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STAINLESS STEEL – THE REAL MIRACLE METAL

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Reducing profile and flatness failures

A significant improvement in profile and flatness failure reduction is achieved by precise process control through artificial intelligence (AI) and machine learning (ML). The main innovation is not only predicting profile and flatness deviations, but computing optimal hot strip mill settings in a fully automated way for each campaign and each process step, for each slab, transfer bar and strip. Automated optimisation based on AI and ML is applied during campaign planning and online during production. By **Selim Arikan[1], Dr. Jan Daldrop[1], Dr. Otmar Jannasch[2] and Dr. Falk-Florian Henrich[3]**

PROFILE and flatness failures are well-known problems at hot and cold rolling mills. They are difficult to precisely predict and directly affect the quality of the strip especially for ultra-thin strips, high-tension grades and non-oriented electrical steels. Over time, improvements in thickness accuracy, width accuracy and profile (cross-strip direction) thickness distributions have been made.

Yet, steelmakers are still suffering from deviations in process parameters (for example, inadequate reduction profiles and non-homogenous reheating) that might lead to local variance in strip profile and consequently result in flatness failures. These failures introduce additional costs to steelmakers for reworking the coils to meet the required quality specifications. Therefore, it is crucial to predict the flatness deviations and failures correctly and early enough to prevent them from being introduced at all.

Generally, finite element and rule-based models are used for predicting profile and flatness failures. If the parameters (such as roll temperature and roll gap settings) deviate from accepted ranges, flatness failures may emerge. However, the rule-based models can only produce useful results when the flatness failures are imminent because they do not take into account the historical values of all operating parameters and upstream process steps. In the actual production process, many other factors come into play that affect the expected flatness of the strip, such as non-uniform thermal gradients, failure in force distribution, local irregularities in roll thermal expansion due to zone cooling failures and so on.

Compared to typical machine-learning-based solutions, Smart Steel Technologies' approach not only predicts the flatness deviations and failures, but also automatically computes the optimal mill settings so that fewer flatness failures occur in the end.

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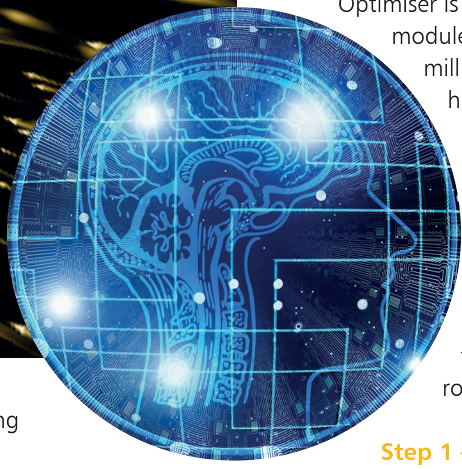

above challenges and computes in a fully automated way a complete set of optimal settings for all relevant finishing mill parameters to minimise all profile and flatness failures. When setting all rolling parameters for the upcoming strip, prior to the start of rolling, Smart Steel Technologies' system takes the existing mill settings as an input and automatically outputs optimised settings. The optimisation of all finishing mill settings takes place not only for each process step, but in particular for each slab. The Smart Steel Technologies Rolling Optimiser is complemented by online modules that support rolling mill operators to reach the highest level of precision and to minimise all process deviations. Thus, Smart Steel Technologies significantly reduces the rate of profile and flatness failures through the elimination of their root causes.

While the underlying reasons for flatness deviations and failures are well-known, steelmakers cannot predict these failures early and precisely enough to prevent them from happening. This is because existing approaches focus mainly on rolling parameters only and do not consider upstream events, steel properties or the historical behaviour of the previous strips in a sufficient way during rolling. Current models are unable to take the specifics of very similar steel grades or strip dimensions rolled in the past into account. So, one example out of many is the correct choice of bending forces of the work rolls based on the non-uniform thermal gradients across the strip profile. If the local temperature deviation around the edges of the strip falls out of the temperature tolerance range for the selected rolling schedule, high reduction ratios may lead to edge waves. The key question is, how can we find and eliminate the actual root causes of edge waves to prevent them from happening in the first place? Potential candidates for root causes are many and include roll gap settings, reduction plans, non-homogenous reheating of slabs, lubrication of working rolls and more.

