Optimizing Strip Speed Measurement for Mass Flow-AGC & Elongation Control with Laser Surface Velocimeters

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INTRODUCTION

In order to compete in the global steel markets, manufacturers seek out ways to increase yield, improve quality and reduce operating costs. Mass Flow – AGC and elongation measurements have become standard control techniques used in cold rolling to achieve these goals. Within this controls philosophy, Laser Surface Velocimeters are well known for improving process 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 outlines a case study to illustrate best practices for selecting and configuring a sensor system, installing and optimizing the measurement signal and integration to control systems.

Mass flow, automatic gauge control and elongation control are techniques used for many years to control strip thickness, surface quality, mechanical specifications and other strip parameters in Tandem, Temper and skin-pass cold rolling mills. These control 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 mass flow AGC 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 – AGC / ELONGATION CONCEPT

The mass flow technique (Fig. 1a & 1b) 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 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.

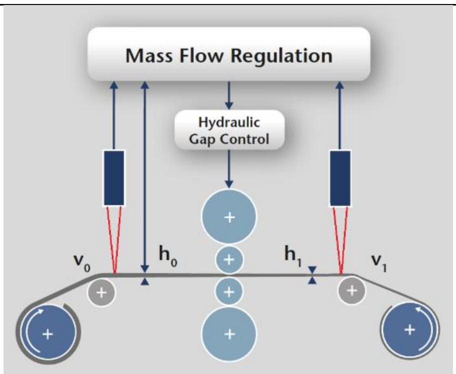	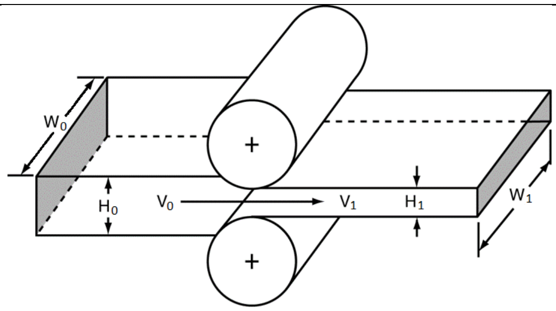
Fig. 1a: Mass flow regulation principle	Fig 1b: $v_0 \times h_0 = v_1 \times h_1$ (where $w_0 = w_1$)

Where:
v_0 = Velocity IN
h_0 = Thickness IN
v_1 = Velocity OUT
h_1 = Thickness OUT
w_0 = Width IN
w_1 = Width OUT

Elongation is achieved through the temper/skin pass mill. Unlike tandem mills, which are designed for major reduction, temper/skin pass mills are designed to achieve the desired specifications for flatness, surface finish & 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.

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

METHODS OF MESAURING 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 upon 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 & 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 standalone 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 strip speed where slippage is also occurring with contact methods, to a lesser degree.

LASER SURFACE VELOCIMETER
PRINCIPLE OF OPERATION

Laser Surface Velocimeters (LSV's) 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, galvinizing 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. Laser Surface Velocimeters 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.

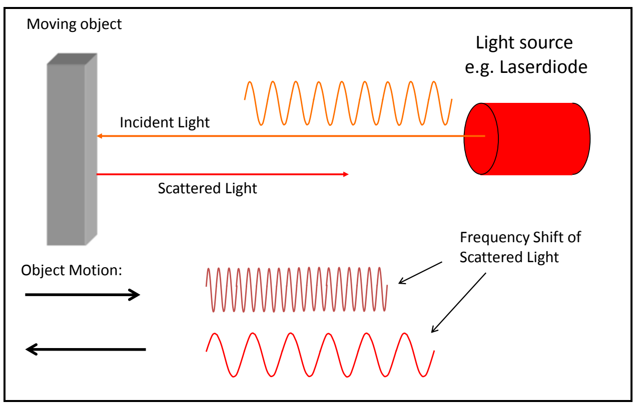

Fig. 2: Principle of Doppler shift with laser light

LSV's 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 stand-off 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 will measure the speed and length of any surface passing within this depth of field.

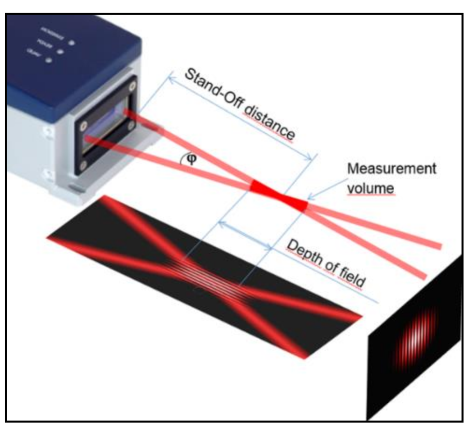

Fig. 3: Scheme of depth of field area generating a fringe pattern

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 center line 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 & velocity data is 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 LSV's 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.

POSITIONING THE SENSOR HEAD

The LSV is designed to be installed such that the optical axis is perpendicular to the target and at a stand-off 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.

