In-line laser gauging in rolling mills

Laser-based dimensional measurement is used widely in metals rolling applications. Some systems, like shadow-based contour gauges, have been used for many years, but newly available technology developments based on light sectioning and laser triangulation today allow even more measurement functions, including multiple dimensions along the full process route from casting to finishing, to automatic detection of rolling defects. This versatility supports process optimisation and product quality improvements, enabling more rapid returns on investment. Laser thickness gauging can also replace more dangerous radiation sensors (X-ray and radioactive absorption measurement) in a cost-efficient way.

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Laser measurement was introduced in metal rolling applications about 30 years ago and, although initially some considered this approach too esoteric, today it has become standard equipment in many mills. Modern LAP GmbH systems use optical non-contact systems to provide the dimensions of long and flat products, including width, thickness, diameter, contour and shape, even speed, along the entire process chain, from continuous casting to the finished product. They can be installed with minimal effort and do not require expensive safety precautions, as with some technologies. *Figure 1* shows simple layouts of wire rod mills, bar mills and tube welding lines, indicating typical measurement points. These applications are expanded below.

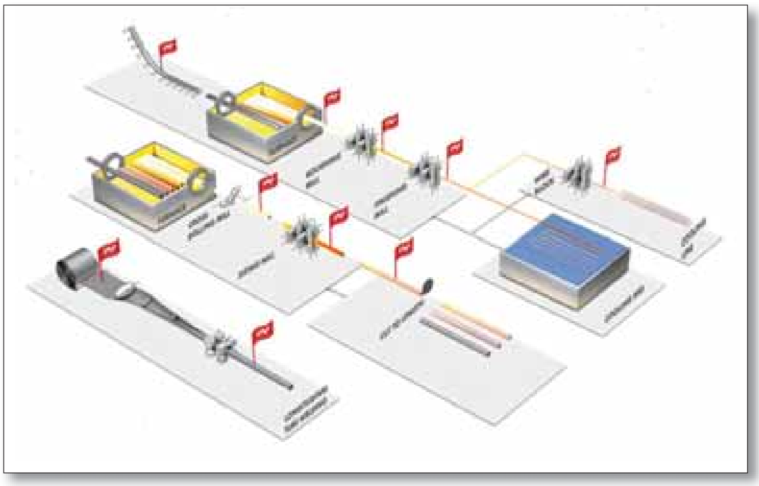

Fig 1 **Locations for dimensional measurement of long products**

LASER MEASUREMENT APPLICATIONS

Continuous casting Laser gauges are used for measuring the thickness, width and length of continuously cast products and can be used to optimise the casting process and to control the cut-to-length operation for slabs and billets. Precise readings of slab width, side profile, thickness and length allow exact determination of the slab weight and documentation of the output of the caster. In subsequent production stages these slabs can then be easily allocated to customer orders.

Wire rod and bars Measuring the position of billets before they enter the reheat furnace helps to control the charging process, so optimising furnace utilisation and reducing the possibility of misaligned billets.

Profile measuring systems provide all the information needed for fast and precise adjustment of rolling lines and can measure rounds, rebar, flats, squares, hexagons and angles (see *Figure 2*). Elimination of sample cutting reduces the ramp-up time after a size or product change and precise determination of off-size lengths at head and tail allows crop-optimisation, so further increasing mill yield.

Beams and rails The key dimensions, such as width, height, web thickness, straightness or contour conformity are measured in-line and so allow interventions immediately in the case of process deviations.

Flat products Measurement of the slab position, both on the charging side and inside of the reheat furnace, ensures optimal positioning of the slabs and maximises throughput of the furnace.

