Achieving Successful Laser Velocimeter Measurements for Unguided Products Using New Innovative Technology for Tension Control of Wire Rod in Hot Rolling

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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Laser doppler velocimetry (LDV) technology is a well-proven method for accurately measuring speed and length. However, several applications, including those involving long cylindrical products, contain measurement difficulties that need to be overcome to achieve reliable measurements. For example, lack of guidance systems, high vibration levels and movements outside the range of the gauge make it difficult to use traditional LDV gauging methods, which require the laser to stay pointed at a certain area of the surface of the product. This issue is particularly challenging on round or cylindrical products. For this reason, for certain applications, it is difficult to gauge the speed of the material in a continuous and reliable way 100% of the time with traditional LDV systems.

A new LDV speed measurement technology (patent pending) improves the capacity and reliability of measurements for products in ways not previously possible. This paper focuses on this and other improvements made to the gauging of length and speed, including examples where this technology can be incorporated. For example, the optimization of cropping shear in rolling applications, gauging the flow together with a dimensional gauge, and control and monitoring of the high-speed processes in real time are some applications with potential benefits and savings that could benefit organizations and their processes.

Specifically, this new technology applied to the hot rolling of wire rod is revolutionary. It is now possible to apply control factors to the flow of steel between rolling devices at speeds higher than 120 m/second, virtually controlling the tension between the no-twist mill (NTM) and the sizing mill (RSM), improving the lifetime of guiding elements in the loop shaper, and controlling the discarded materials cut off by the shears throughout the process, as well as other applications.

Benefits of LDV Technology to Gauge Products Reliably at High Speeds

LDVs gauge speed and length without coming in contact with the product being measured. This technology is superior to older gauging methods, such as tachometers, contact encoders, and other older and more common measurement techniques. These gauging systems contain errors due to:

- Calibration errors — Diameters change as a result of dirt and wear.
- Maintenance — Wear on bearings and mechanical parts.
- Sliding/slipping — Caused by friction, pulley pressure, buildup of dirt, lubricants and coolants, and mechanical inertia.

LDV technology is robust and reliable even in extreme environments. It stays permanently calibrated and contains powerful and modern signal-processing systems that provide extremely fast signal processing and measurement response to the product being measured. The LDVs offer interfaces compatible with the older technologies, such as encoder pulse outputs, and also new industry-accepted fieldbus communication protocols that can be easily integrated into the systems within the scope of the application. Other advantages offered by LDV technology include:

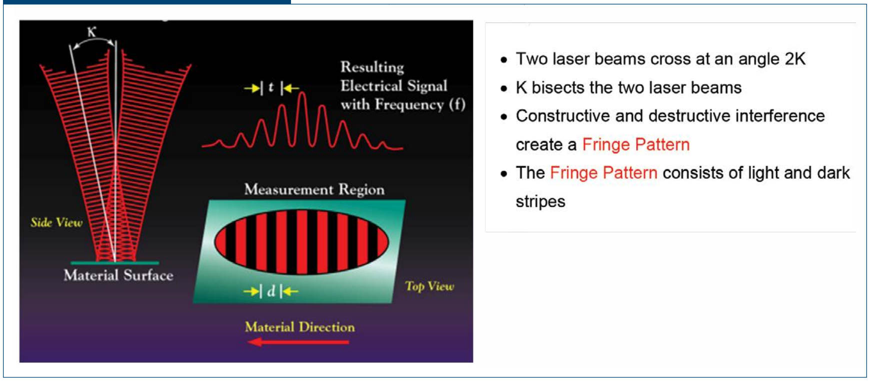
- Ability to measure forward/backward/zero velocity.
- Ability to measure extremely high levels of acceleration (>500 m/second).
- Speed measurement range from 0 to 20,000 m/minute.
- High precision or accuracy — 0.03% in measured length and 0.02% repeatability.
- Based on an optical system without any moving parts to wear out.
- Measurement of any flat or round material.
- Flexible industrial communication interfaces that allow for simple implementation with users' systems.
- Configurable settings to tailor the LDV's operation and optimal performance to each application.
- Availability of different models to address the specific needs of each application.

Modern laser velocimeters are encased in small, sealed and robust protective boxes with optional additional protection for extreme environments in applications such as slabs and billets, strip mills, bars, wire rods and other hot rolling uses where heat, steam, mist, dirt and other contaminants pose an extreme challenge to robust and reliable operation of the LVD.

Operation

The operating principle of the LDV gauge is based on dual-beam laser doppler velocimetry (DBLDV). When two laser beams intersect, an interference pattern of both light and dark fringes is created. This is called the measurement region and is illustrated in Fig. 1.

Figure 1



Measurement region, fringe patterns, beam geometry.

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

$$d = \frac{\lambda}{2\sin\kappa} \quad \text{(Eq. 1)}$$

Nearly all materials have light-scattering sites — particle and minute facets that make up the surface microstructure. As a light-scattering site passes through the measurement region, light is scattered every time it passes through a light fringe. The scattered light is collected and converted to an electrical signal that has a frequency (*f*) proportional to the material velocity (doppler frequency).

The material velocity (ν) is distance/time where the distance is the distance between light fringes and time is the time it takes to move from one fringe to the next:

$$\nu = \frac{d}{t} \quad \text{(Eq. 2)}$$

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.