Smart Steel Technologies has created a software system that solves all of the

Step 1 – Predicting flatness deviations

Defining a correct and precise target signal is vital for a successful machine-learning-based quality optimisation project. Measured flatness values obtained from strip inspection systems contain valuable information. However, they are insufficient for a modern quality control approach if they are used alone without considering

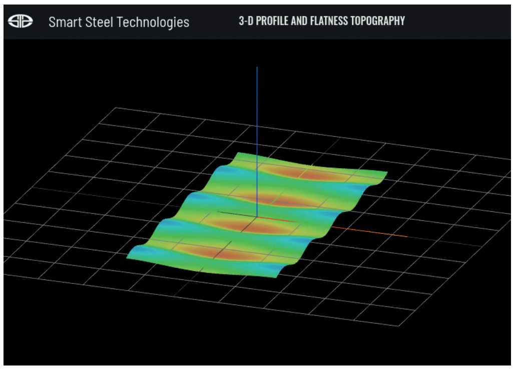

Fig 1. Profile and flatness deviation heatmap

any of the corresponding process information such as slab and transfer bar dimensions, rolling speed, roll gap settings, bending forces, leveling, the lifetime of the work rolls, information on looper positions, roll-gap-lubrication and interstand cooling.

Smart Steel Technologies uses the measured flatness values along with all relevant upstream data for the prediction of flatness deviations. The source data consisting of thousands of signals with varying tick frequencies from 0.5 Hz up to 50 Hz and associated metadata is piped through advanced predictive models based on proprietary recurrent neural networks to predict the flatness deviations. An example illustration of flatness deviation is shown by SST Coil Topography in **Fig.1**.

Smart Steel Technologies provides a fully-developed model for the prediction of profile and flatness. This model is then only tailored to the specifics of the particular hot strip mill in order to reach the highest possible performance value.

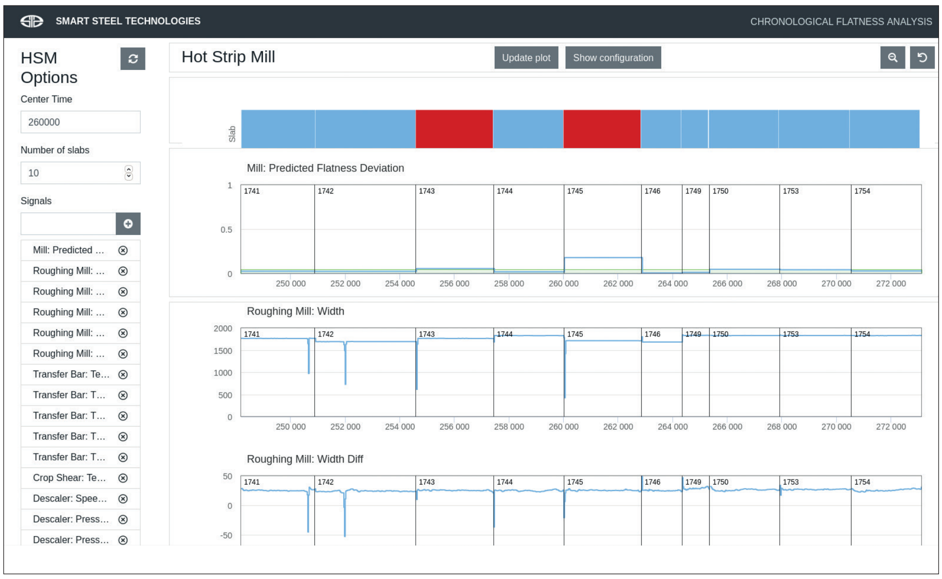

Fig 2. The user interface for inspection of merged data from roughing mill and descaler

Fig 3. Analysis of the quality effects of different parameter combinations

All existing historic slabs, transfer bars and strips are then processed with this new technology. Finally, the signals and prediction information are mapped to a common co-ordinate system as a precondition for the root cause analysis to achieve a precise position-based matching for every strip.

All profile and flatness values are predicted online and mapped onto Smart Steel Technologies' Flatness Analyser shown in **Fig.2**.