In flat product rolling the most important measurement is thickness after each rolling stage. Both strip and plates benefit from checking the dimensions at several steps during their production. *Figure 3* shows simple layouts of strip and plate mills together with possible gauging positions. In both hot and cold strip rolling mills laser measurement of the strip geometry allows mills to produce strip to the exact dimensional and flatness specifications of the customer, resulting in a smooth and efficient operation. Laser sensors mounted at the coilers ▷

Fig 2 **Contour gauge in the production line**

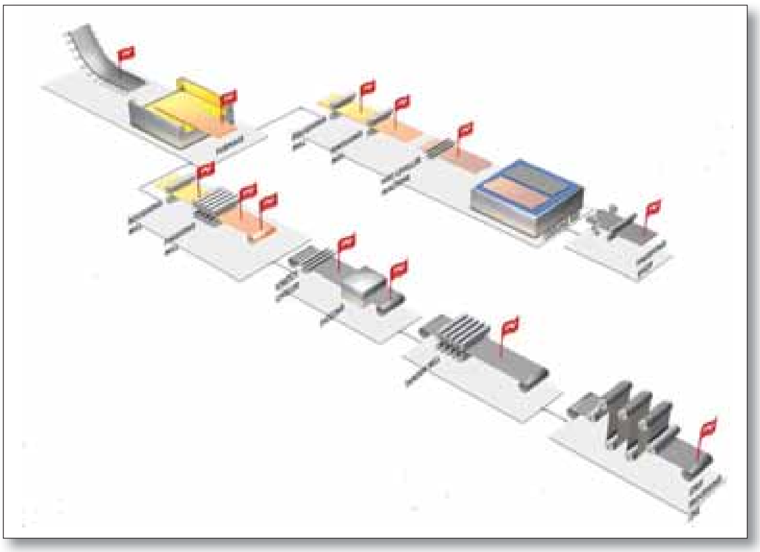

Fig 3 **Locations for dimensional measurement of flat products**

precisely measure diameter and side profile of the coils.

In plate rolling, laser systems measure length, width, taper, necking and curvature and the results are available immediately, and are archived for each plate. Special software helps to minimise crop losses so as to optimise the yield of every plate and optimally allocate the plates to the customer's order.

Tubes Laser gauges are used to measure the outer diameter, length, straightness and ovality of tubes in the rolling line, so helping to avoiding costly post-processing. Producing to tighter specifications also increases the yield ratio. Laser measurement systems for final inspection of tubes before shipment provide essential data for quality assurance.

Strip processing In annealing, hot dip galvanising, or coating in strip processing lines, width, thickness and flatness are essential quality parameters. Measurement of sag allows precise control of the strip run and can therefore optimise the strip treatment. On exit of the plant, all strip dimensions and flatness are fully documented.

RELIABLITY IN HARSH ENVIRONMENTS

In the steel industry, measurement systems have to be fully reliable under difficult operating conditions. Laser sensors are delicate products with high accuracy and sophisticated mechanical and electronic components so they need to be well protected to keep them working. Outstanding sensor technology, mechanical stability, shock and dirt resistance, thermal insulation, cooling systems and easy maintenance contribute to the overall performance of the systems.

CONTOUR GAUGES FOR LONG PRODUCTS

With entry level in-line contour measurement based on shadow measurement, bar diameters can be measured and ovality can be estimated. With the latest advanced full contour gauges, rolling defects like over- or under-filling and roll off-set and wear can be detected automatically. Additionally, singular surface defects such as scrap marks, trays or grooves and repeating defects such as those from roll eccentricities can be found automatically.

Especially in the finishing mills for quality products producers need a complete high resolution recording of the bar contour over the entire perimeter. Small rolling seams, for example, caused by an incorrect filling in the roll nip, can significantly affect the quality of a wire rod.

Traditional shadow systems generate shadow outlines of the sections in up to six axes, but with some rolling defects, parts of the contour remains concealed in the shadow so it is not possible to differentiate geometrical deviations such as overfills/underfills and roll misalignment or wear with certainty. The inspection results in all cases require more or less subjective interpretation by experienced operators. Defects affecting only a small portion of the contour, such as a seam caused by overfill, for instance, cannot be reliably detected by shadow sensors.