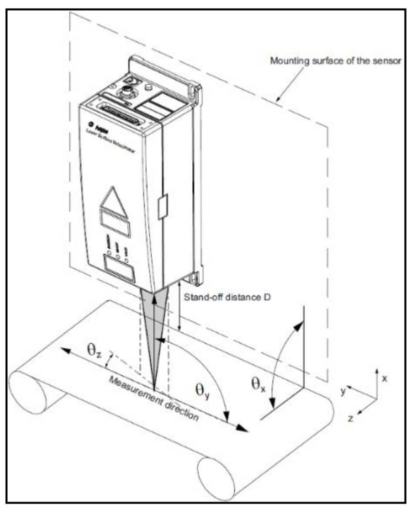

Fig 4: Positioning of the sensor head

APPLICATION & INSTALLATION CONSIDERATIONS

Installation conditions vary significantly from process to process and mill to mill. The conditions at a temper or skin pass 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, 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.

		
Fig LSV sensor with air wipe	Fig 3-axis adjustable mounting plate	Fig Thermo-protective housing

CASE STUDY ‘WAELZHOLZ’

As a global leader in the field of high-quality cold rolled steel strip and profiles, Waelzholz is well aware of the benefits of Laser Surface Velocimeters and has been using them for over 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 & skin pass at Hagen, its location in Germany. In this case, each mill utilizes stand-alone LSV sensors for strip measurement.

The application at each roll mill required a set of two LSV’s, 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 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:

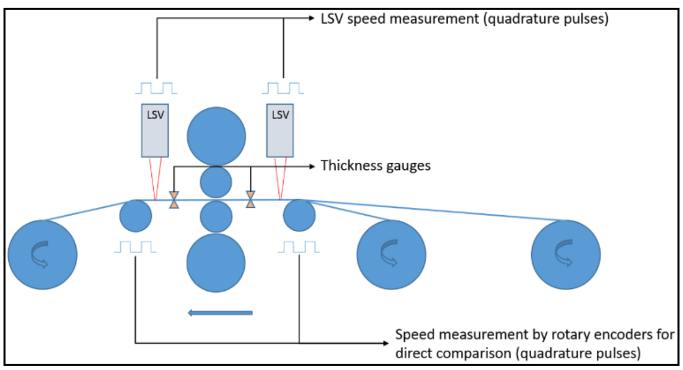

Fig 8a: Schematic of 4-High rolling mill

	
Fig Polytec LSV at right side of 4-High rolling mill 1	Fig Polytec LSV at left side of 4-High rolling mill 1

RESULTS & MEASUREMENT DATA

As stated above, the advantage to using LSV’s is the improved strip speed measurement for mass flow calculations and elongation measurements. The following graph (fig. 9) show a comparison of speed as measured by a Polytec LSV and that of the deflector roll encoder.

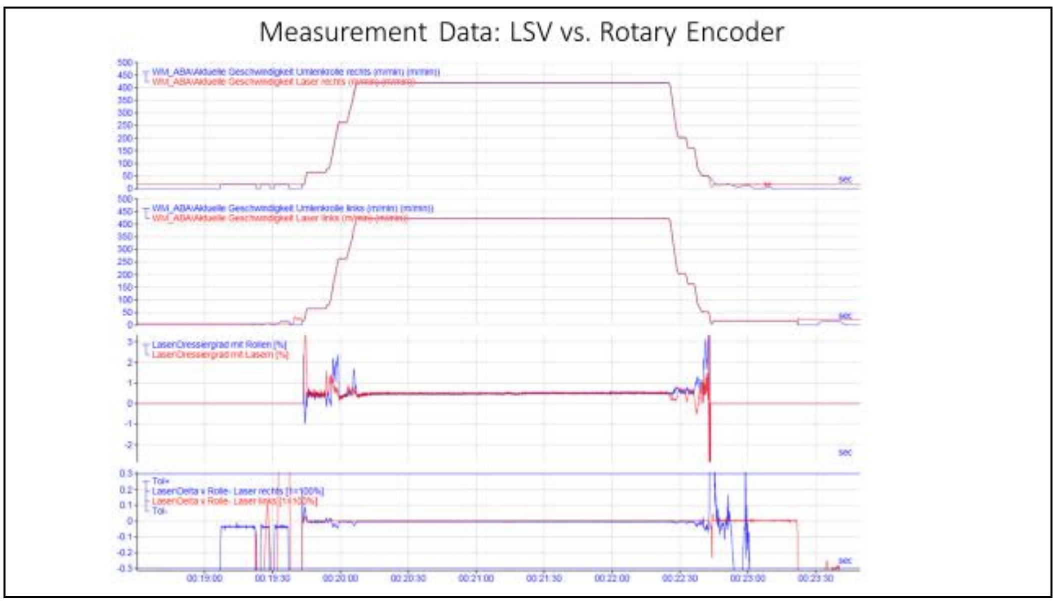

Fig. 9: Mill entry/exit speed & elongation: (LSV in red: deflector roll in blue)

- 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 (figure 10a), 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.

