rather than direct strip speed. The assumption is that the roll will spin at the same speed as the strip. However, in practice, this is not always true and depends on the conditions of contact between the roll and the strip. In short, these contact techniques are always susceptible to slippage between strip and roll, especially at the leading and trailing ends of the coil and during periods of mill speed transition of acceleration and deceleration. These errors generate inaccuracies in mass flow/elongation calculations and thus reduced control of the roll gap, causing variability in strip thickness or properties. The result is that less of the strip meets the specified requirements, which eventually affects quality, grade, yield and final market pricing.

Unlike contact methods, which do not directly measure strip speed and are susceptible to mechanical slippage between roll and strip, laser surface velocimeters are non-contact speed and length sensors that directly measure strip speed during the rolling process and are not susceptible to slippage. They have proven successful in many installations over the years as stand-alone sensor systems or built into the c-frame of a thickness gauge. Data not only show improved speed measurement during periods of acceleration and deceleration, where slippage of contact methods is most prominent, but indicates improved measurements at constant mill speed, where slippage may also occur with contact methods, to a lesser degree.

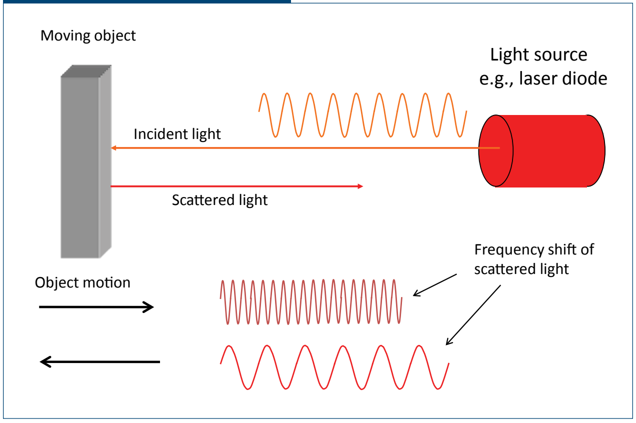
Laser Surface Velocimeter Principle of Operation

Laser surface velocimeters (LSVs) are non-contact, optical sensors that measure the velocity and length of a passing material. They are used for non-contact length and speed applications throughout the steel process, not only in cold rolling, but also in continuous casting, hot rolling, pickling, galvanizing lines, tube/pipe mills, rod/bar and more.

Doppler shift (Fig. 2) states that waves emitted or scattered from a moving object will undergo an apparent shift in frequency, proportional to the velocity of the moving object. As with sound emanating from a moving vehicle, light waves will also appear to compress (or increase in frequency) as the object is moving toward the viewer and appear to stretch (or decrease in frequency) as the object is moving away from the viewer. The object's velocity is determined by measuring this frequency shift. LSVs are designed to measure the doppler frequency shift of laser light scattered from the object and provide a direct output proportional to velocity. By integrating the velocity in real time, these systems will also determine the accumulated length of material that passed by, in real time.

LSVs utilize a differential doppler method to measure velocity, where the laser beam from a single laser diode is split into two beams and then directed so as to intersect at a fixed point in space, forming an "X" pattern (Fig. 3). This fixed focal point is called the standoff distance of the sensor system. As the beams intersect, they overlap in the area around the standoff distance, forming what is called the measurement volume or depth of field of the sensor system. The sensor

Figure 2



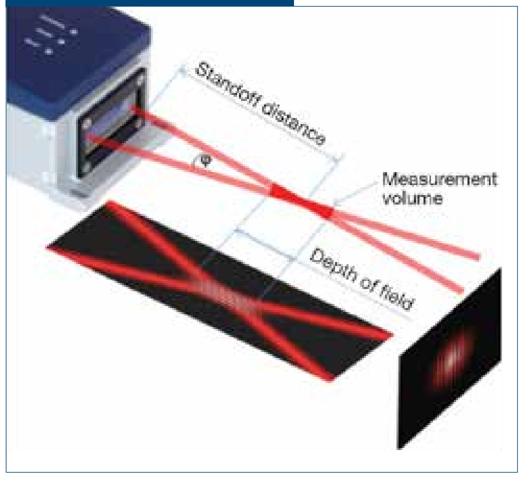
Principle of doppler shift.

will measure the speed and length of any surface passing within this depth of field.

Constructive and destructive interference of the light waves occurs within the depth of field area, where the two beams overlap, to generate what is called a fringe pattern. This is a pattern of parallel bright and dark fringes. A detector at the sensor head is aligned along the optical centerline of the system to view this pattern and to measure the intensity of light that is scattered from the area. As a surface moves through this fringe pattern, doppler shift of the two scattered beams occurs, causing the intensity of light at the detector to modulate. This modulation in intensity or "beat frequency" corresponds to the doppler shift and thus the velocity of the moving surface. Length and velocity data are then made available as process outputs in the form of quadrature encoder pulse, RS422, Ethernet and Fieldbus interfaces.

