OVERCOMING MECHANICAL ISSUES IN OBTAINING ACCURATE, STABLE LENGTH AND SPEED MEASUREMENTS IN STEEL MILLS AND BILLET CASTER APPLICATIONS[1]

Manufacturers realize significant quality, productivity, and cost benefits

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Abstract

Accurately measuring the length and speed on continuous slab, billet, and bloom casters has been very difficult due to a number of mechanical system challenges, such as heat, scale build-up, and the deterioration of mechanical parts. It is well documented that mechanical encoders do a poor job of measuring the actual length and speed on continuous casters during production. The heart of the problem is that mechanical encoders do not measure the product length and speed directly; they perform these measurements indirectly by using a tachometer connected to a roller or wheel in contact with the product. These mechanical systems are subject to slippage and calibration changes caused by variations in the diameter of the roll or wheel due to dirt build-up or wear. In addition, it is extremely difficult to obtain accurate measurements in extreme hot manufacturing environments. A non-contact gauge that directly measures the product length and speed would eliminate the measurement errors associated with contact measurement techniques. The new generation of cost-efficient, higher accuracy gauges, such as the LaserSpeed gauge, is utilized in many continuous caster manufacturing applications today. For example, this advanced measurement technology has the ability to measure these dimensions at very slow speeds with 0.05% accuracy and without contacting the slab or billet. It can even accurately measure the length and speed of the line when it is at a standstill, and it can accurately measure the cast and slag equally as well. Maintenance costs are also reduced since the gauge can be mounted up to 2.5 meters from the slab or billet, reducing cooling requirements and premature failure risk due to excessive heat. This paper describes a proven method to accurately and consistently capture length and speed measurements on continuous slab and billet casters and other processes during production, and discusses some process improvements that have been achieved.

Key words: Non-contact gauge; Laser measurement; Length and speed; High accuracy.

SUPERANDO PROBLEMAS MECÂNICOS EM OBTENDO PRECISO, COMPRIMENTO ESTÁVEL E MEDIÇÕES DE VELOCIDADE SEM CONTATO EM USINAS SIDERÚRGICAS E APLICAÇÕES *BILLET CASTER*

Fabricantes percebem benefícios significativos de qualidade, produtividade e custo

Resumo

Medir com precisão o comprimento e a velocidade em lingotamento contínuous de placas, tarugos, e bloom tem sido muito difícil devido a uma série de desafios em sistema mecânico, como o calor, carepa, e a deterioração de peças mecânicas. É bem documentado que os encoders mecânico fazem um impreciso trabalho de medição do comprimento real e velocidade de lingotamento contínuo durante a produção. O coração do problema é que os encoders mecânico não medem o comprimento e a velocidade do produto diretamente, eles executam essas medidas indiretamente usando um tacômetro ligado a um cilindro ou roda em contato com o produto. Estes sistemas mecânicos estão sujeitos a deslizamento e calibração alterações causadas por variações no diâmetro do cilindro ou roda devido à acumulo de sujeira ou desgaste. Além disso, é extremamente difícil obter medidas precisas em ambientes extremos de fabricação a quente. Um medidor sem contacto, que mede diretamente o comprimento e a velocidade do produto elimina os erros de medição associados as técnicas de medição de contato. A nova geração de custo-eficiencia, medidores de alta precisão, tais como LaserSpeed, é utilizada em muitas aplicações de fabricação lingotamento contínuo hoje. Por exemplo, esta tecnologia de medição avançada tem a capacidade de medir essas dimensões em velocidades muito lentas com precisão de 0,05% e sem contato com a placa ou tarugo. Ele pode até mesmo medir com precisão o comprimento e a velocidade da linha quando ele está parada, e ele pode medir com precisão o fundido e escórias tão bem. Os custos de manutenção também são reduzidos, uma vez que o indicador pode ser montado até 2,5 metros da placa ou tarugo, reduzindo as necessidades de resfriamento e de risco de falha prematura devido ao calor excessivo. Este artigo descreve um método comprovado de forma precisa e consistente de captura de comprimento e medidas de velocidade em contínuo rodízios de placas e tarugos e outros processos durante a produção, e discute algumas melhorias de processos que têm sido alcançados.