Isolated surface defects, such as rolling inclusions, scabs and scoring are also difficult to detect from only a few diameter measurements, and cyclical defects, such as roll spalling, for example, are also only discovered by the end customer, resulting in claims. Even rotating systems scan the surface in all cases only in a spiral pattern, and fail to detect these defects.

The producers of long products need zero-exception high-resolution scanning of the contour around the entire periphery, particularly on production lines for high-quality products. Even a rolling seam of only a few tens of microns in height, caused by an incorrect filling ratio in the roll gap, can significantly impair the quality of a wire product. A typical screen output is shown in *Figure 4*.

In addition, systems are also needed which classify geometrical deviations such as rolling defects and surface defects automatically on the basis of objective criteria and provide the operators with unequivocal recommendations for countermeasures.

Unlike shadowing systems, laser section-based gauges measure the contour across the entire periphery, producing no shadow effects, and which depict the true cross-sectional surface of the section with no omissions. Available systems today scan up to 2,000 complete sections per second at a resolution of several thousand measuring points simultaneously. The system detects geometrical deviations at a resolution of up to 5μm.

The new system now automatically classifies rolling defects, therefore it is not dependent on the skills of individual operators, either at commissioning or during operation. The system uses the data to generate specific recommendations for action. In case of roll misalignment, for example, it signals not only the defect type, but also the degree of misalignment. The operator thus knows immediately what change needs to be made to the setting of the rolling stand.

The high data volume permits not only greater accuracy in contour measurement and detection of rolling defects, but also the inspection of isolated and cyclical surface defects, thus allowing comprehensive and objective monitoring of the entire rolling process. These systems can be used at all stages of the rolling process, from the billet to the finished section or wire. LAP supplies a variety of standardised systems with measuring ranges between 50 and 450mm.

These systems function at material temperatures of up to 1,200°C and measure the entire profile, including the corner radii, on rectangular cross-section stock, such as billets, bars and sections. On round-section bar and wire they also detect geometrical deviations such as ovality and a range of rolling defects. They generate warnings and alarms if the contour data deviates from specification. They also determine across the length of the stock data such as off-size length, which is necessary for optimisation of trimming scrap at both ends of the product.

A list of defects detected are shown below:

Technological rolling defects
- Overfill and underfill on one or both sides
- Incorrect roll-gap setting
- Ovality
- Roll misalignment
- Roll wear

Isolated surface defects
- Rolling inclusions
- Scale
- Scabs

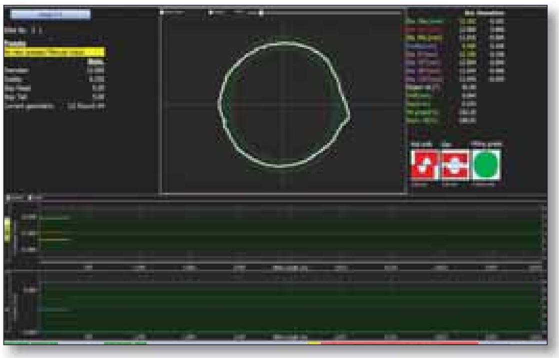

Fig 4 **Typical online display of a contour gauge, here with an overfill defect**

- Scoring

Recurring surface defects
- Roll spalling
- Roll eccentricity

Process analysis across multiple production stages

The interlinking of data from a number of systems makes it possible to detect immediately the effects of upstream rolling stands on the contour of the finished product across a number of process stages. LAP's CONTOUR CHECK CC software permits the display of data from multiple systems on the same monitor screen. Geometrical data from the roughing and medium-section mills can thus be compared against that of the finishing block in real time. It is of no importance in this context whether the upstream systems function using the shadowing method. This makes it possible to detect trends on a supra-machine basis, take corresponding action and check its effectiveness immediately.

