Rolling mill simulator

A new platform for testing, analysis and optimization of cold rolling mills.

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The cold rolling of flat metal products especially in tandem or multi-stand mills is a highly complex process where the product quality is influenced by various aspects. With the help of a hardware-in-the-loop simulator, the complete rolling process can be simulated and tested in real-time. This allows pre-commissioning and pre-optimizations before the actual commissioning work is done on the plant site. This reduces project schedule and safety risks and guarantees a much faster plant start-up.

In hot and cold rolling mills, the demands on mill profitability, productivity and product quality are on the rise. Thickness and flatness tolerances are decreasing while surface quality must further improve. At the same time, mill flexibility has to match the growing variety of products, while high mill productivity (throughput and yield) is a key issue to remaining competitive in the global economy. Strip quality and mill throughput are influenced by various factors such as mechanical design, electrical and hydraulic equipment, auxiliary supplies and control strategy. The many associated variables have to be tightly controlled to meet product quality targets. The entire control process enters into extreme parameter ranges, especially when one considers controlling up to 40 tons of moving parts to a precision of 1 µm with rolling speeds of up to 100 km/h.

To be able to control such a large and complex plant and meet the high demands on process speed and product quality, a powerful controller is needed to handle all required functions from low level binary control up to advanced and sophisticated control solutions. The high end AC 800PEC controller from the 800xA Automation platform is outstandingly well suited to meet these requirements [1].

The complexity of the process and the corresponding requirements with respect to the control system are rising with the number of stands being involved. Tandem Cold Rolling Mills (TCM) with up to four or five stands in a row can be considered as a most demanding example of what has to be handled by the control system 1. Some of the main aspects explaining the complexity are:

- highly non-linear process, eg with respect to roll-gap
- interstand coupling and interaction via strip
- loop interactions from interstand-tension and thickness control loops
- rolling speed dependant transport-delay between stands
- on-line tracking for head, tail and strip weak points
- synchronization required for all stand interactions
- variety of different disturbances, eg eccentricities, coil-bump, input-thickness and hardness disturbance, Coulomb friction, etc
- various operational modes, eg threading, acceleration / deceleration, tail-out, low / high speed
- large range of thickness reduction from 6 mm down to 0.2 mm

Risk management

Exploiting the full production potential requires an overall and well-integrated approach to cold rolling mill automation, optimization, control, adaptation and supervision.

This approach has to cover:
- mechanical and hydraulic systems
- drive trains
- material flow
- visualization and control system
- modeling and simulation
- pass scheduling and set-up
- technological control
- supervision and diagnosis solutions

To efficiently design, test, analyze and optimize such a complex system, simulations based on a process model are necessary. This is the best and only way to fully understand the complete system with its various interactions without having the actual plant available.

Therefore a non-linear dynamic process model of a multi-stand cold rolling mill was developed to meet the technological demands of such a complex system with respect to required product quality, disturbance rejection, plant stability and reliability, safe operation and fast commissioning. This is especially important in case of a revamp in order to keep the downtime to set up the new automation system as short as possible and to guarantee a fast start-up to full operation.

Off-line simulation

Based on process and plant data as well as measurements and data recordings from the actual rolling operation, a non-linear dynamic simulation model of the process was developed, validated and extended with respect to control functionalities [3]. This allows the simulation of rolling a complete coil including threading, acceleration, deceleration, tail-out, changeover between different operational control modes for thickness and tension control, tracking of head and tail and dynamic program change, eg for continuous rolling.

This simulation setup can be used to test and develop new control concepts in order to improve thickness quality and to meet the increasing demands with respect to off-gauge length. For this purpose the complete process model is realized as an off-line simulation programmed in MATLAB®/Simulink® [3], thus allowing flexible testing, optimizations and evaluations with far more degrees of freedom than on the actual plant.

The performance of different control strategies, mechanical configurations, sensor equipment and drives can be compared in simulation studies. From these, the most suitable setup can be selected and effective process improvements identified. Dynamic simulation can also be used to analyze customer specific problems such as oscillations, which can have a negative impact on product quality.

