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FLATNESS CONTROL OPTIMIZATION UTILIZING THE LATEST MEASUREMENT TECHNIQUE[1]

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Abstract
For high quality hot strip mills, the tight control of the strip flatness at the exit of the finisher is more and more a decisive factor where the final strip quality is concerned. Therefore, the performances of the flatness gauge, especially its accuracy, fast response time and reliability becomes of prime importance. These aspects are especially critical with thin strip rolling practices where faster rolling speeds may generate uncontrolled strip movements that can considerably disturb conventional flatness gauges. Since some years, other processes, such as wide plate mills, are more and more in need for flatness gauges in order to control the quality of the plate in the hot or cold section. This type of applications required new flatness measurement solutions, providing flatness measurements that meet and exceed international standards.
Key words: Steel; Flatness; Plate; Strip.

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1 INTRODUCTION

In hot rolling mills, a strong demand took place in the early 80's for a gauge able to help control strip flatness at the exit of the finisher. IRM group was a pioneer in laser-based flatness measurement and introduced its well-known "Rometer" industrial gauge on the market in the mid 80's.
The evolution of rolling practice towards thin strip rolling put the limitations of the existing flatness gauges into evidence (higher and faster strip movements resulting in disturbed flatness measurements). Confronted to that challenge, IRM group developed in the late 90's a new gauge based on the "3-plane" method (Rometer 2000) which confirmed its total insensitivity to strip movements. Over the following years, new improved versions (Rometer F100, Rometer F200) were successfully proposed to the market.
In the early 2000's, flatness measurements were also strongly requested for plate mill applications (finisher and hot or cold leveller). A version for plate mills was especially designed to warranty the same level of performance as the strip mill gauge while the size of the sensor has been adapted to cover the plates width range (up to 5 meters).
The latest version of IRM group flatness gauge (Rometer FQC) is dedicated to cold leveller flatness quality control.

2 Hot Strip Mill Flatness Control

Requirements for strip flatness at the exit of the hot strip mill finisher may vary based on the final product type and requirments. IRM group has thus developed multiple versions of its Rometer flatness gauge in order to propose the optimal flatness measuring package adapted to each case: Rometer FQC-1 aiming to monitor flatness over the whole strip and deliver detailed coil reports for quality control, Rometer F100 and F200 more dedicated to flatness on-line control. The F100 (fixed fibres) and F200 (movable fibres) are declined in 3 versions (1, 2 or 3 measuring planes).
1-plane and 2-plane versions can be used when the minimum strip thickness is over 1.8 mm, as strip movements can be eliminated by fibre integration.
3-plane versions are systematically used for demanding applications such as the automotive industry: thin strip (down to 1 mm) rolling practices generate more often uncontrolled strip movements such as flapping, transverse and longitudinal rotations. Moreover, the 3-plane version can be located close to the finishing stand (typically 5 meters, or even less). Therefore the uncontrolled portion of the strip head-end can be minimised to this distance plus 1 meter (first valid flatness measurement), i.e. about 6 meters. This is particularly efficient for strip yield optimisation.

2. 1 3-Plane Measuring Principle

In the 3-plane method, the 3 planes are created by 3 rows of high energy laser spots on the strip (Figure 1).

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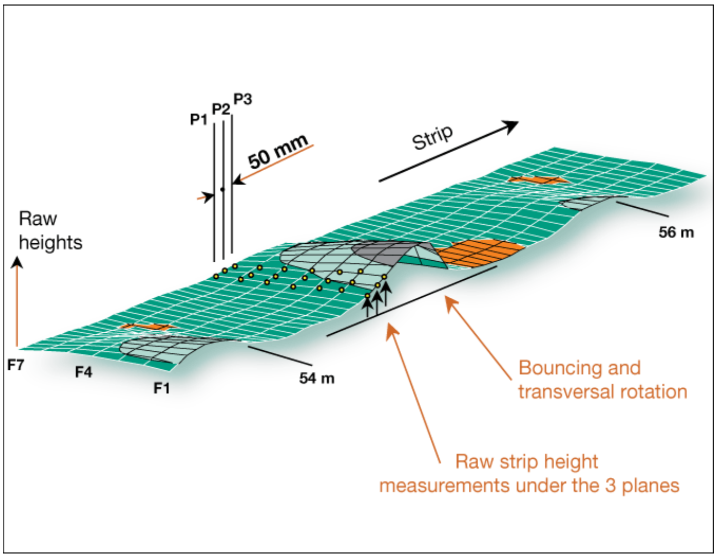

Figure 1: Spot locations.