$$t = \frac{1}{f} \quad \text{(Eq. 3)}$$

Therefore,

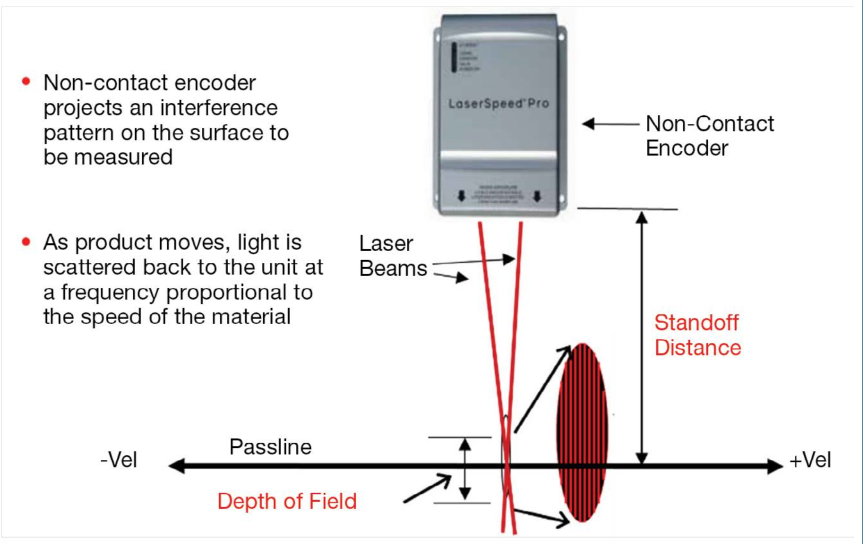
$$\nu = d * f \quad \text{(Eq. 4)}$$

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

$$L = \int_0^T \nu \, dt \quad \text{(Eq. 5)}$$

There are many applications for length and speed measurement using this technique. It is

Figure 2



Application principle of laser doppler velocimetry (LDV) technology.

very accurate and consistent and works on virtually all surfaces. An application view is shown in Fig. 2. It illustrates a simple measurement application and details industry-accepted terms and definitions.

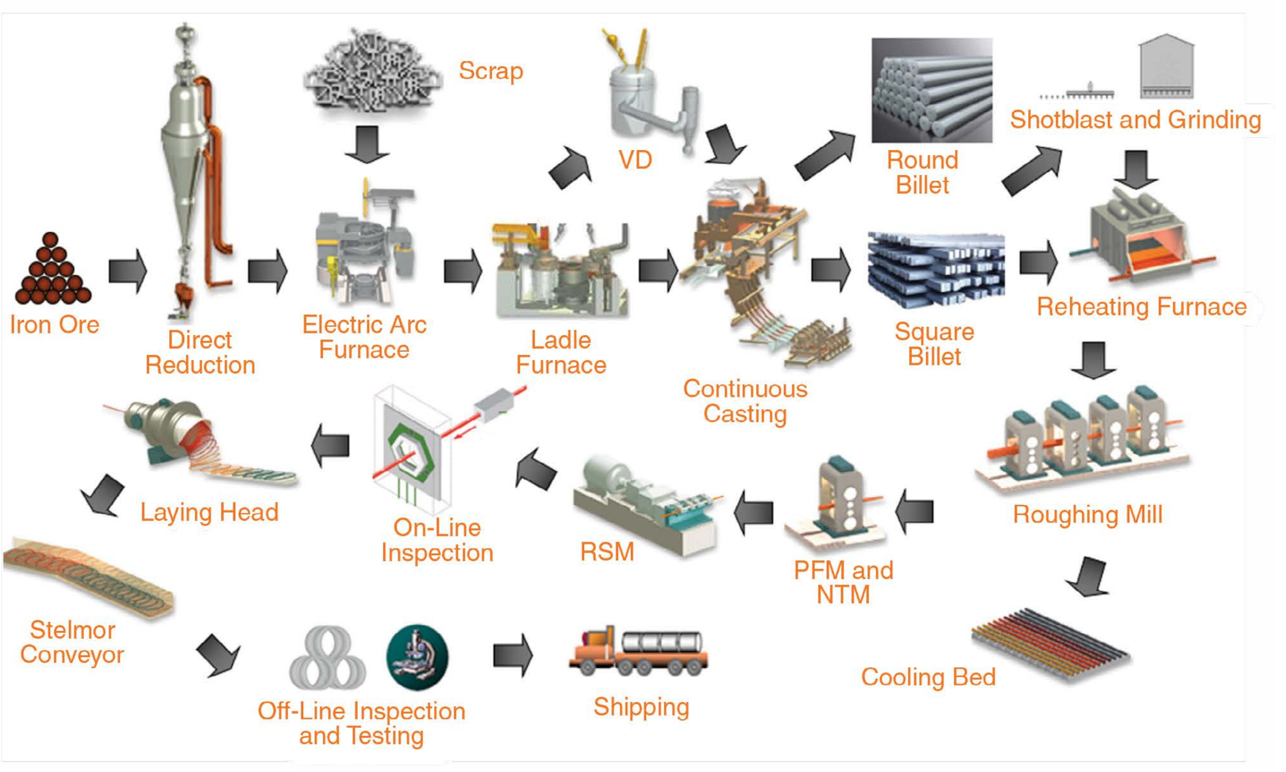
Process Diagram

LDV technology is especially valuable for use in the metals industry for many applications, some of which will be discussed. A schematic showing the manufacture of special steels, with an electric arc furnace route and with application for long products, is shown in Fig. 3.

Generally, hot rolling of long products, such as wire rod, has a configuration consisting of a roughing mill, intermediate mill and pre-finish mill (PFM), NTM, RSM, and laying head for roll products, which are coordinated by a control system based on speeds, distances between equipment and photocell signals for process control.