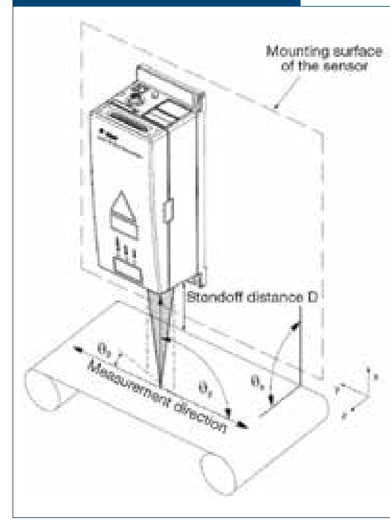
For those processes running at very slow speeds, reversing or experiencing frequent start/stop events, it is imperative to use a frequency-shifted system for highest accuracy. In such a system, the frequency of one of the exiting beams is shifted by a known offset frequency. This causes the fringe pattern in the measurement volume to modulate at a known frequency when the material is at standstill (v = 0). This technique enables LSVs to measure very slow speeds with high accuracy, actively measure at standstill (v = 0) and to determine the direction of the material (forward/reverse) for positioning-type applications.

Figure 3



LSV laser distance definitions.

Figure 4



Positioning of the sensor head.

Positioning the Sensor Head

The LSV is designed to be installed such that the optical axis is perpendicular to the target and at a standoff distance such that the measured surface remains within the depth of field. As shown in Fig. 4, there are three angles that can influence the measurement. Angles θ_y and θ_z will influence the measurement by introducing a predictable offset that follows the well-known cosine rule. As long as the angles are not changing, this will not affect the repeatability of the system and can be corrected through a simple, one-time process calibration of the installed systems. The third angle, θ_x, has no influence on the accuracy of the measured value, but rather the signal level returning to the sensor. It is recommended to keep this angle close to perpendicular, but, here, greater flexibility exists.

Figure 5

LSV with air wipe.

Figure 6

Three-axis adjustable mounting platform.

Figure 7

Thermo-protective housing.

Application and Installation Considerations

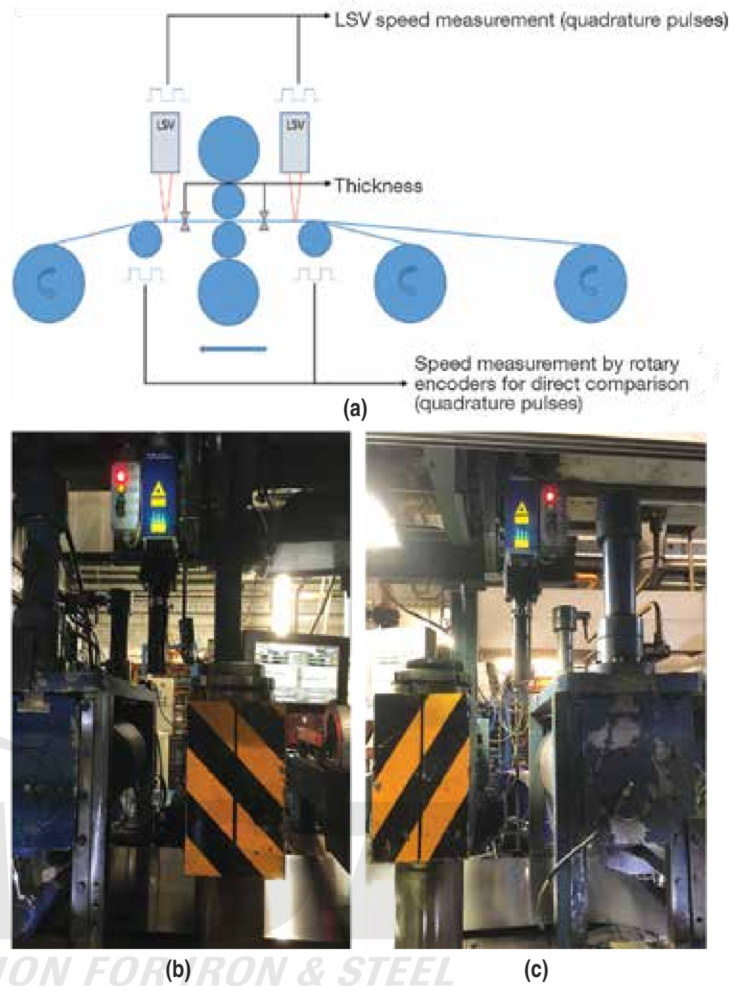
Installation conditions vary significantly from process to process and mill to mill. The conditions at a temper or skinpass mill will be very different than the conditions at a tandem mill, and so require different accessories and system configuration. Thoughtful consideration of these environmental conditions and project requirements will determine the success of the installation. Process speed, sensor working distance, depth of field, ambient temperatures, environmental conditions, line of sight and interface requirements are all parameters that should be known in order to build a proper configuration. With the appropriate accessories, sensors will operate well, even with steam and mist. However, care must be taken to keep the strip surface clear of rolling fluids at the point of measurement. Fluid passing through the spot can cause dropouts in the signal and affect the calculations and control. Cooling plates, full cooling housings, air wipes, quick-exchange protective windows, air amplifiers, tip/tilt alignment brackets and c-frame mounting kits are all available to optimize measurement reliability and long-term survivability in the application. Figs. 5–7 show some examples of various accessories.