Palavras-chave: Equipamento sem contato; Medição a laser; Comprimento e velocidade; Alta precisão.

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[1] *Technical contribution to the 48th Rolling Seminar – Processes, Rolled and Coated Products, October, 24th-27th, 2011, Santos, SP, Brazil.*

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1 INTRODUCTION

The operating principle of this 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 Figure 1. The distance (*d*) between the fringes is a function of the wavelength (λ) of light and the angle between the beams (2 sin K). It is represented in the Equation 1.

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

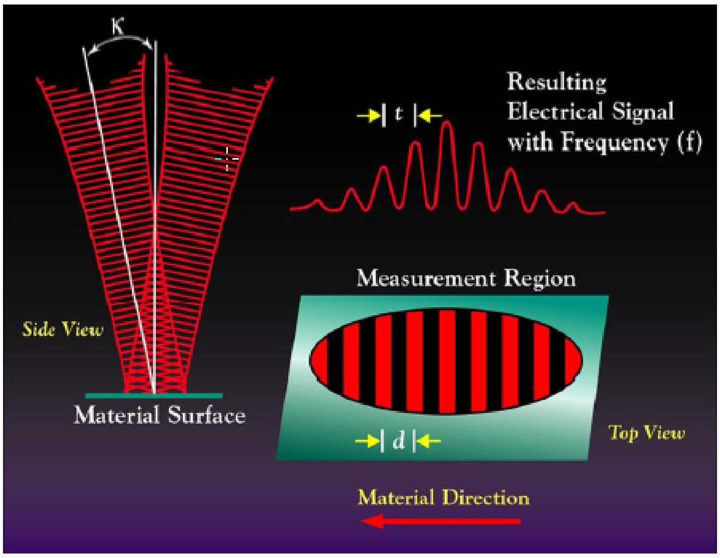


Figure 1. Measurement region.

Nearly all materials have light-scattering sites: that is, particles 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 (*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.

$$v = \frac{d}{t} \quad (2)$$

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.

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

Therefore, *v=d x f*.

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

$$L = \int_0^T v\,dt \qquad (4)$$

Essentially, the gauge measures the speed of the surface and integrates the speed value over the total length of the material to obtain accurate length measurements. As material 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. Such electrical signals are then processed by digital signal processors (DSPs) to obtain frequency information, subsequently calculating speed and integrating it to determine the length.
A block diagram of the gauge is shown in Figure 2.

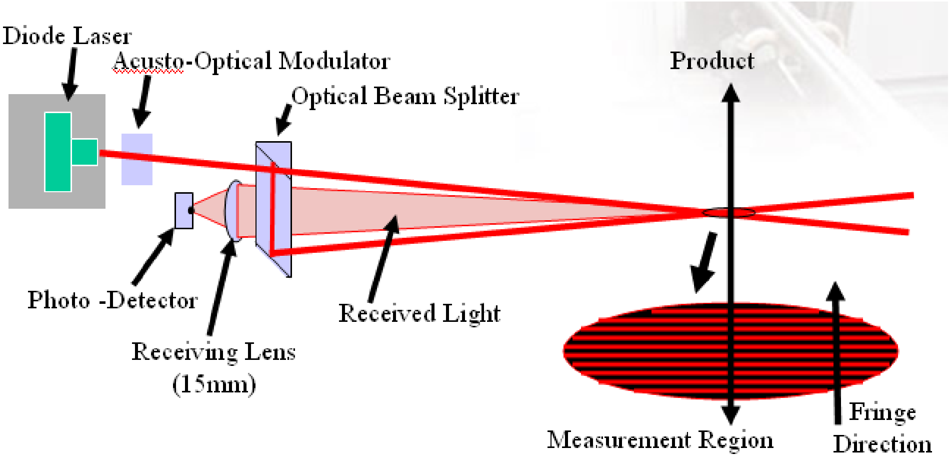


Figure 2. Block diagram of a laser doppler gauge.