Step 2 – Optimising the hot rolling process

Based on SST's own cross-product position matching technology, the flatness target signal, which is the flatness deviation level per metre of the strip, is assigned to each position on the transfer bar automatically.

Simultaneously, Smart Steel Technologies' software automatically merges flatness deviations with all Level 1 hot rolling signals such as reheating oxygen percentage, roughing temperature between passes, settings for all mill stands, looper positions and information on lubrication or cooling and many more.

Modern systems typically provide thousands of high-frequency raw signals with different sampling rates. Smart Steel Technologies analyses the actual high-resolution time series. This is of vital importance because short spikes in signals (such as loop lifter tension) contain valuable information.

Smart Steel Technologies also provides visualisation tools for easy manual inspection of the merged and transformed data as depicted in **Fig.2**.

At this point, it is important to note that all the mentioned data is obtained from the live production system rather than doing a post-mortem analysis. Also, the recommendations for the finishing mill settings are directly submitted online to the live L2 system.

Clearly, the raw signal data from the finishing mill is still of limited use even after all relevant reheating furnace and roughing mill data have been merged correctly. Therefore, the next step is to extract meaningful features from each relevant hot rolling mill signal.

In addition to the finishing mill, the relevant process steps include the upstream stages (roughing mill, descaler and slab reheating furnace) whose process status influences the finishing mill. Subtle deviations in timing, temperature and geometrical adjustments can add up to influences that lead to deviations in rolling and could cause profile or flatness failures.

Based on the information extraction described above, Smart Steel Technologies provides an easily understandable system that allows technologists to inspect the feature space of the hot rolling mill. The users of the software can select arbitrary combinations of roughing and finishing mill parameters, steel grades, operational data and inspect their effects on the flatness deviation as depicted in **Fig.3**.

The cleaned and transformed live production data then allows Smart Steel Technologies to algorithmically find the optimal combination of finishing mill parameters with respect to strip flatness uniformity based on historical data. The optimiser takes all relevant process constraints into account. To achieve this, Smart Steel Technologies combines deterministic, physical process modeling of the hot rolling process with probabilistic modeling based on methods from Artificial Intelligence and Machine Learning.

Through live integration with the production planning system, an optimised rolling schedule is computed automatically for each production campaign, see **Fig.4**. Additionally, live model output supports operators of the rolling mill itself with live recommendations for settings, such as rolling speed, roll gap settings, bending forces, leveling, tension control, roll-gap-lubrication and interstand cooling to reach the highest precision in process control.

The consistency of the Smart Steel Technologies' software suite allows the extension of the optimisations to all upstream and downstream processes through the connection of all relevant parameters and model outputs. This state-of-the-art optimisation approach is the most promising solution for the whole production process in order to achieve the best quality in final products. ■

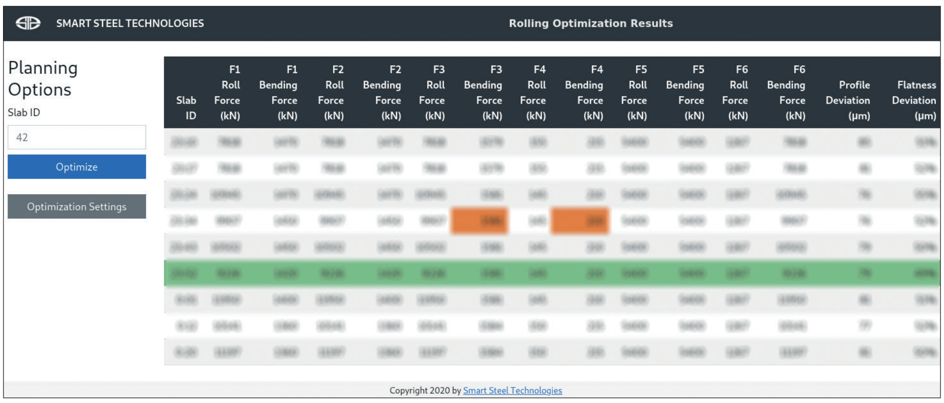

Fig 4. Automated parameter optimisation for each rolling campaign, selected sample parameters