The surface of the strip is analyzed by simultaneous measurements of the heights of key points on the strip with laser-based triangulations. These height measurements are repeated every 50 mm of strip.

The characteristics of the surface between the 3 planes are computed for each snapshot. This computation is free from any influence of the strip movement. Incremental flatness elongation indices are computed from the first measurement taken, and a valid flatness measurement is already available after half the flatness defect period, i.e. about 1 meter in most cases.

Flatness elongations differences related to the central fiber are computed and expressed in I-Units.

In order to reveal “Symmetric Flatness” (used for Bending control) and “Asymmetric Flatness” (used for Levelling control), Rometer computes the best fitting parabola curve Ax^2+Bx+C across the elongation indices, where “A” is an image of Bending and “B” an image of Levelling (Figure 2).

Positive A values indicate the presence of “wavy edges”, negative A values indicate “center buckles” while zero value is the control system target. The Rometer detects “quarter-buckles” by computing and providing higher order fitting curves (Figure 3).

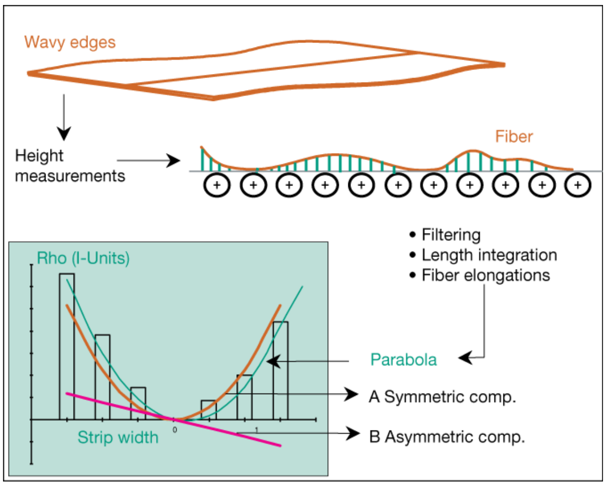

Figure 2: Parabola fitting.

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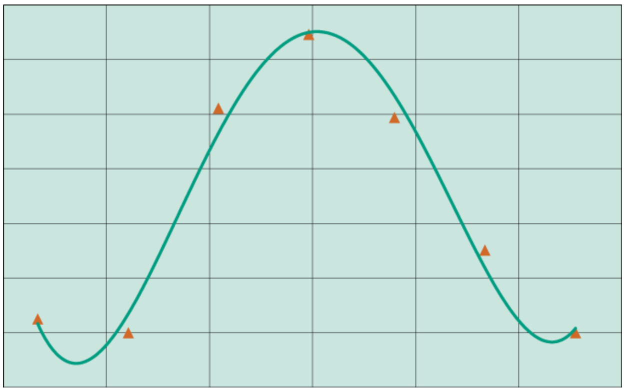

Figure 3: Higher order fitting.

2.2 3-Plane Method Advantages

Over 50 Rometer 3-plane gauges feed AFC (Automatic Flatness Control) on hot strip mills worldwide. They are generally mounted in a gauge house (also used for other measuring gauges – Figure 4).

Figure 4: Rometer gauge installed in common gauge house.

A few examples of results obtained with industrial gauges are discussed below.

2.2.1 Rometer 3-plane insensitivity to strip movements

Figure 5 shows flatness measurements achieved by a Rometer 3-plane gauge during rolling of a
1.2 mm thick strip. It also shows the would-be results in case of the application of a 1-plane method:

- From 50 to 70 meters (strip not yet under tension), the diagram clearly shows a levelling defect (wavy edges on the operator side, flat on drive side). Asymmetric “B” factor (coefficient of the elongation parabola curve) is about 250 I-Units. 1-plane and 3-plane results are in agreement.
- At 55 m, a strong wave (80 mm amplitude) appears on the operator side, followed by a second one at nearly 58 m. “B” factor (Levelling) measured by the 1-plane method climbs up to 500 I-Units, before coming back to 250 I-Units after 60 m, while the 3-plane gauge is not influenced at all by this strip jump.

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- Between 55 and 60 m, the 1-plane symmetric "A" factor is also more significantly disturbed than that of the 3-plane system.