Unequivocal automatic classification of rolling defects means that their causes can be systematically eliminated as rolling-parameter settings are no longer dependent on subjective estimates or on the skills of the operator. Process-induced deviations, such as an irregular temperature profile in the feed materials, for example, are detected in real time.

This system makes a significant contribution to cutting costs in-so-far as off-line samples from every coil are no longer necessary in the finishing shop. In many mills, this effect alone enables this system to recover its costs in only a few months. Users have reported that, before installing the dimension-checking system, they used to cut a sample from every billet and measure it manually. This new system eliminates this operation entirely, thanks to its high precision and dependability, and these users now no longer cut samples from their billets.

THICKNESS GAUGES FOR FLAT PRODUCTS

For strip and plate mills thickness measurement is essential. ▷

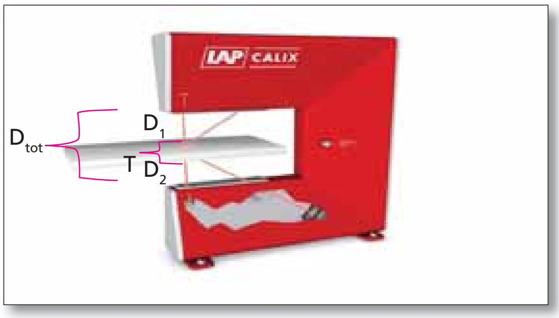

Fig 5 **Laser-based thickness gauge**

Fig 6 **Different throat depths of laser thickness gauges: 200mm at CALIX S (*left*) and 1,020mm at CALIX XL (*right*)**

Usually X-ray or isotope (gamma ray) gauges measure the absorption of the radiation in the material, which is proportional to the thickness. Increasingly mill operators want to get rid of these dangerous measurement methods and have started to use cheaper and almost maintenance-free laser gauges.

Laser-based thickness gauges operate by differential triangulation, similar to a mechanical micrometer. *Figure 5* shows such a thickness gauge with two triangulation modules. They measure the respective distance D1 and D2 to the object surface from opposing directions. The zero point of each module is determined during production.

Thickness is calculated by subtraction of the measured values from the fixed distance between the opposing sensors: $T = D_{tot} - D1 - D2$

Laser-based thickness gauges have great potential, but they are competing against X-ray, isotope, and contact gauges that have over 50 years of design evolution and are well entrenched in the industry, both technically and culturally. Laser gauges have many advantages over these other gauges, but LAP understands that the history and culture of customer's existing gauges may raise comparison issues that may or may not be valid.

There are two major scenarios in the general application principles for the laser thickness gauges:

Process lines These are lines in which the metal undergoes some type of value-added process that does not involve reduction in thickness. Examples are slitters, cut-to-length lines, galvanising, tinning and pickling lines, tension levellers and inspection lines. In general, these operate at room temperature so the measurement environment is relatively benign. The gauge is used for monitoring only and is not normally involved in any type of control loop.

Cold rolling mills These applications include single and multi-stand reduction mills, single pass and reversing mills, and can exhibit somewhat more hostile environments than process lines. The gauges are considered critical sensors in control loops including automatic gauge control (AGC). Temper mills are included in this category because elongation effects can reduce the thickness up to 2% and can be tied into a control loop. The C-frames have to be more robust than in process lines.

Design and construction The present design is acceptable for process lines with the consideration of other issues discussed below. Because some rolling mills exhibit more hostile environments, additional protection is required. Some strip temperatures can reach over 200°C, so some cooling of the C-frame may be required and rolling solutions are sometimes used. These can be water, petroleum or mineral oil based, and kerosene (in aluminum mills). Therefore, the C-frame must be resistant to these types of solutions. The solutions are sometimes present in the measuring area, so air blow-offs are sometimes required on the C-frame.