Case Study: Waelzholz

Waelzholz is well aware of the benefits of LSVs and has been using them for more than 20 years. After a detailed analysis of available technology, Waelzholz selected the Polytec LSV Laser Surface Velocimeter for recent upgrades on two 4-high rolling mills used for reduction and skinpass at its Hagen, Germany, location. In this case, each mill utilizes stand-alone LSV sensors for strip measurement.

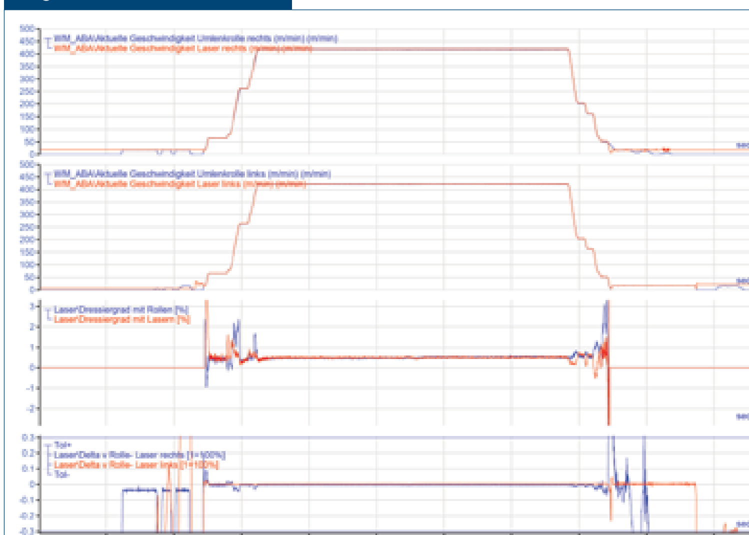
The application at each roll mill required a set of two LSVs, one located on either side of the mill. The combination measures strip entry and exit speed for determining elongation or for mass flow calculations. One of the 4-high rolling mills is a reversing mill so the strip could be moving in either direction.

Figure 8



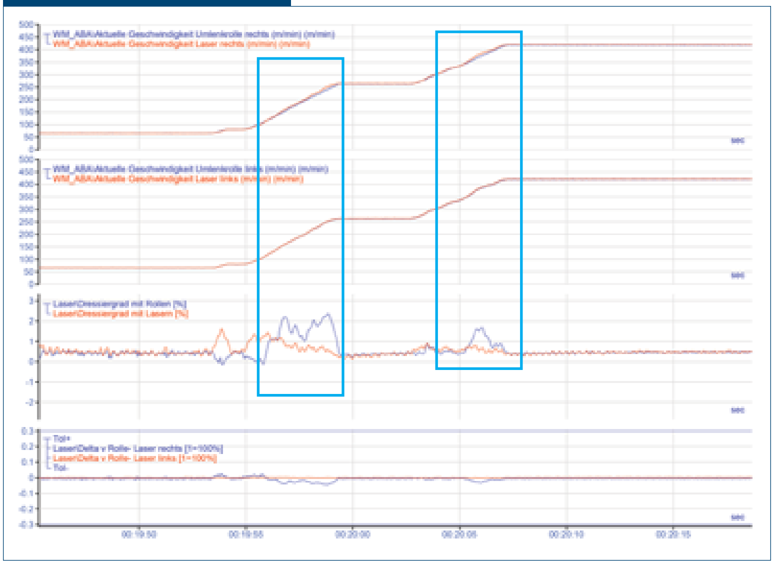
Schematic of 4-high rolling mill (a), Polytec LSV at right side of 4-high Rolling Mill 1 (b), and Polytec LSV at left side of 4-high Rolling Mill 1 (c).