At 55 and 58 m, the two sudden waves on the operator side appear simultaneously with similar but smaller waves on the drive side. This implies that the strip is moving vertically while rotating transversally. The 3-plane gauge is insensitive to this disturbing movement while the 1-plane gauge would interpret this as a strong levelling defect (the movement period is about 1 meter, which is too close to the flatness defect wavelength to be discriminated by digital filtering).
For thin strip rolling (strip thickness below 1.8 mm), disturbing movements (strip bouncing and rotating) occur more often and 1-plane gauges are unable to deliver accurate flatness measurement to the mill AFC. In some cases, the controller can even be misguided by false information on the nature of the defect.

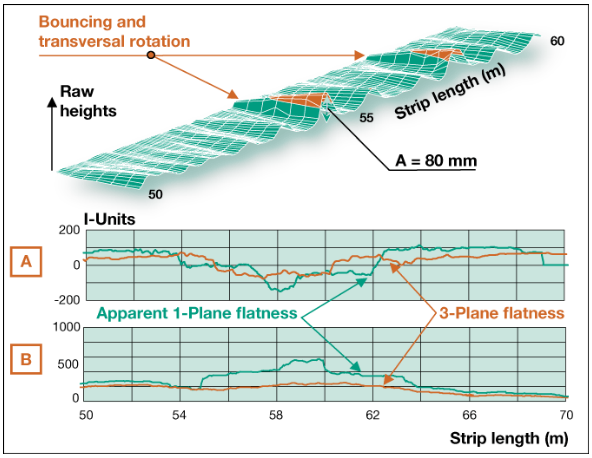

Figure 5.

2.2.2 Rometer 3-plane flatness measurement reliability

Figure 6 shows a portion of the strip just before the strip head enters the coiler. The information (symmetric A factor evolution) given by 1-plane and 3-plane gauges is similar (at a low flatness level < 20 I-Units), but it is sometimes inconsistent. At 74 and 85 meters for example, the 3-plane gauge clearly detects center buckles (I-Units negative values) that the 1-plane gauge is unable to see. If the mill AFC reacts to the 1-plane gauge signal, it results in flatness oscillations and instability.
Moreover the 3-plane measurement trend shows very low noise level, as compared to the 1-plane curve. This is remarkable at this very low I-Units level and confirms the superior performance of the 3-plane gauge.

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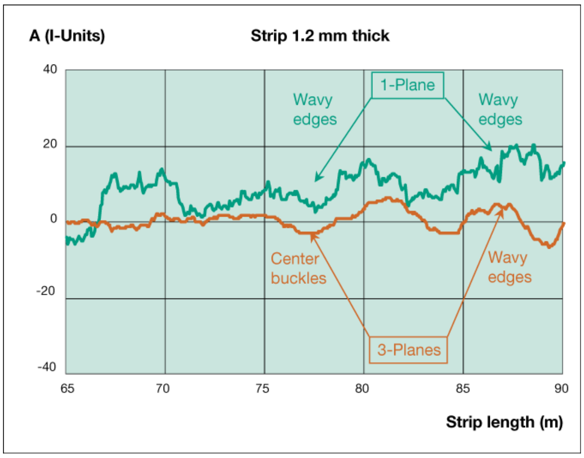

Figure 6.

2.2.3 Rometer 3-plane flatness measurement high reactivity

Figure 7 compares the information from the two types of gauges for the strip head end. It confirms the fast reaction of the 3-plane gauge (flatness measurement stabilized in less than 1 meter) and the long integration time required by the 1-plane method (only giving a correct measurement after about 5 meters). After 5 meters, the curves also show significant discrepancies due to strip movement (for example between 17 and 20 m).