Throat depth (measuring depth) and air gap (throat height) LAP offers three sizes of their CALIX laser thickness gauge with 200, 400 and 1,020mm measuring depth (see *Figure 6*). In comparison, the standard gaps for isotope gauges range from 200 to 300mm, and for X-ray gauges the air gaps range from 300 to 600mm. LAP's family of laser thickness gauges have an air gap of 200mm.

AGC output In rolling mills the automatic gauge control (AGC) system controls all of the critical parameters for the mill. These include gap control, drive control, speed, tension and winders. The thickness gauge is the critical sensor for providing feedback of measurement results (and feed forward for mass flow systems).

Accuracy and other performance specifications Laser gauge specifications represent more or less fixed off-sets at various thicknesses using various sensors, therefore accuracy decreases as thickness decreases. In general, performance (accuracy) in radiometric gauges is expressed as a percentage of target thickness and the sensors (X-ray source size, isotope type and strength) are selected according to the range of measurement required. Full performance specifications for a wide range of radiometric gauges and applications can be quite detailed and extensive. X-ray gauges achieve, under optimal (laboratory) conditions, a relative accuracy of 0.1% of the nominal thickness. In practice, 0.2% is reached. The best laser thickness gauges achieve an absolute accuracy of 2µm independent of the thickness. 0.2% is 2µm with a nominal thickness of 1mm, which means today's laser gauges are more accurate than X-ray gauges above a thickness of 1mm.

Visualisation, data logging and archiving While some rolling mills already use an integrated logging and analysis software system, most users still need these functions integrated into the thickness gauge. *Figure 7* shows a typical on-line screen visible for the operator in the pulpit. Analysis functions on already logged data allow the observation of quality trends and approval support for customer deliveries.

MEASUREMENT SYSTEM COMPARISON

Comparisons between the traditional absorptions gauges (X-ray and isotope) show the following characteristics:

Safety Class 2 lasers do not pose any safety risk or concern. In most industry countries, radioisotopes, however, have to be governed and licensed by government agencies, and must regularly be leak tested. Significant regulations govern the use of all radiation gauges.

Maintenance Because of the nature of X-ray system design, there are much more electronics, temperature regulation, absorption sensing, and control hardware in comparison with laser gauges. Even isotope gauges contain more electronics than laser gauges. The more hardware that exists in any system, the more that system exhibits maintenance concerns and requirements.

Component failure This relates mainly to X-ray sources. Similar to an incandescent light bulb, an X-ray tube filament will burn out after a certain time. Also, because most X-ray sources contain high voltage components in the same housings, they are prone to high voltage and high temperature related failures. Typical lifetime for an X-ray source on a cold application is 2-4 years. X-ray sources are the single highest replacement cost of any component.

Alloy composition Since laser gauges are measuring distances to the surfaces, the material is irrelevant. In radiometric gauges, however, significant errors are experienced unless the gauge is precisely compensated for alloy content. In an uncompensated gauge, these errors can be up to 4% of target thickness for low carbon steel, up to 10% for stainless steels, and over 100% for aluminum.

Fig 7 **Typical online display of a traversing laser thickness gauge including cross profile**

Coatings Some applications require measurement of the coating material (zinc or tin for example) and the compensation techniques become more complex. With laser gauges this is not a concern.

Price This may be the key real advantage for laser gauges, even if the features described above do not add significant cost to the current base system. Even with these features, isotope gauges can range from US$40,000 to US$90,000. X-ray gauges range from US$70,000 to US$150,000 or higher. In comparison, small laser gauges start at US$20,000, rising to US$60,000 for the larger machines.

CONCLUSIONS

Laser-based dimensional measurement is already widely used in metals rolling applications. Some of these applications, like the shadow-based contour gauges have been used for many years, but newly available technology developments based on light sectioning and laser triangulation today allow even more measurement functions. Automatic detection of rolling defects on long products supports process optimisation and product quality improvements enabling more rapid returns on investment. Laser thickness gauging can replace more dangerous radiation sensors (X-ray and radioactive absorption measurement) in a cost efficient way. MS

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