There are many applications for length and speed measurements using this technique. This method is very accurate, very consistent, and works on virtually all surfaces. Examples of the savings produced, as compared to conventional methods, are provided in the following application notes.

2 APPLICATIONS

2.1 Billet Caster Application

Billet casters pour liquid steel through a water-cooled mold. The cold mold starts the solidification process and also creates the shape of the billet being cast. The billet is cast in the vertical direction and uses straightening rollers to change the direction from vertical to horizontal. The horizontal cast passes through a torch cutter that cuts the billet into the specified length. After the billet has been cut to the correct length, it moves onto the cooling beds to cool. The torch has to make the cuts while the cast is moving. In order to do this, it uses a torch clamp to grab onto the cast and pull the torch along at the same speed as the cast. This allows the torch to make square cuts. One or more rotary encoders are attached to rolls in the straightening section or to idler rolls after the straightening section to provide the PLC with continuous length and speed measurements. The PLC obtains length measurements by counting the number of pulses outputted by the encoder and provides the torch cutter with a clamp/cut signal when the target length is reached. An encoder outputs “N” number of pulses per revolution of the attached roller. Calibration is achieved by knowing the circumference of the roller and number of pulses the encoder outputs per revolution. For example, if an encoder outputs 3000 pulses /revolution and the circumference of the wheel is 1.0 diameter (diameter = 318.3 mm), then the calibration is:

(3,000 pulses/rev) / (1.0/m/rev) = 3,000 pulses/meter (0.33 mm/pulse)

The problem occurs when there is slippage between the encoder's roller and the billet. If the encoder is attached to a driven roller, the driven roller will always move faster than the billet and the measured billet length will be longer than the actual billet length because of slippage between the driven roller and the billet. If the encoder is attached to a non-driven roller, like an idler roller, then the billet will always move faster than the idler roller and the measured billet length will always be shorter than the actual billet length because of slippage between the non-driven roller and the billet.

Figure 3 shows a picture of a LaserSpeed Model LS9000 non-contact length and speed gauge mounted above a billet caster. The output of the non-contact length gauge is fed into the PLC pulse counter input instead of the encoder. When the encoder was used for cutting control, the billet length errors were as much as ±125 mm. When the non-contact length gauge is used for cutting control, the length error was reduced to ±12.5 mm and the overall yield of the caster was improved by 1%. This represents a huge savings over the course of one year. The non-contact length gauge does not touch the billet and thereby eliminates all slippage errors that occur with mechanical encoders with contract rollers. In addition to the yield savings, the encoder maintenance was completely eliminated because the non-contact gauge has no moving parts or bearings to wear out and replace, In addition, the gauge is permanently calibrated so frequent recalibration is not needed.

Figure 3. LaserSpeed gauge installed on a billet caster.

The length gauge is enclosed in a water-cooled, stainless-steel housing and uses compressed air to keep the gauge's optical window clean, further reducing maintenance issues.

2.2 Slab Caster Application

Slab casters operate almost the same as billet casters with one difference: billet casters can cast 3 to 6 billets in parallel. Slab casters cast much larger profiles and usually only cast one or two slabs at a time. Slabs radiate much more heat because they have a much larger mass. This makes it difficult to cool and maintain a non-contact length gauge when mounted above a slab like on a billet caster. An alternative is to mount the gauge from the side as shown in Figure 4. The gauge is mounted on a water cooling plate inside a stainless-steel enclosure. The gauge looks at the edge of the slab. An automatic traversing mechanism moves the gauge in and out, to keep track of slab width changes. An Ethernet output from the gauge is fed to the control computer and is used to control the torch cutter's clamp when the target length is reached. As with the Billet caster application, the cut length is repeatability to +/-12 mm.

Figure 4. Side-mounted gauge on a slab caster.

2.3 Plate Length Application

Plate mills roll the heavy plate to the proper thickness, and then square the ends and divide the plate into the desired length. Non-contact gauges are used at three locations on a plate mill. First, a gauge is mounted upstream of the shear to measure the overall length of the plate. This information helps to determine the best way to divide the plate into lengths required by the end customer, while leaving as little scrap as possible.