Figure 9



Mill entry/exit speed and elongation: (LSV in red: deflector roll in blue).

Figure 10



Acceleration phase.

Figure 11

End of run.

The top graph shows the measured speed at mill entrance by the laser (in red) and the deflector roll (in blue).

The second graph shows the measured speed at mill exit by the laser (in red) and the deflector roll (in blue).

The third graph shows percent (%) elongation as calculated by the laser (in red) and the deflector roll (in blue).

Measurement Data at Start of Coil — Zooming in to analyze speed at the beginning of the run (Fig. 10), differences in measured velocity become apparent, especially at the entrance (graph 1). This is where slipping and momentum cause inaccuracy in the deflector roll-encoder measurement, while the LSV maintains true strip speed measurement. Graph 3 indicates the difference in measured elongation. As discussed above, the greatest differences in elongation calculation occur during periods of acceleration.

Measurement Data at End of Coil — Similar results are illustrated by zooming into the end of the run. Large differences occur during mill deceleration (Fig. 11).

Measurement Data at Mill Speed — Fig. 12 provides data at constant mill speed. Here it is seen that differences in measured speed between the laser (in red) and the deflector roll-encoder (in blue) also exist, even at constant mill speed. The differences, however, are less pronounced and start to accentuate as the mill begins to decelerate. In this case, a periodic oscillation exists in the deflector roll measurement that does not reflect true strip speed. This oscillation also causes an oscillation in elongation calculation, as seen in graph 3 of Fig. 12.

Fig. 8a is a schematic of the mill configuration while Figs. 8b and 8c show the Polytec LSV sensor installations at 4-high Rolling Mill 1.

Results and Measurement Data

As stated above, the advantage to using LSVs is the improved strip speed measurement for mass flow calculations and elongation measurements. Fig. 9 shows a comparison of speed as measured by a Polytec LSV and that of the deflector roll encoder.

Conclusion

Mass flow/elongation control theory has been used for many years in cold rolling. The control philosophy requires measurement of strip entry and exit speed, among many other parameters. Although encoders on deflector rolls or drive rolls will enable control of the mill, slippage between deflector roll and strip, changing roll diameter or shape and roll momentum all introduce variation into the speed measurement, thus introducing variability in mass flow/elongation calculations. Many rolling mill operations utilize LSV technology for direct measurement of strip entrance and exit speed to eliminate the inherent variations associated with contact measurement techniques. This enables optimization of mass flow/elongation control, which, in turn, provides greater control and tighter tolerance of strip thickness and elongation through the length of the coil. The result is a higher quality product that achieves tighter control of strip thickness, surface quality and mechanical properties, for more advanced applications and greater overall yield per coil. ✦

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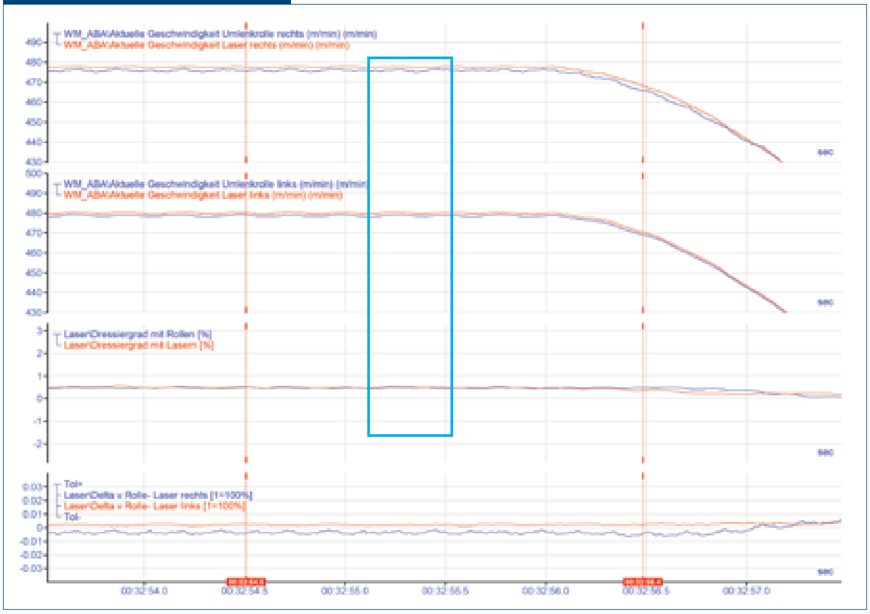
Figure 12



Measurement data at mill speed.