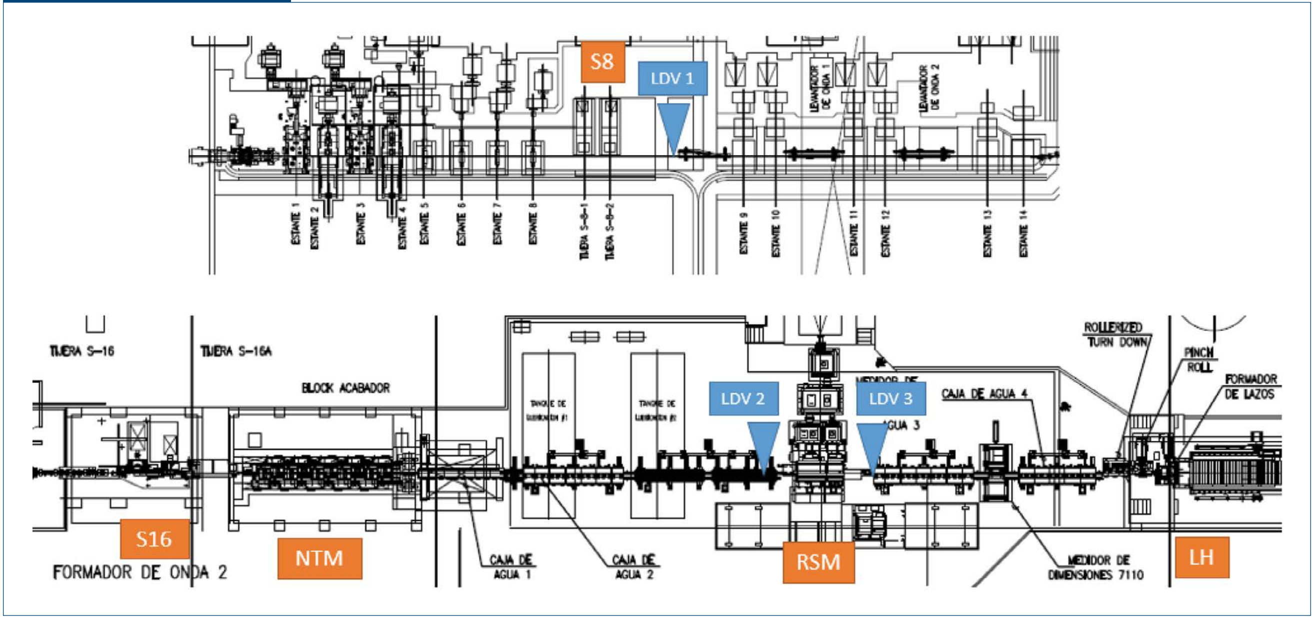
The loop shaper is made up of a straight input section aligned with the inside rotation axis of the tube, a middle curved section that has a gradually increasing radius, and a delivery section that has a design diameter similar to the one expected for the turn.

Figure 3



Process diagram for Ternium Puebla (long products).

Figure 4



Detailed view of the rolling mill and current location of the LDVs.

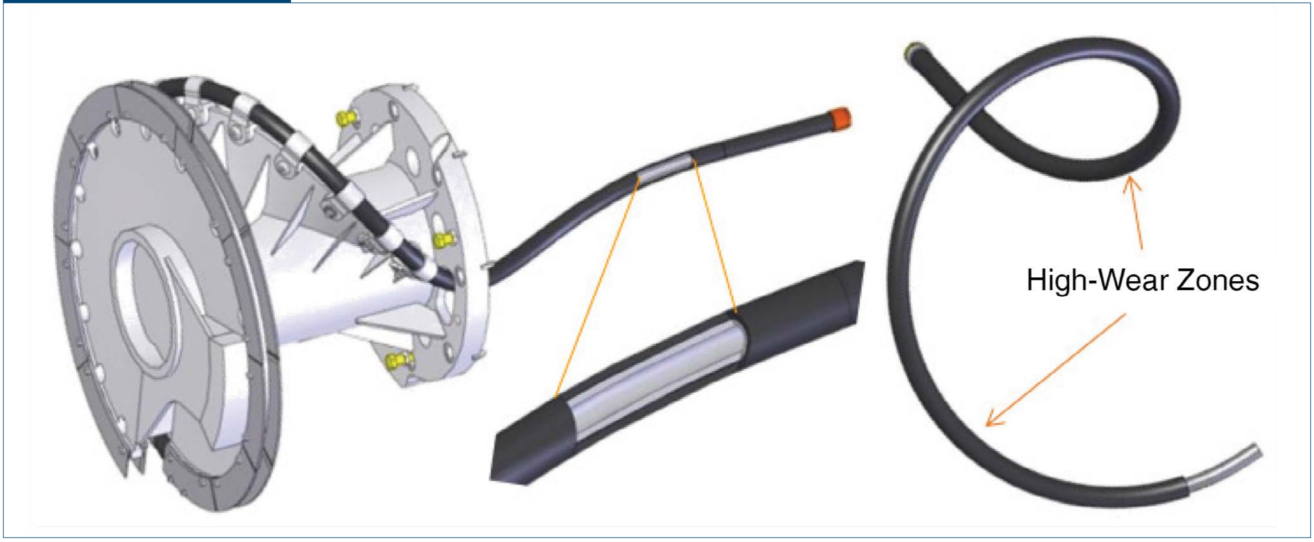
Conventional LDV vs. New LDV Technology Control

There are significant challenges associated with the gauging performance on round products using LDV technology because the gauging point (LDV laser spot) is required to remain on the product. This is especially challenging when the product size is small and is not able to be guided, so the violent action of size reduction or other processing causes significant product positional movement. Assuming the laser spot on the product to be quite small, as it is for standard LVD implementation to achieve reliable and accurate measurements for these types of products, the following is required:

- Align and keep the beams of the laser within 20% of the center of the diameter (±10%).

Examples of both successful and unreliable measurement situations using standard LDVs are shown in Fig. 6.

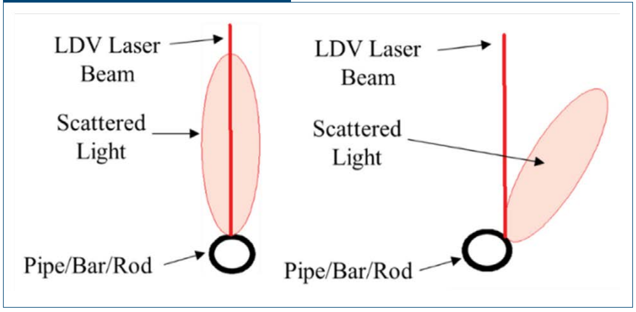
Figure 5



Loop shaping set and tube showing areas of premature damage.

- Bottom left: Proper gauging due to light reflected toward the velocimeter.
- Bottom right: Less reliable gauging due to absence of light reflected toward the velocimeter — may result in minimal or no velocity measurements as product moves positionally.

Figure 6



Measurement/gauging of wire rod speed.

Unfortunately, it is not always possible to keep the laser energy of standard laser velocimeters on the crown of round products, especially if the product is moving violently and the product cannot be guided. As a result, a new type of solution is needed.