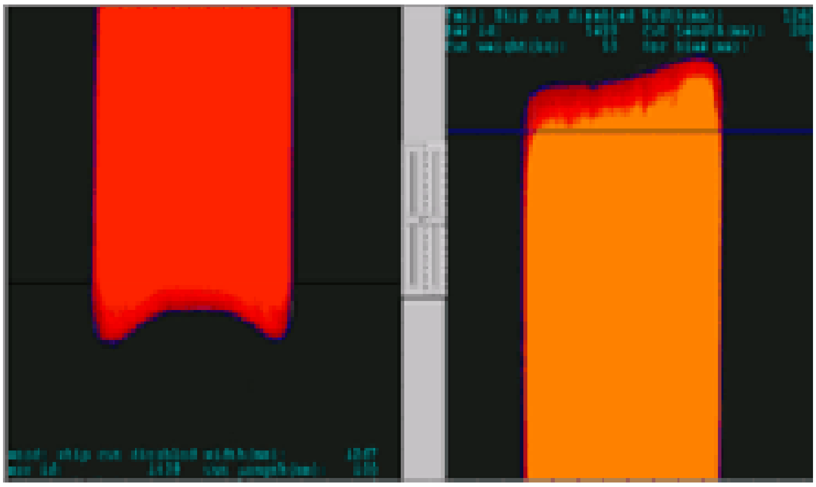


Figure 5. Head and tail profile of hot plate.

The plate is then fed into the crop shear to square up the front and back ends. A PLC acquires the shape of the plate's front end from a line scan camera and the position of the plate from a non-contact gauge. From these two pieces of information, a profile of the front and tail end can be established and the optimum crop can be determined.

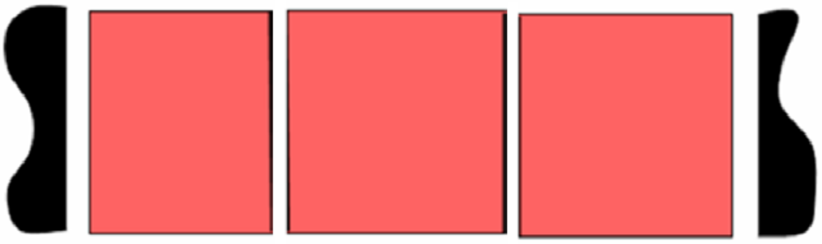


Figure 6. Crop shear, dividing shear optimization.

The non-contact gauge continues to provide plate position information, so the PLC can make an accurate front-end crop. Once the plate is cropped, the PLC continues to use the position information from the non-contact gauge to cut the plate into target lengths according to the customer requirements. It also determines the optimum use of the plate to minimize waste.

A third non-contact gauge is placed just downstream of the shear and measures plate position once the tail end passes the gauge upstream of the shear. The position information from the downstream gauge is used to make the final tail-end crop.

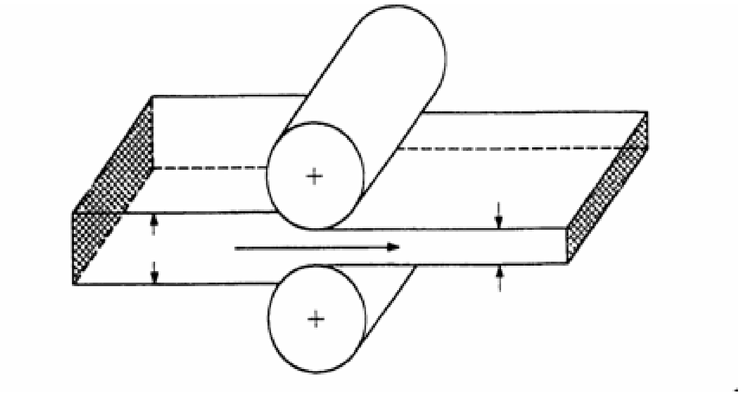
The non-contact gauge greatly improves the yield of the plate mill and minimizes scrap because of the slippage that occurs between the plate and the encoder rollers. Non-contact gauges can provide plate position to within a few millimeters, whereas the encoder roller can have errors up to 20 mm or more.

