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.

Stability of the hot strip mill rolling process remains a main topic when it comes to processing thin and hard materials. Strip steering, especially at the end of rolling and tail-out rips, is a main source of unscheduled downtimes in a hot strip mill (HSM). The main focus of this paper is the new X-Roll® Guide system to improve mill stability and quality. An overview of SMS group developments in the recent years regarding equipment and control strategies is given in this article.

The new sideguiding system in the entry area of the finishing mill is introduced and explained with operational examples. The system provides reproducible conditions for the threading process and during rolling. Steering control has a direct benefit on the availability of the mill. New developments of the roll alignment control strategies based on roll force and mill stand entry guide force measurement will be presented.

Additionally, a camera-based measuring system is introduced that generates a direct process feedback of the strip position. It provides together with the roll alignment control the necessary control parameters for adjusting the roll gap and guiding the strip correctly centered through the mill. At the downcoiler area, the coiling stability and quality with best coil shape is controlled with the sideguides and especially for high-strength material with the controlled chute roll.

The new X-Roll Guide system comprises the SMS group’s holistic approach to improve hot strip mill rolling stability in all relevant process steps.

Discussion

Strip Steering Control as a Major Influencing Factor for Hot Strip Quality — In hot rolling, the stability of the process is a major issue for commercial success.
Strip steering is the key factor to avoid cobbles, wrapped strips and surface defects due to marked rolls. The various process steps — roughing, finishing and coiling — require different measures to assure a straight, wedge-free and centered strip.

Fig. 1 shows a typical hot strip mill layout. After discharging from the furnace, the roughing mill reduces the slab from 220 mm to 280 mm thickness to the transfer bar thickness of 22–60 mm. The main quality parameters of transfer bars are thickness and profile uniformity and a straight and camber-free shape.

Camber and wedge in transfer bars can only be rolled up to a certain value in the finishing mill. The tail end becomes more and more off-centered when it is passing through the finishing mill stands. The side-guiding systems in finishing mill interstand areas can only correct the off-center situation at thicker gauges. At thinner gauges, the strip will be damaged with the sideguide contact. The double-rolled material can cause strip breaks or marked work rolls, affect the strip edge quality, etc.

In the finishing mill, the roll leveling at the consecutive mill stands is essential to rolling stability. Threading in is one task to fulfill. The operator has to observe the strip head movement and must react quickly to correct the leveling. During rolling, the fillet — when the strip is under tension — is very stable and only little operator intervention is necessary. Tailing-out is a short but instable phase. The operator has only little chance to do any corrections. The rolling speed is too fast to interfere and perform the correct leveling manually, especially at the last stands. In the downcoiler area, the final product of the HSM is generated. One coil quality parameter is rectangular shape. Sideguides in front of the coiler assure a centered winding of the first wraps. A proper coil buildup is difficult to achieve if the strip is cambered and telescopicity is unavoidable.

In recent years, SMS group has developed equipment and automation solutions for all mill areas to improve the stability of hot rolling. This paper gives an overview on the X-Roll Guide system for hot rolling mills.

Roughing Mill Wedge and Camber Control — The roughing mill has the task to transform the incoming slab into transfer bar with typical quality parameters of:

- Uniform thickness <1.5%.
- Wedge in cross-profile <0.5%.
- Camber (straightness) <50 mm.

Thickness accuracy and wedge control must be done in most roughing mills without any thickness measurement device. Only the roll force and the cylinder position can be used to control thickness and wedge. Fig. 2 provides a sketch of the technological control system for roll tilting of SMS group at the roughing mill stand. Based on the force measurement at the load cells, the differential force between operator and driveside is forwarded to the automatic gauge control system. A digital twin of the mill stand describes the elastic behavior and calculates the strip thickness and wedge. The roll alignment control (RAC) system based on this model is proven technology and has been installed in many hot rolling mills. With these control systems, thickness and wedge can be controlled precisely.

