Energy efficient rolling

On-line minimization of energy consumption in the hot rolling of long products

Anders Daneryd, Mats G. Olsson, Rickard Lindkvist

A typical working day for a rolling mill operator is not as straightforward as one would think. In fact a typical day can often mean a turbulent one where the operator has to battle process instability that interferes with production. Finding his way out of certain situations such as unstable rolling, which results in down time, less yield, and frequently the appearance of cobbles as a result of bar derailing, may be very time consuming.

Regaining stable rolling is often based on the individuals' experience. Judging what the best set of process parameter settings should be is a black art representing the very core of their professional pride. However, by the time production is back on track, valuable material and energy have been wasted in ensuring correct dimensional accuracy usually through trial and error. To aid operators in their task as well as to eliminate such waste, help is now available in the form of a software package for advanced rolling process optimization from ABB.

A product change (PrC) generally refers to the process of changing one stable rolling configuration for one material with specific finishing dimensions to another configuration with a different material and finishing dimensions, with minimal downtime and scrap production. Frequently, the number of rolling stands is also varied. An unsuccessful PrC may result in production delays of more than one hour, whereas a successful one is usually completed in a matter of minutes.

The difficulties of repetitively reproducing a product change with minimal disruption have challenged ABB's researchers, who now have responded with a unique online software tool for operators. This tool is based on state-of-the-art rolling models and optimization, simulation, and statistical methods, that guide the operator to optimal process parameter settings for stable and dimensionally accurate rolling.

Models for optimization, simulation and calibration

Mill availability and yield will certainly improve by being able to model, simulate, and optimize production speed and energy requirements, while controlling bar dimension, roll load sharing, groove utilization, and similar important process quantities. The *Adaptive Dimension Models (ADM™)* tool advises the mill floor worker – via an easy-to-use HMI – about the parameter settings that should be used to reach optimal conditions. With this tool complex calculations take less than a minute to complete, but in actual fact most are often completed in no more than ten seconds.

This tool can be accessed through an auxiliary PC located in the operators' booth 1 alongside the regular ABB Rolling Mill Control (RMC™) and Interstand Dimension Control (IDC™) displays.

Interstand Dimension Control for rolling stability

The IDC concept has been developed for rod and bar mills to achieve tighter tolerances head to tail, as well as improved product quality, yield, and availability. In addition it ensures fast product and dimension changes. It functions as an early indicator of abnormal mill conditions, which ensures a more consistent mill set-up and improved pass schedules.

The key IDC component is the U-gauge™ for online bar dimensional measurement 2. Online information from the drive system and U-gauge is seamlessly communicated to the ADM tool 3. As well as this data, a few parameter settings (selected by the operator) required for various process simulation and optimization tasks make up the rest of the inputs. The output, in the form of adjustment lists, tables and charts, is usually given within a few seconds.

Stable rolling is defined by a continuous mass flow rate throughout the process line with minimal interstand forces, and in particular compressive stresses.

This configuration in combination with high speed algorithms allow for a great number of interactive process optimization tasks in a short period of time. Having identified parameter settings that meet his demands, the operator can store these results as a new RMC rolling schedule for retrieval at some later date. In summary, the ADM tool requires only minimal configuration work before it starts delivering useful results.

Rolling maximization and minimization

Stable rolling is defined by a continuous mass flow rate throughout the process line with minimal interstand forces, and in particular compressive stresses. Maintaining this together with the required dimensional accuracy of the finished product challenges the operator's skills. The ADM tool provides additional capabilities to assist the operator in fully understanding changes that occur in the state of the current rolling, and to plan for the optimization of an upcoming production run. With this tool stability and product dimensional quality are ensured and a vast number of related and important aspects previously beyond the reach of the operator can now be controlled. The core of the ADM optimization module permits the *maximization or minimization* of selected production aspects while keeping related and dependent aspects within permissible constraints 4.

Factbox What causes derailment

Derailment happens because of a massflow mismatch, which occurs when an upstream pair of rolls "feeds" more material per unit of time than the neighbouring downstream pair of rolls is able to "swallow". The underlying cause of derailment is a lack of quantitative understanding as to how various process parameter settings (roll gap, motor speed, interstand tension etc.) affect bar deformation in the roll groove and hence the process massflow.

In mills with frequent Product Changes (PrC) and small batches there is a risk of several such events per day.