This new gauging solution provides a much larger measurement area. With these new dimensions, it can be guaranteed that the energy of the laser remains focused on the crown of the round product and reliable measurements are achieved, even under the following conditions:

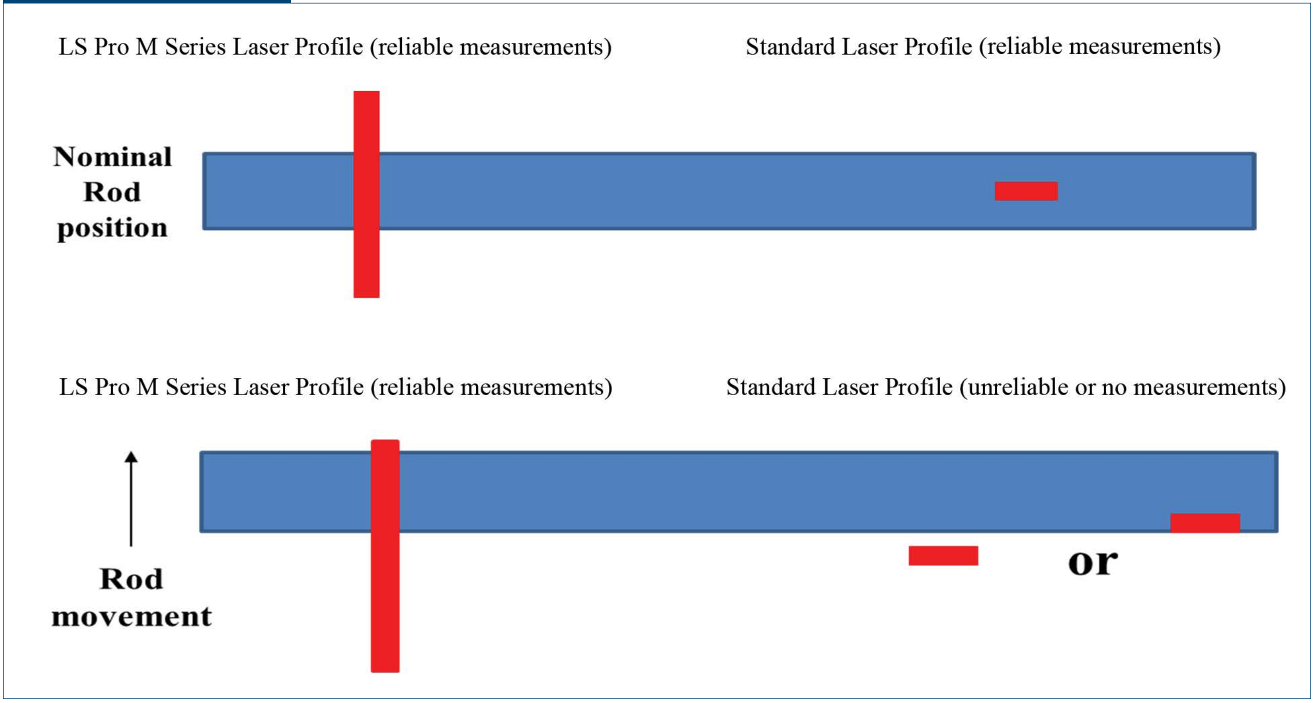
- The product is round, moves positionally and cannot be guided.
- The product vibrates considerably during the process.
- The product is red hot with high levels of infrared (IR) radiation.

A patent for this solution is pending. This new line of laser velocimeters (marketed as LaserSpeed Pro M Series) has the following advantages:

- Larger laser measurement area — 20 mm, so the product always reflects laser energy and measurements are achieved.
- Patented laser profile to guarantee a high level of accuracy and a sufficiently high level of signal sensitivity.
- Excellent performance on products emitting high levels of IR radiation.

See Fig. 7 for the proper or optimum product positioning of a product with respect to the LDV laser.

Figure 7



Position of laser on a rod with a standard laser and a LaserSpeed Pro M Series velocimeter and effect on measurement capability.

This results in accurate and reliable measurements.

However, if the product position moves, the standard laser profile contacts the product at a high angle, or misses the product completely, resulting in unreliable or no measurements. In this case, however, if the expanded/rotated laser beam profile is used, it remains in contact with the product, resulting in accurate and reliable measurements.

The conditions outlined in Fig. 7 were tested on-line at a hot rod process line to determine the effectiveness of utilizing this new measurement concept. Data shown in Figs. 8 and 9 were taken on the same hot rod line, with the same product, using standard LDV technology, as well as with the LaserSpeed Pro M Series, running at approximately 35 m/second.

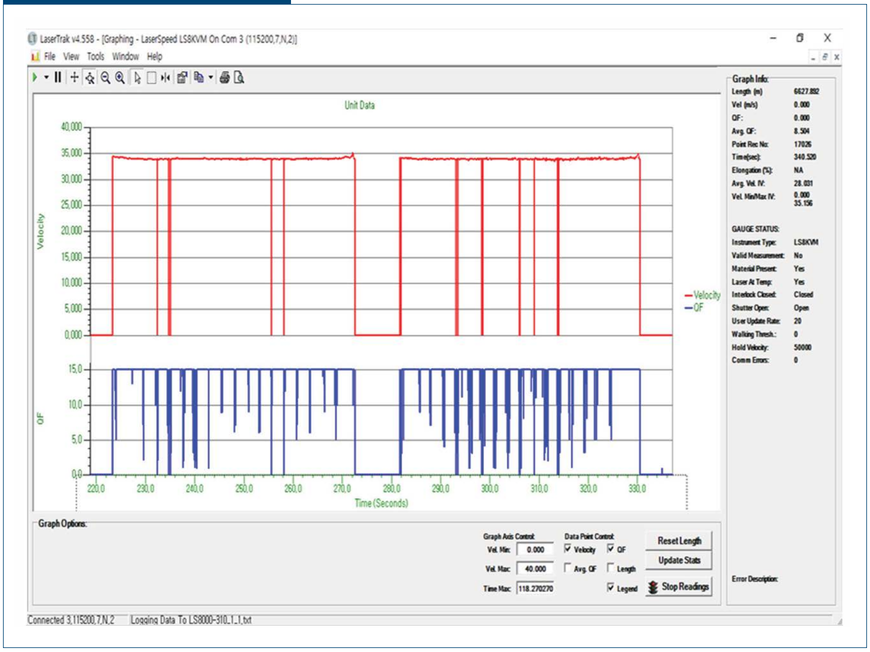
If one analyzes speed signals (shown in red trace) and measurement quality factor (shown in blue trace) in Fig. 8, a clear difference can be seen between the quality of the measurement and reliability of both systems to measure wire rod speed.