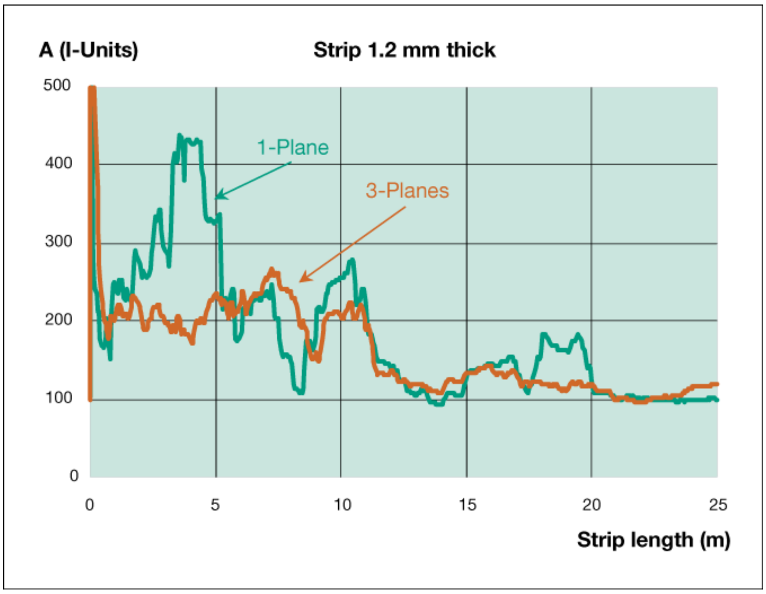

Figure 7: Flatness of the strip head end

2.2.4 Rometer 3-plane flatness measurement high sensitivity

Figure 8 shows an example of the flatness profile evolution along strip length. Red points illustrate the flatness indices measured by a 9-fibre, 3-plane Rometer F200 gauge. Their distribution cannot be fit with a parabola curve. In this case, a higher order fitting has been applied (blue curve).
The high measurement resolution and low noise/signal ratio enables the gauge to detect with high flatness accuracy (typical 1 I-Unit) the “camel” shape of this curve, which indicates the presence of quarter-buckles:

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- Quarter-buckles are measured all along the strip. After entering the coiler (strip length > 120 m), the strip is under tension and the flatness amplitude is low (flatness scale is set to +/- 5 I-Units, instead of +/- 400 I-Units before coiling).
- The quarter-buckles are already detected after 2 m strip. This confirms the very fast reactivity of the 3-plane method.

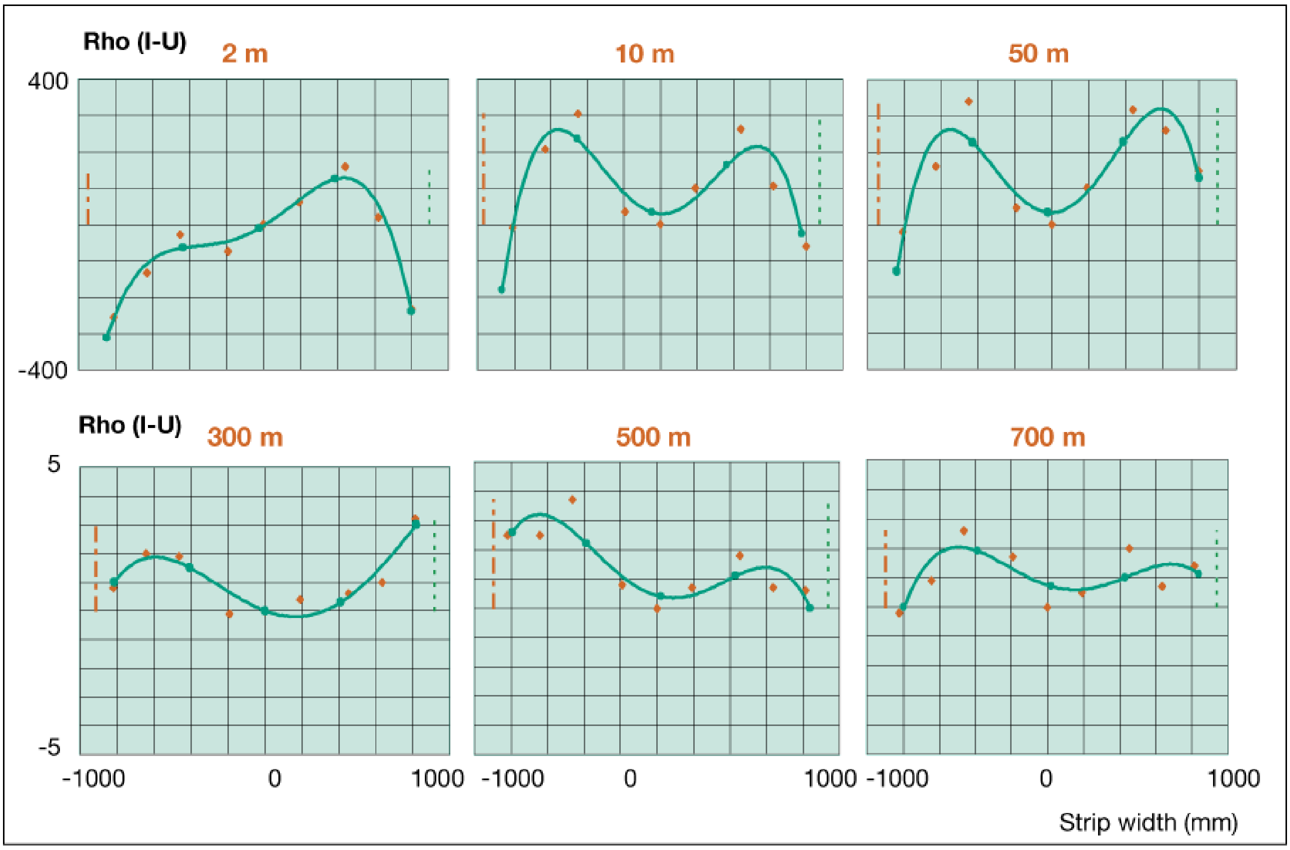

Figure 8: Flatness profile along strip.

