Aluminium Melting Furnace after Revamping
150 to/day melting capacity
83 to content
8 MW EcoReg (r)
Photo credit: Jasper GmbH
FLATNESS CONTROL INSTALLATIONS IN HOT STRIP MILLS

Although flatness control for hot rolling is less understood compared to cold rolling, the introduction of this new measurement placed near the roll gap of a hot mill means a technological step with potential for higher productivity and tighter strip tolerances for the whole strip processing line. The reasons are the following:

Historically, technological advances in the design and control of rolling mills have led to metal strips with homogenous prescribed properties in both longitudinal and transversal directions. The downstream rolling processes can influence thickness and flatness differently. Thickness profile is determined early in the hot rolling phase. This initial profile will persist during the subsequent downstream processes. The adequacy of this profile is significant since the cold rolling process has limited possibility to change profile, e.g. only locally, closed to strip edges. Therefore it is important that a correct profile is determined from start. The possibility to change profile diminishes as the aspect ratio of the rolled strip (i.e. width/thickness ratio) increases due to decreased thickness. By contrast, the ability to correct flatness defects increases with each processing step and is largest at the final rolling stand. These differences in profile and shape control capacity across processing lines along with the inherent measurement and control difficulties explain why historically measuring flatness in hot rolling mills had a slow progress: flatness in hot rolling was hard to measure and for many years it was not clear how can this measurement be used for better strip quality.

Today, the allowable parameter tolerances along the longitudinal and the transversal directions of the strip are not shared equally. Statistically, most of the permissible tolerances such as flatness or thickness are caused by variations in the transversal direction. This means the battleground for increased quality is still today on the transversal control of strip thickness and flatness. Longitudinal control problems still remain, related to rolling start and end phases of a coil and related to off-line flatness effects.

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Even if profile and flatness in hot rolling mills is not yet as well understood and formalized as for
cold rolling, an increased interest can be observed for measuring flatness in a hot rolling mill. What is then the explanation for this new focus on flatness in hot rolling mills despite all difficulties? In short the answer is the following: there is a need for tighter tolerances for thickness profile and flatness and for increased speed (productivity) in the cold rolling process. This means an appropriate thickness profile must be determined with higher precision early in the hot rolling process. Therefore setup and on-line models are required to quantify different interactions in the mill during the hot rolling process. Parameterization of models and dynamic control of the mill require therefore more measurements done as close as possible to the hot mill’s roll gap. Flatness was always part of such interaction models and is therefore a strategic measurement. The results obtained in this way can improve both transversal and longitudinal parameters of the strip.

It was realised early on, in the 1940’s, that accurate rolling models are a key for achieving a homogenous, high quality rolled product. One reason for models is to have accurate parameters for the mill setup. Secondly, many parameters in the rolling process are either difficult to measure or measurements have long time delays. Therefore a model-based prediction (a feed-forward control action) usually gives better results than a traditional non-model-based feedback control.

A rolling model typically quantifies the interactions among many parts of a rolling mill: roll gap deformation zones, elastic deflections of the rolling stand, strip stress distributions and for tandem mills profile transversal influences among consecutive stands. Roll gap deformation zones must consider entry and exit tension of the strip and transverse strain. Roll stack deflections consider shear and banding deflections, etc. Many of these interactions are yet not completely known. For example the relations between thickness profile and downstream buckling is known just from 1971 (the Shohet and Townsend model), a rather recent date in the history of metal processing. The physics, the analytical solid mechanics, the material knowledge and the thermal generation and transfer involved in these models are all rather complex. Even with today’s fast computers, these computations are still slow. There are several ways to perform such calculations: by a finite element method (FEM), by vector analysis, by differential equations or by heuristics. Heuristic methods will include even simplified models that achieve faster computation by making simplified assumptions about different interactions in the mill. These methods include today even genetic, soft-computing and machine learning algorithms. Contemporary models for example are using on-line full 3D models of the roll stack deformation and these models are complemented by thermal expansion models and roll wear models.

Modeling rolling mills often means a tradeoff between the space granularity and the dynamics (time) granularity of the model. A FEM analysis has a fine spatial granularity, however it has poor means to characterize system dynamics. By contrast, a dynamic system with observers has a poor spatial representation, but gives a very precise dynamic prediction of the system. Vectors have more balanced properties. Practically, models in the rolling industry are using several of such approaches together to achieve both acceptable granularity and short computation time.

There are three typical ways to use models for rolling mill control: set-up (off line) models, look-up table-based models and on-line models. Look-up table models are a middle stage between off-line and on-line models. For example a dynamic flatness target curve along the length of the strip is a look-up table model. On-line models are used for different kinds of model-based control such as internal model control or optimal control. A steady-state model describes a system with parameters that are not changing in time (all partial derivatives with respect to time of all properties are zero). Dynamical models have parameters that change in time, i.e. partial derivatives of certain parameters are variable.

The control objectives in a cold rolling mill are to produce a strip with a defined thickness and flatness profile. The flatness profile has to be decided by a model that compensates post hot rolling effect such that a suitable flatness profile will be available for the cold rolling phase. The control has to consider effects of plastic deformations inside and outside the roll bite, entry and exit strip tension, thermal camber, measurement noises and measurement and actuator delays.

The decoupling algorithms that isolate flatness and profile control are more complex in hot
rolling than in cold rolling. An optimization of the rolling process across a number of degrees of freedom means having command over a rather complex set of methods.

The factors described above are leading to the conclusion that many comprehensive models across several processing lines, allowing for many parameters that influence profile and flatness, will be reconsidered and improved after the introduction of this new flatness measurement technology in hot rolling mills. Both set-up and dynamic models will benefit from better parameterization possibilities following the new measurement technology.

Since the measuring rolls have been introduced only recently, the experimental results are few, yet promising. The new Stressometer roll is currently installed and working in a modern hot rolling mill for aluminium. The flatness control is an optimized, model-based, decoupled control. The results show significant benefits in process repeatability, yield and strip quality. Improvements in the edge trimming pass speed were about 15%. Edge trimming pass yield improvement was about 2%. Side trimming was improved leading to lower odds for strip breaking events. Cold rolling, due to better tail out from the hot mill was significantly improved as good tail from hot rolling means a good start in the cold rolling phase. The experience of the rolling mill professionals with the new Stressometer can be described as a new opening of a visibility window into the hot rolling process. The insights gained by this new visibility helped in understand relations among different parameters influencing the rolling process and indicated novel ways for improvements. As one engineer remarked, maybe the visibility aspect is most important with the new technology.

Summary
The introduction by ABB of a new flatness measurement device for hot rolling mills means a new stage for process execution, planning and real-time control of hot mills. Better models and a better understanding for how parameters are influencing rolling are expected to increase substantially strip quality and mill productivity. The experimental results, though at an initial stage, are promising.

George Fodor
george.a.fodor@se.abb.com