The results shown in Figs. 8 and 9 illustrate that the quality and reliability of velocity measurements with the LaserSpeed Pro M Series' laser profile eliminates the challenges of product movement for this application, and therefore support the advanced control of these processing lines.

Test conditions for the trial were constant while each LDV was used to measure the rod velocity. Quality factor is a quantitative measure of the quality and number of measurements that are possible. A stable number of 15 indicates excellent results, whereas drops in this number and trace indicate a reduced number of valid measurements or a drop of measurements.

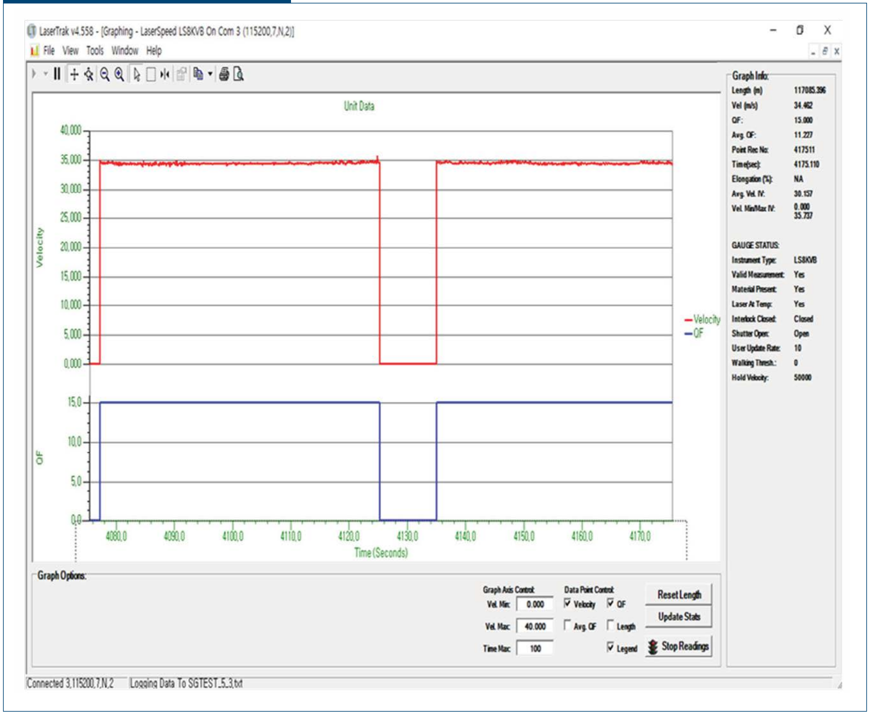
Applications for the use of LDV velocimeters for long products

Figure 8



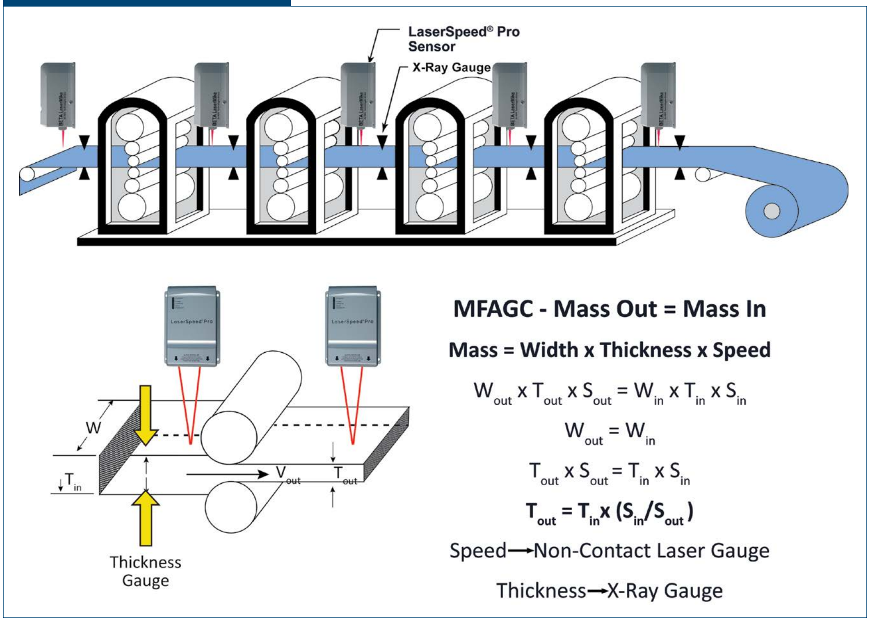
Standard LDV measurements on rod mill (red trace – velocity, blue trace – quality factor).

Figure 9



LaserSpeed Pro M Series LDV measurements on rod mill (red trace – velocity, blue trace – quality factor).

Figure 10



Velocity for mass flow automatic gauge control (MFAGC).

(in addition to the many flat product applications) include:

- Pipe/tube mill — Length verification, cut to length/saw applications, camera inspection applications.
- Rod/bar mill — Length verification, cut to length/shearing, elongation/tension control applications.
- Wire drawing lines — Elongation, velocity control, total length measurement.
- Bar/billets — Profile measurement applications (OEM), cut to length.

Mass flow automatic gauge control (MFAGC) for cold rolling mills is one application that has been greatly improved by non-contact speed measurement gauges. All major single-stand and multi-strand tandem cold rolling mills in the world today use LDV measurement gauges to improve the performance of their MFAGC or elongation control. See Fig. 10 for an illustration of MFAGC or elongation control.

The concept of mass flow/elongation and tension control now can be applied successfully to long (cylindrical) products, given this recent advancement in measurement capability as achieved by the LDV implementation discussed in this paper.