1 Operator's booth with control and monitoring equipment

2 U-gauge in operation for dimensional measurement

Energy consumption minimization

Minimizing energy consumption is one such optimization choice available to the operator, while at the same time allowable upper and lower limits are defined for bar width, area, speed, interpass tension, roll gap and motor speed. The finishing dimension and speed of the production to be analyzed is always prescribed without the need for user intervention. Using the selected aspect values the ADM optimizer then solves this nonlinear minimization problem and returns the optimal rolling energy consumption value, or power 5, as well as the influence of the determined optimal parameters (usually roll gaps and reduction factors) on width, area, tension, etc. The complex dependencies between process parameters are handled by consistent rolling models linking mass flow, spread, interpass tensions, torque and power. Controlling bar width and area, so called *groove utilization control*, is not only of importance when reducing roll wear, but it also plays an important part in preventing damage to the bar by ensuring it does not overfill the roll groove. Should the user by accident define inconsistent parameters leading to a solution exceeding one or more of the parameter bounds, a solution diagnostics procedure advises him how to obtain an admissible solution in an ADM rerun.

A real mill example

A real ten-stand example is solved in less than ten seconds on a regular PC. Potential energy savings have been shown to be as large as 10 percent for real rolling schedules. The starting point in 6 (iteration "0") corresponds to the actual mill process parameter settings, and the iteration history illustrates the convergence of the ADM optimization procedure towards a total rolling energy which is about 10 percent lower than at the outset. This implies significant cost savings for a continuously operated mill. Furthermore, ADM optimizes an imaginary process line with 20 stands within 30 seconds.

Other optimization objectives include:

- *The maximization of production speed*. Again system limits such as maximum available motor power, torque, and speed are set as well as limits defined at the operator's discretion based on his experience and knowledge.
- *The matching of individual stand powers to predefined targets*, so-called load levelling.
- *The matching of individual bar widths and cross section areas*, also with predefined targets.

The latter case is of concern when groove utilization control is the primary goal of optimization. Objectives, constraints, and process parameters controlling thermodynamics and microstructural properties will be included in ADM extensions.

The simulation functionality of the ADM tool allows quantities such as bar width, area and speed to be quickly calculated. It also allows sensitivity analyses to be performed.

Interpass tension modelling

In all optimization selections the interpass tension plays an important role and constraints ensuring stable rolling without compressive stresses may be specified, as well as tension setpoints. A unique modelling feature is the way in which tensions change bar dimensions, both in the deformation and interstand zones, while at the same time the overall model maintains a continuous mass flow. This is not only violated in other modelling approaches, but it also paves the way for a consistent analysis of the so called "endless rolling", in which bar dimensions may be controlled by relatively high interstand tensions.

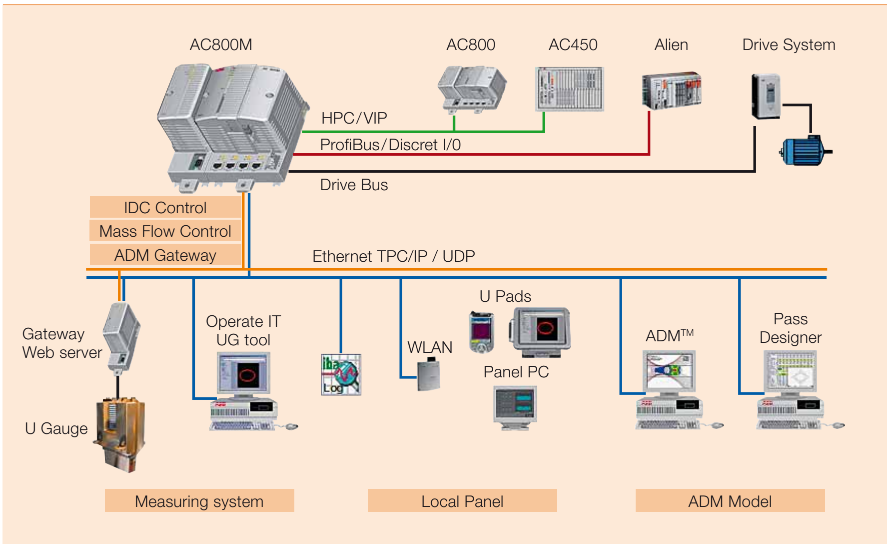
Model adaptation

Optimization may be carried out either for the current production run or for an upcoming one following a PrC procedure. For a current run, on-line drive system and U-gauge readings are used for model adaptation so that model accuracy is enhanced. Calibrated models from previous production runs may also be used in the PrC optimization provided their rolling conditions are similar. The logic of the ADM tool automatically decides the best model adaptation scheme. It is common knowledge that a rolling power model greatly benefits from adaptation and this in turn affects the accuracy with which energy consumption is determined.