Other upstream processes have a large impact on the camber performance of a roughing mill:

- Wedge and/or camber from casting.
- No uniform heating of the slabs over width.
- Wedge and/or camber from proceeding roughing passes.
- Off-center bar during rolling.

SMS group developed the X-Roll Guide CFR system to improve the camber and wedge performance (Fig. 3). Strong sideguides are in operation during rolling and not only for centering in between roughing passes. These sideguides are active on the entry and exit side of the mill stand. Both guiding and roll
aligning are required to adjust wedge and camber independently. This mechatronic system combines reliable mechanical actuators with sensors to establish a smooth operation at high productivity level. Revamps on existing facilities are easily possible as shown in the following example.

X-Roll Guide CFR system results can be observed in Fig. 4, which shows the rolling of a transfer bar with a strong wedge and camber. From pass to pass, the transfer bar is straightened and the wedge is eliminated. Fig. 5 shows results from a recent modernization of the reversing roughing stand at a conventional hot strip mill. In this project, the existing sideguides on the entry and exit side of the roughing stand were replaced with strong and independent hydraulic-driven sideguides. In addition, the necessary automation for the camber and wedge-free rolling was installed as a stand-alone system and connected to the plant automation. The results of the head hook before and after the modernization, which were evaluated over several weeks, show a strong improvement and a large reduction of the camber. Similar results were achieved for the fillet and the tail end. Additionally, significant improvements on the final rolled strip wedge were achieved with this modernization project.

Finishing Mill Entry – When the transfer bar is transferred to the finishing mill (FM), it has to be centered. This is done to achieve a straight and centered threading of the finishing mill. After the start of rolling in the first finishing mill stand, the strip position can only be corrected slowly and with high force.

The X-Roll Guide FM entry system is shown in Fig. 6. It is designed to provide a long guiding length. A good
alignment of the transfer bar requires centering at more than one point along the bar length. Therefore, the strip is centered in front of stand F1 and in front of the crop shear. The sideguides are activated step by step by the technological controls and the tracking system and work together as one long guiding system to assure smooth operation with low guiding forces to improve the strip alignment.

All guides are equipped with large rolls to avoid strip edge damages. To increase the lifetime, the rolls have a wear resistance surface and a water cooling system (Fig. 7). Flexible positioning during threading allows adaption to any transfer bar shape. The system is active during the whole rolling process to align the strip over the total length.\(^3\)
In a modernization project in 2019, a CSP® mill was equipped with the new X-Roll Guide FM entry system. The left diagram in Fig. 8 shows the improvement of the strip position after the finishing mill. The strip shows less variation of the strip centerline position. As a result from the stable strip flow, the variation of the strip wedge measured after the finishing mill is also reduced, shown in the right diagram in Fig. 8.

**Finishing Mill Interstand Area** – The strip threading and especially the tailing-out process are the most critical rolling phases in the FM. They can cause disturbances and can lead to ripped and folded head and tail ends, to work roll damages and, in the worst cases, to cobbles and mill downtimes. All the strip steering components were combined for safe tandem mill rolling in the X-Roll Guide FM system. All mill stands are equipped with the RAC system similar to the one at the roughing mill stand. For mill stands with hydraulic work roll shifting systems, the thrust force compensation (TFC) can be added to compensate axial forces, which can disturb the measurement of the differential forces.

The X-Roll Guide FM system is completed with the tail-out monitor (TOM), which calculates the leveling error for each mill stand and displays a leveling amount and direction after each strip. The operator can use this leveling recommendation to pre-level for the next strip. In the FM, with separately driven hydraulic sideguides it is possible to detect when and where a strip tail end hits a sideguide (Fig. 9). This information can also be integrated in the RAC to improve the performance and to stabilize the tail-out process.
A new optical sensor that supplies the interstand strip position for a direct centerline control has been developed. With this camera system working in the infrared frequency spectrum together with a fast digital image processing system, the position of the strip can be measured. The so-called X-Pact® Sense hotCAM camera system is positioned on the top of the mill stand and thus protected very well. The generated strip center signal is transferred to the controller and used to level the mill stands. The integration of the X-Pact Sense camera system in the X-Roll Guide FM system is shown in the block diagram in Fig. 10. All steering and leveling actions are coordinated by the X-Pact Strip Steering Control. Leveling control is active for head steering, during filet rolling and tail-out phase.