Optimization of Processes With LDV Technology

Tail-End and Front-End Cutting Control at the Shear S8 — The need to detach and shear in rolling is meant to avoid passing cold material that may cause events such as cobbles, damage of the guidance system and rolling rollers. As such, it is sought to reduce these issues to a minimum while maintaining the continuity of the process. The current control form is based on the theoretical speed of lamination — that is, the roller diameters and the speed reference are taken according to the revolutions at which each stand rotates (see next formula) to obtain the speed of the material in the control zone of the shear S8 (roughing mill and intermediate mill between stands 8 and 9).

$$\left(Roller\ diameter - Factor\ groove\right) \times \left(Roller\ speed\right) = Speed\ linear\left(\frac{m}{s}\right) \tag{Eq. 6}$$

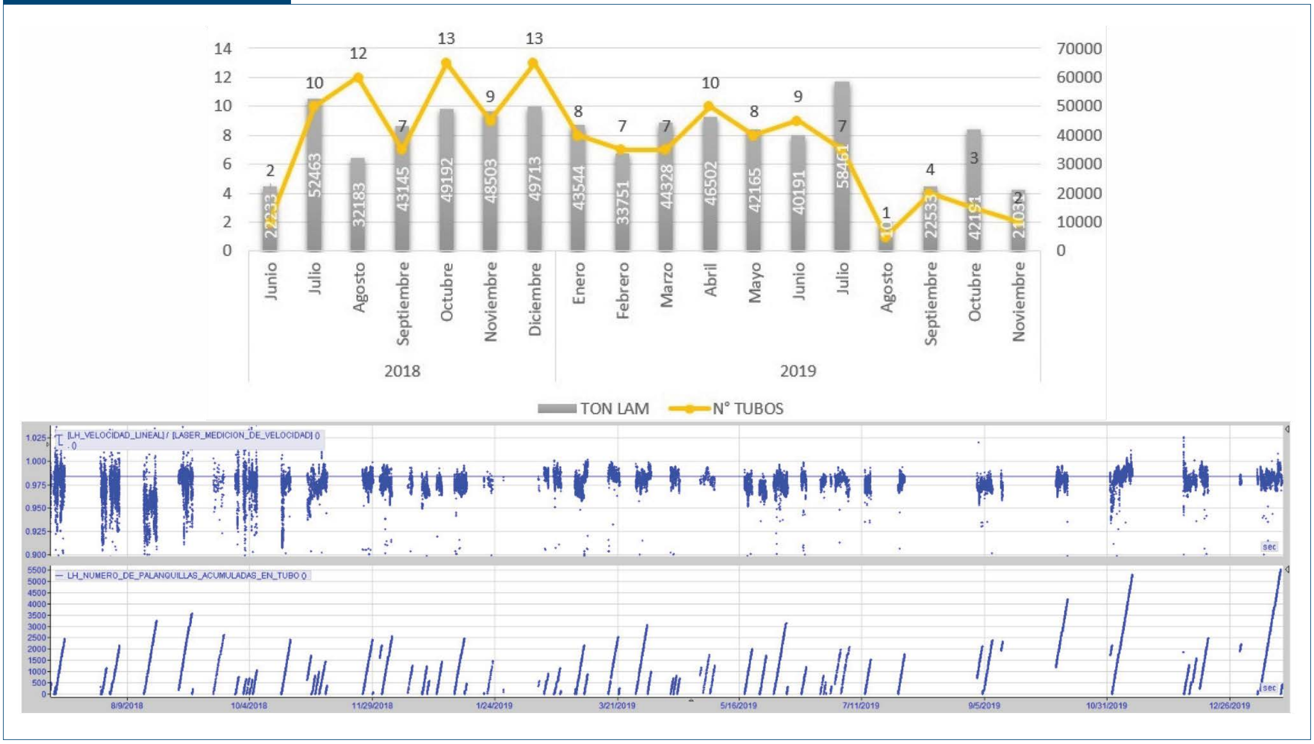
This calculation is strongly affected by the gap adjustment between rollers and the flow of the

Figure 11

Loss of PAM cutting control (kg/ton)	0.59
Annual production reference (Mt/annum)	601
Annual PAM decrease (tons/annum)	355
Average cost of PAM (US$/ton)	164
Cost of charge (US$/ton)	471
Scrap recovery (US$/ton)	307
Annual economic benefit of PAM (MUS$/a)	58

Cutting shear between roughing and intermediate mill and the economic benefit.

Figure 12



Reduction in the consumption of tubes in the loop shaper vs. rolled tons and control objective in the process between the speed ratio of the material vs. 5.5-mm loop former.

material that is fed to stand 8. Once the material leaves stand 8, its speed is governed by stand 9 so that the greater the tension between them, the greater the increase in the speed of the material.

The speed increment (tension between stands) generates a variation that affects the start time of the beginning of the cut, causing a variation on the length of cutting tail end versus the selection on the control. This dispersion is caused by variations in the rolling process (gaps, temperature, type of steel, etc.). In order to rationalize the waste material by this cut, an LDV is placed to measure the speed in real time and use the information for the control and time coordination to start the cutoff, improving the accuracy, precision and decreasing the amount of material removed. The greatest variation occurs in the cutting tail end. That's why the laser is placed at the exit of the scissors to be able to have a reading of the speed of the material when it leaves stand 8.