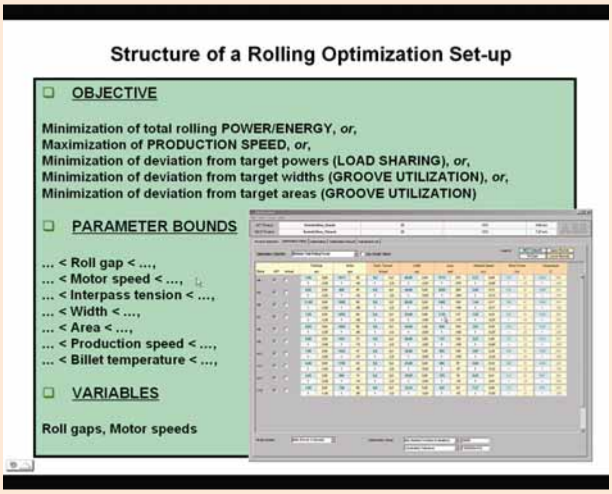
Fast simulations for sensitivity analysis

Another important feature of the ADM tool is the simulation functionality, which allows quantities such as bar width, area, speed, interpass tension, to be quickly calculated. Process pa-

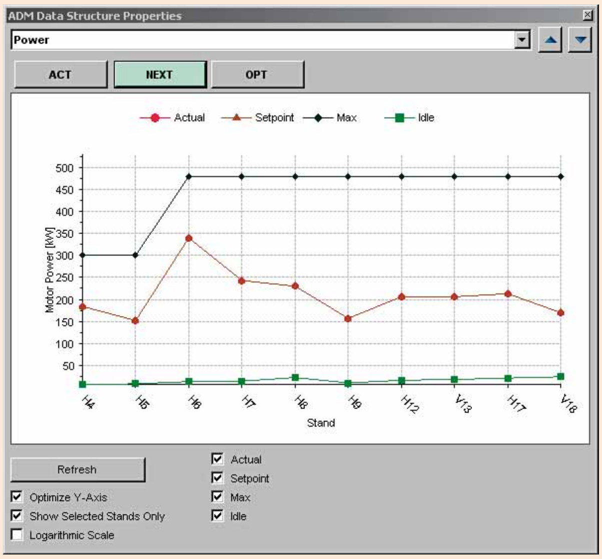
3 Interstand Dimension Control (IDC) system components. The ADM tool runs on a dedicated PC connected to the system communication bus



4 The setup for a nonlinear optimization task with objective choices, parameter constraints and primary optimization variables is depicted. Also included is the corresponding ADM window for data entry.



5 Results chart for rolling power quantities

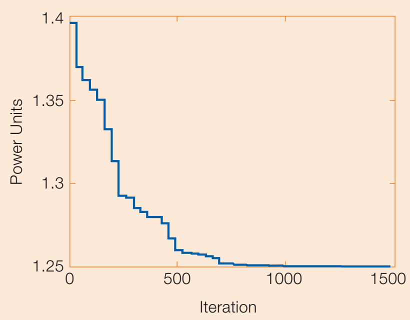


rameter inputs include roll gaps and motor speeds, along with information on billet and roll grooves. This feature is very useful when analyzing the effect of small changes or disturbances to the process parameters obtained in an optimization – so called *sensitivity analyses*. One simulation task requires a few tenths of a second for a 10-stand configuration whereas a 20-stand configuration requires slightly more than a second.

A statistical approach with uncertain materials and process conditions

Suppose a new material with uncertain materials properties (essentially its flow stress or resistance to deformation) is to be rolled the first time. To check for potential problems the operator may want to investigate for example the safety margins with respect to unstable rolling. He may then launch another simulation-based feature of the ADM tool, a *statistical evaluation* of the likelihood of interpass tensions exceeding allowable ranges. The core of this feature is based on the well known Monte Carlo approach, which has been adapted to the rolling models in a novel way. Results are presented as a probability of stable rolling for the configuration and process parameters at hand. In fact, all types of results pertaining to the bar, rolls and drives previously discussed may now be expressed as confidence intervals with lower and upper limits, rather than as one specific value obtained in a regular deterministic simulation. This also improves the accuracy of the energy requirement prediction as this is very sensitive to bar materials deformation properties.

6 Minimization of total rolling power (proportional to energy) for a Swedish 10-stand mill (intermediate and finishing part) configuration for the production of round 20 mm diameter bars.



ADM – a new standard in hot rolling

It is believed the ADM tool will set a new standard in a mill floor worker's daily strive for production perfection. HMI ease-of-use, robustness, and accuracy are corner stones of the ADM optimization, simulation, and model adaptation logic. It also provides an excellent educational platform to unite the many different "black art" PrC and process line fine tuning philosophies that usually exist among mill operators.

Towards on-line optimization

Further reduction of optimization times towards just one or two seconds is within reach using the latest numerical optimization developments. A fully automatic on-line optimization tool is envisioned thus alleviating the need for trial billets. To be more precise, optimization and adaptation is carried out during the time the bar head travels between the first two stands in a multistand rolling line.

Anders Daneryd
Rickard Lindkvist
ABB Corporate Research
Västerås, Sweden
anders.daneryd@se.abb.com
rickard.lindkvist@se.abb.com

Mats G Olsson
ABB Automation Technologies
Västerås, Sweden
mats.g.olsson@se.abb.com