The first complete installation was commissioned in a 7-stand hot strip mill in Germany. All six interstand areas are equipped with X-Pact Sense hotCAM camera systems. The strip center positions measured by the cameras and the differential forces of each stand are used to control the strip steering especially for the tail end. The control of all stands is done by a stand-alone automation system connected to the existing automation. The control is constantly in operation, contributing to the stabilization of the rolling process, especially during tail-out. Fig. 11 shows the human-machine interface (HMI) for the mill operator directly after a strip has tailed out. Photos of the tail end from each stand are displayed together with the tail end positions and the actual leveling values. In preparation for the next strip, a recommendation for the amount and direction of the leveling for each stand is shown.
**Digital Transformations**

**Downcoiler Area** – To achieve a proper coil shape, X-Roll Guide Coiler was established. Operator and driveside sideguides are operating independently, hydraulic controlled, highly dynamic and with low friction. Damages at the strip edges are avoided and different control modes are selectable. The general design is shown in Fig. 12.

The coiling quality for high-strength material or thick pipe grades can be improved with a controlled chute roll shown in Fig. 13. The chute roll is in contact with the strip during coiling and supports the bending process. This stabilizes the coiling process and leads to straight and tight coils with minimum telescopicity.

**Conclusions**

Different systems to control the strip steering developed by SMS group were explained in this paper:

- Roughing mill: X-Roll Guide CFR; perfect transfer bar shape and reduction of wedge.
- Finishing mill entry: X-Roll Guide FM entry; stabilizing the threading and fillet rolling process.
- Downcoiler area: X-Roll Guide Coiler; straight coils with minimum telescopicity.

All performance modules combine reliable mechanical actuators, sensors and automation systems with adequate control loops and tracking. The result of these mechatronic systems are controlled and adapted with related measuring devices. They can be added to an existing rolling plant in total or in packages. Each module has its own advantages and helps to increase rolling stability and yield of the hot strip mill. The selection of the technology packages depends on pre-conditions such as product mix, mill condition or used automation standard.

The investment in these systems must return in an adequate time. In a hot strip mill, the investment can be justified simply by the amount of ripped strips, downgraded material and the resulting efforts for roll change, unscheduled downtimes and roll grinding. Additional rolling time can be used to boost the production capacity. The higher the production amount of thin-gauge hot strips and hard material, the greater the benefits of the systems.

**References**

1. SMS group graphic, Compact Hot Strip Mill.
4. W. Rohde, EP763391B1; Method for Compensating Forces Resulting From Horizontal Movements of the Rolls in a Rolling Stand.

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**Did You Know?**

*ArcelorMittal, Zeleros Test Steel Performance for Hyperloops*

A testing facility has been built at ArcelorMittal’s Rail Excellence Center in Spain to test how certain steels perform in ultrahigh-speed conditions in cooperation with hyperloop designer and manufacturer Zeleros. The testing facility comes in the form of a spinning wheel that can reach linear speeds of up to 500 km per hour. Results from the testing provide data that will aid in the selection of the best steels for hyperloop use.

The partnership between Zeleros and ArcelorMittal has been in place since 2017. Since then, experts from both companies have jointly developed studies to analyze how materials behave in high-speed conditions.

“The work we have been doing with Zeleros reflects the importance we place on our involvement in innovative projects using steel in infrastructure and transportation, and that contribute to reducing CO₂ emissions,” said Nicoleta Popa, portfolio leader of Construction Applications, Infrastructures and Long Products for ArcelorMittal Global R&D.