3 PLATE MILL APPLICATIONS

In plate mills, flatness gauges can be installed at the exit of the finisher after the hot leveller or after the cold leveller. They are generally mounted on isolated open platforms, high above the roll table (from 4 to 6 m). The gauge size is adapted to the maximum plate width rolled, i.e. between 3 and 5 m (Figures 9 and 10).

Figure 9: Rometer F100-2P gauge at mill exit.

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Figure 10: Rometer FQC-2 gauges at cold leveller exit (2 lines).

The plate mill Rometer versions are adapted to specific plate mill conditions by:

- increasing the mechanical stability of the sensor and its support to ensure that time intervals between successive calibrations remain long enough (> 1 year) in spite of the much larger gauge size,
- keeping flatness measurement accuracy high by optimizing the number of cameras,
- adapting the gauge configuration to each specific mill to eliminate bumping and eventual transverse rotation movements.

Although the flatness characterization based on fiber elongations is still available, a 3-dimensional flatness diagram showing the location, amplitude and period of the flatness defects is typically more useful to the operator. This also corresponds to the normalized manual method applied on inspection tables.

In addition to the visual display (Figure 11), the gauge computes average flatness amplitudes and periods (and consequently average flatness steepness) as well as other summarized data as requested specifically by the operator (maximum flatness amplitude over the plate surface, eventual detection of skis in the plate head and/or tail ends, …). The portions of the plate which exceed user-defined tolerances are highlighted. A hard copy plate report is automatically printed and/or saved as requested.

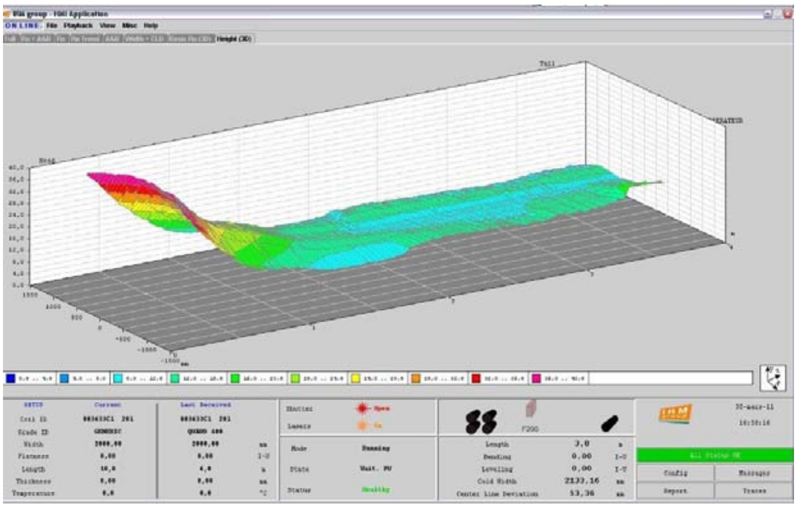

Figure 11: Plate mill flatness map.

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4 ROMETER SENSOR BOX COMPACTNESS AND STABILITY

All Rometer versions present advantageous operational features:

- The optical triangulations are mounted in a common and compact sensor box, on the same optical bench perpendicular to the strip direction. This layout provides a stable and accurate measurement over long periods as compared to other solutions where light sources and receivers are installed in separate locations.
- This configuration requires a very narrow sighting field (150 mm) in the rolling direction, which can easily be kept free of steam and water. This feature is also advantageous in the finishing mill where several sensors have to coexist in a small area (thickness, width, speed and surface inspection).

5 CONCLUSION

The evolution of hot strip rolling during the last 10 years required a parallel evolution of optical flatness gauge technology, especially to face the new challenges from thin strip rolling production.
The many industrial gauges in operation confirm that the Rometer is the most efficient way to measure true flatness and remains the most accurate and fastest sensor to optimize flatness control.
In recent years the technology has also been successfully applied in plate mills, in particular for cold levelled plate quality control.