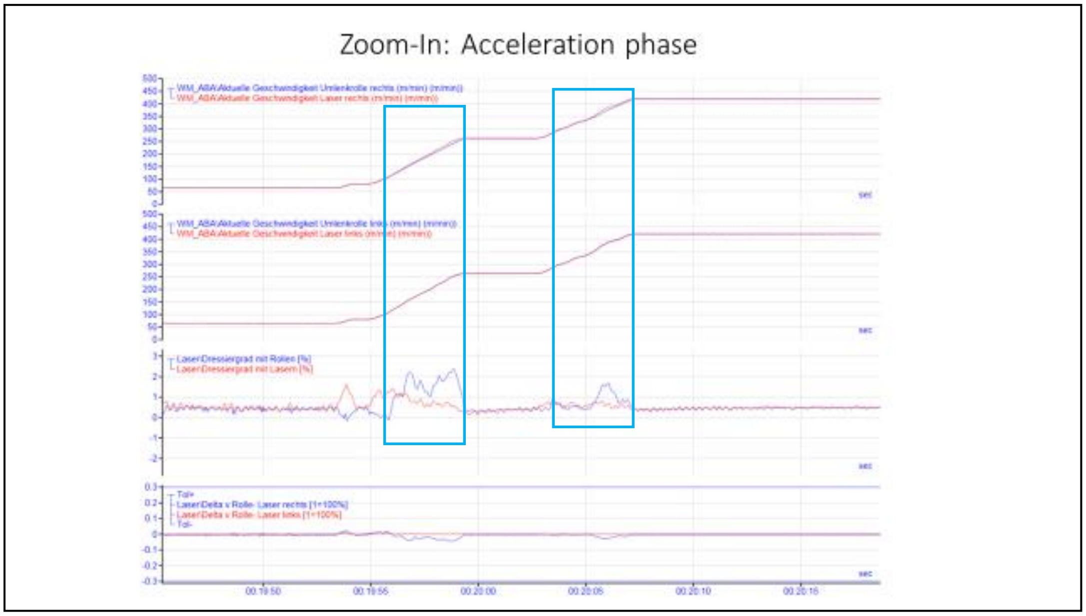

Figure 10a: Graph describing the acceleration phase

Measurement data at end of coil

Similar results are illustrated by zooming into the end of the run. Large differences occur during mill deceleration, see Fig 10b.

Fig. 10b: Graph describing the end of a run

Measurement data at mill speed (fig. 10c)

Figure 10c 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 figure 10c.

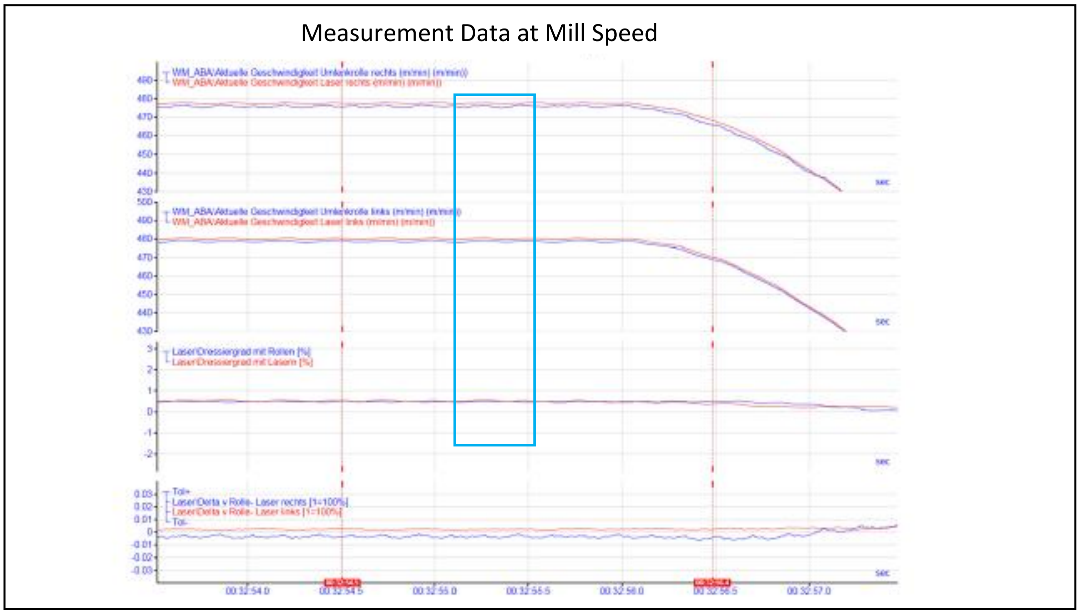

Fig. 10c: Graph describing the measurent data at mill speed

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 Laser Surface Velocimeter 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.