2.4 Cold Rolling Mill Application

Cold rolling mills take hotband 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 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 wear out sooner than projected if the steel is too thick. Stamping molds are very expensive to replace.

MFAGC requires thickness and speed measurements at the entry of the mill stand and speed at the exit of the mill stand. Rotary encoders and tachometers have speed errors due to slippage and changes in roll diameter. Figure 7 shows the Mass flow calculations. Basically, the mass flowing into the mill stand has to equal the mass leaving the mill stand.

$$\mathit{Thickness}_{out} = \mathit{Thickness}_{in} \; X \; (\mathit{Speed}_{in}/\mathit{Speed}_{out})$$



$$\text{Volume In} = \text{Volume Out}$$
$$W_1 \times T_1 \times V_1 = W_2 \times T_2 \times V_2$$

For all practical purposes, the strip is rolled under high tension and change in width is very negligible ($W_1 = W_2$). As a result, the above mass flow equation is reduced to:

$$T_1 \times V_1 = T_2 \times V_2$$
$$\text{Where } T_2 = T_1 \times V_1/V_2$$

Figure 7. MFAGC calculation.

In Figure 8, 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. This causes slippage between an encoder roller and the strip. Encoders attached to a driven roller will always lead the speed changes. Also, encoders attached to a non-drive roller will always lag speed changes during speed acceleration and deceleration because of slippage errors.

Figure 8. Cold rolling mill with laserspeed gauge installation.

The slippage errors can be eliminated by using a non-contact length and speed gauge, like the LaserSpeed gauge shown in Figure 8. The non-contact length and speed gauges can greatly improve the mill performance, eliminating the slippage error. Figure 8 shows a LaserSpeed non-contact length and speed gauge installed at the entry side of stand 2 of a four-stand, tandem cold rolling mill. Using MFAGC with LaserSpeed non-contact length and speed gauges and thickness measurement devices, increased the amount of the coil on gauge from 85% to greater than 97%. In addition, the mill also increased the gauge control from +/- 3.0% to +/- 0.25%.

2.5 Tension Stretch Leveler Application

Tension stretch leveling lines remove center and edge buckle by stretching the material, thereby improving the strip shape. Typically, leveling line stretches the strip by only 0.05% to 0.015%. This is a very small amount of stretch or elongation. If the correct amount of elongation is not achieved, then the shape of the strip will not meet specifications and some center or edge buckle will remain in the strip. Encoders attached to the bridle roll can be used to attempt to measure the elongation ratio; but, even a very small amount of slippage or change in the roll diameter will have a big effect on the measured elongation ratio. This will have a big effect on the strip shape. Two LaserSpeed non-contact length and speed gauges were installed on a tension leveling line to measure the elongation ratio (Figure 9). Since the gauges have no slippage error, the elongation ratio was able to be measured with a precision of less than ±0.01%. This means each gauge had to have a precision of less ±0.005%.

Figure 9. Tension leveler line LaserSpeed gauge installation.

3 SUMMARY

The new generation of cost-efficient, non-contact laser gauges, such as the LaserSpeed gauge, offers manufacturers a direct method to measure the product length and speed of products with the highest accuracy. The technology is well established and was developed in more than 25 years ago. It is installed in a wide range of applications throughout steel mills worldwide. For example, it is utilized in continuous slab and billet casters, plate mills, cold rolling mills, and tension leveler lines. The non-contact gauge can measure very high speeds, such as the output of a rod mill (5,500 m/min) or even very low speeds like a slab caster (700 mm/min). It eliminates the measurement errors associated with contact measurement techniques, because it never touches the product and has no moving parts to wear out. The non-contact gauge works on any material, regardless of hot or cold temperatures, shiny or dull surfaces, or color. It can even measure zero speed and determine the direction the material is moving. Looking forward, the non-contact laser gauge will soon become the industry's standard tool for ensuring precision length and speed measurements in metals production. Manufacturers will realize a number of long-term benefits, such as enhanced product quality, increased productivity, and reduced waste to improve the bottom line.