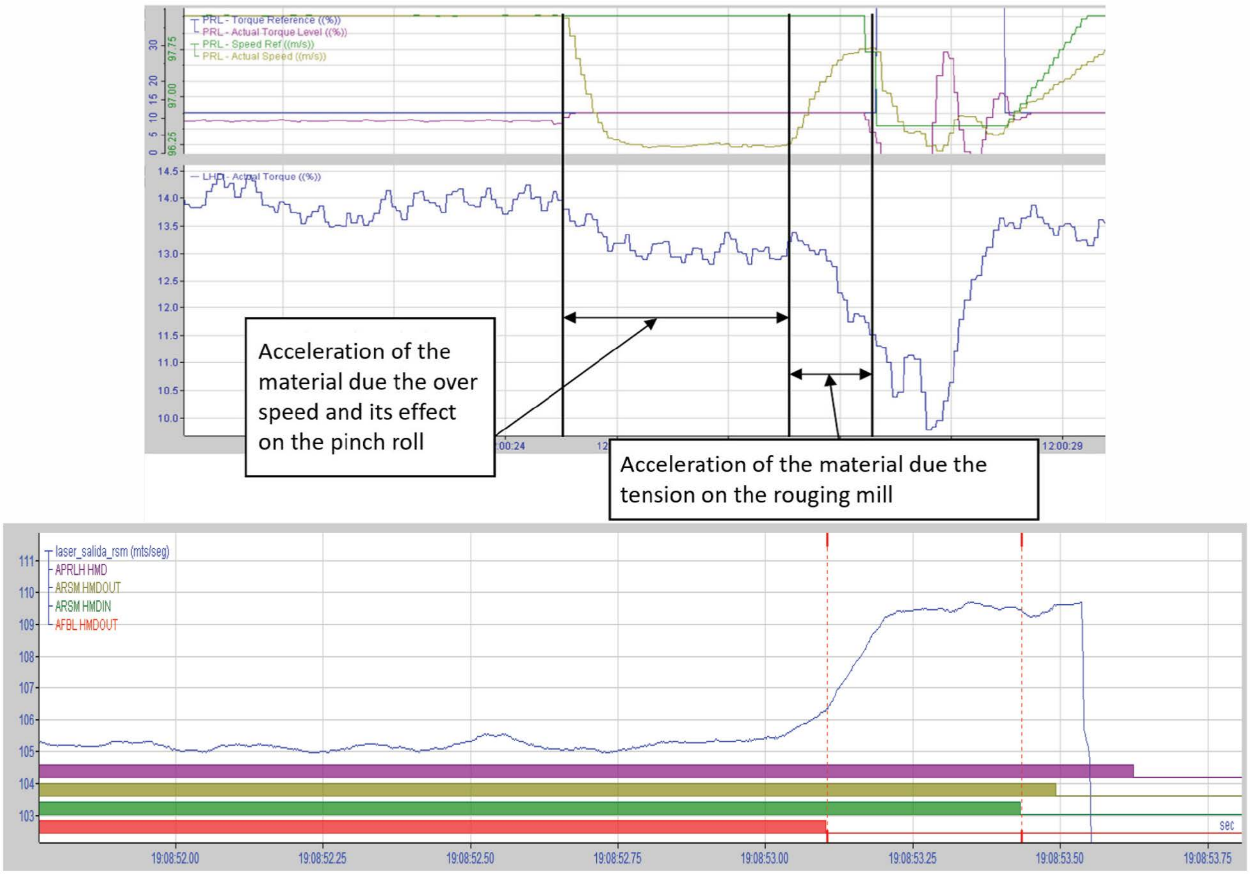
Increased Life of the Tube in the Laying Head — The premature wear of the laying head pipe generates exposure of personnel to maneuvers to replace components at high temperature, exposure to suspended loads, operational delays, and qualitative problems due to surface damage in material and/or bad formation of the wire rod. Therefore, the aim of this project was looking for the best process condition to minimize wear of pipe, increasing its useful life and maintaining the stability of the process.

The life of the laying head pipe depends largely on the correct formation and control of the rings. Originally, the control practice used to have references to control the ratio of rolling speed and the speed of the laying head; therefore, it depended heavily on the experience of the operator and his ability to detect and act on constant changes on the process conditions, such as steel type, gap, tension, downstream adjustments, temperature, etc.

At the beginning of the tests to increase the life of the pipe, the objective was to maintain the charge of the laying head within a control range for a particular diameter and try to control the size of the rings. Although some improvements were obtained, it was not sufficient as a reference since it is affected by the previously mentioned variables and resulted in an indirect approach that only worked under stable conditions.

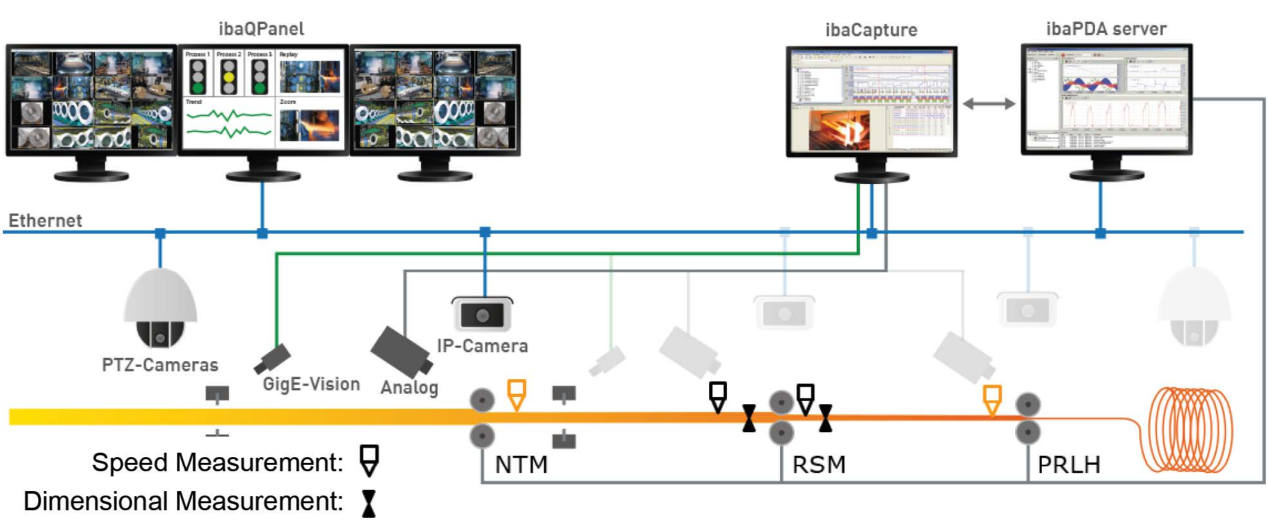
Subsequently, the use of LDV technology was implemented to detect the material at 110 m/second despite the vibration, 100% of the time, managing to measure the real speed of the material and establish a reference against the speed of the loop former. By measuring and creating the relationship of speed of the material against the over speed of the lying head, it was possible to find the reference between this value and

Figure 13



Effect of tension over the tail of the coil[1] and the acceleration of the material from 105 to 109 m/second (4%) in 0.2 second.

Figure 14



Integration of dimensional measurement, LDVs and vision with a signal acquisition program in real time to control the process.

the life of the pipe compared to the formation of the rings and determined the best value through control tests. The result was to lower the range of dispersion and increase the life of the forming pipe (see Fig. 12).

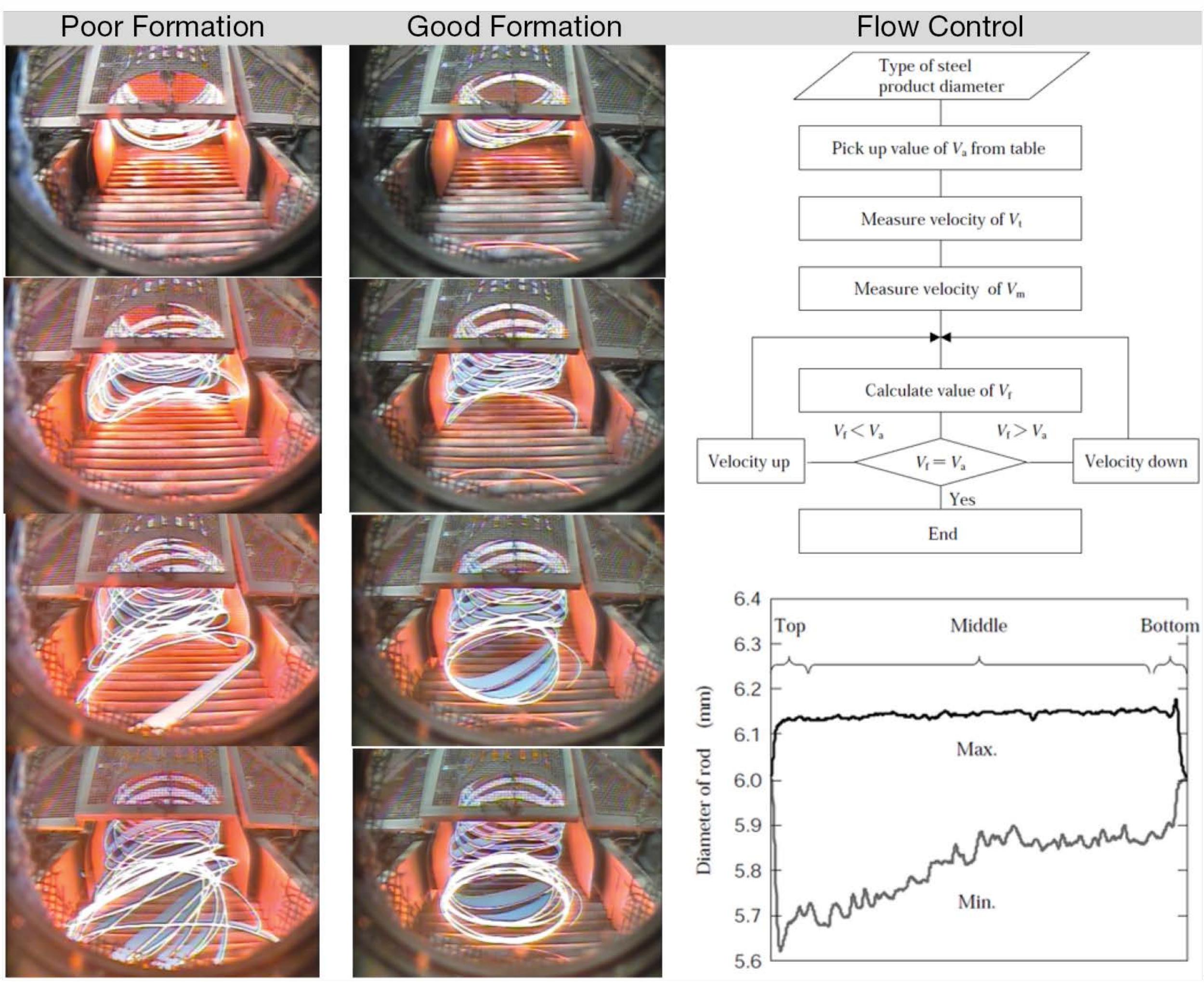
It was possible to achieve a control for around 95% of the length of the material. The measurement of the real speed of the product in real time makes it possible to detect variations in the process, regardless of their origin, and control the formation of the rings. This provides the necessary tools to relate this variation to different components, such as laying head parts and/or changes in the process. As a result, the increase in the lifetime of the tube and the reduction of poor formation of the ring leading to quality problems is archived.

For the rest of the material, the greatest contributor to the variation in the front end and tail end is the tension between the block and the RSM. With the LDV laser technology, it may be possible to control this condition in the near future.

Tension Control — Today, the tension between the NTM and RSM in most of the conventional rolling mills of wire rod around the world is controlled by the over speed factor "R." This paper describes the idea of mounting a virtual looper and by having the on-line speed measurement and knowing the dimension of the material, it is possible to control the flow.

The control at the front and tail end of the coil is the most critical and difficult part to manage. Quality issues must be avoided. With a LaserSpeed Pro M Series at the exit of the NTM and entry of the RSM, it is possible to know the changes in tension when the tail leaves the intermediate mill and PFM. The tension is a known variable of the process and can't be avoided. At this point, the wire rod has a 7- to 9-mm

Figure 15



Effect over the coil formation with and without tension control on the ring, flow chart of tension control and its correlation with change in diameter when speed is varied.[2]

diameter, exits at 70 m/second with a 5.5-mm or 6.5-mm final product dimension.

The focus at this point is to control the elongation between the NTM and RSM and keep it to the minimum to avoid any impact on the critical parts of the coil. As such, it will be possible to control 95% of the material and the diameter of the ring from the laying head to the Stelmor conveyor.

Conclusions

The RSM and auxiliary equipment are critical in the production of wire rod. The applied control technology has a direct influence on the final quality of the product. Therefore, the design and updating of the automation system are very important.[3]

The actual control technology for long mills has not been perfected due to the technical difficulty of measuring the speed accurately. This paper seeks to build the foundations for using LDV technology to control tension and measuring changes in speed in real time on critical moments of the process, such as at the tip and end of the roll.

Future work will focus on automatically controlling variables without saturating the current mill controller, looking for the full control of the material, increasing the lifetime of the mill guidance elements, reducing discarded material costs and operational downtime, and improving the quality of the product.

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