On-line hardware-in-the-loop simulator

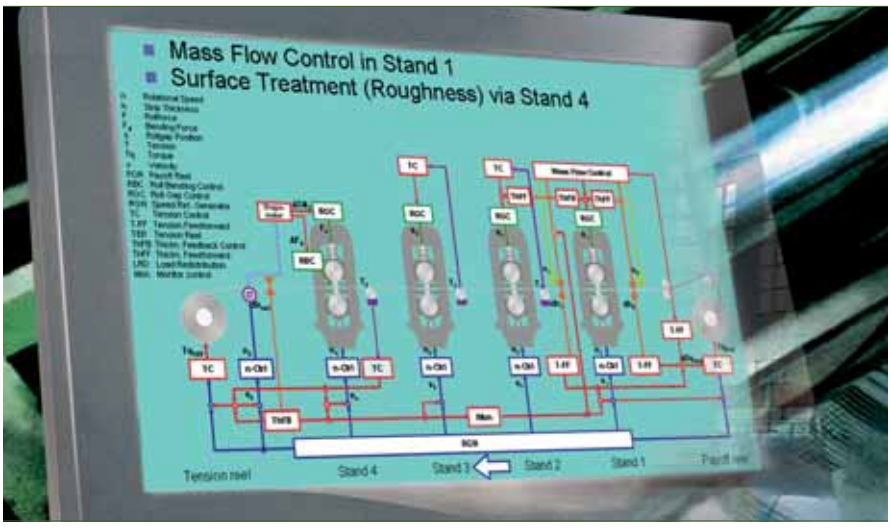
The non-linear process model [3], which was developed for off-line simulation, was transferred and compiled for real-time mode (using MATLAB Real Time Workshop® [3]) and downloaded onto the ABB Process Controller AC 800PEC. Connecting this plant model to the AC 800PEC process controllers that handle the complete automation and application software for the actual plant allows full rolling operation as a Hardware-in-the-Loop (HIL) simulation in real-time [2], [4].

The result is a highly dynamic plant- and process-simulator that acts in real-time and allows ghost rolling for:
- Testing in the lab without having the actual plant available.
- Testing, pre-commissioning and pre-optimization of controller-application software.
- Testing of interface and interaction, eg between the application software of the different controllers.
- Data evaluation and analysis based on process signals that would not be available on plant site as measured signals.
- Testing without risk of strip-breaks, instabilities or causing damages to the actual plant.
- Testing without the need for various test-coils.
- Training for operational personnel to get familiar with the new automation system as well as man-machine interaction.
- Reducing on-site commissioning and plant start-up time.

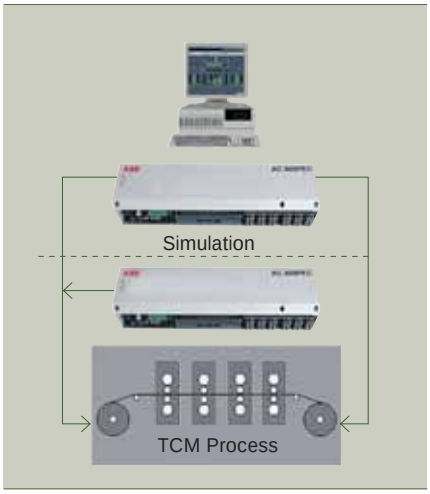
Modular and Scalable

The non-linear dynamic process mod-

1 Four stand rolling mill configuration



2 Ghost rolling using tandem cold rolling mills (TCM) process model as real-time simulator



el for off-line and on-line simulation consists of different modules for coiler/uncoiler, strip, stand, actuators, sensors, filters, control, etc. 3. This allows the modular and flexible design of different multi-stand cold rolling mill configurations. The plant described here is a four-stand cold rolling mill with an uncoiler at the entry and a coiler at the exit side.

In order to be able to perform useful and dependable evaluations, the process modeling has to be detailed enough to cover all dominant static, dynamic and non-linear effects. Some examples of the features that are being covered are:

Coiler / uncoiler

- variable radius as a function of the rolling process
- multi-mass drive-line configuration
- integrated indirect tension control
- speed control including feed-forward compensation
- modeling of torque-loop

Stand module

- dynamic stand model including non-linear roll-gap
- multi-mass mill drive-line configuration
- speed control including feed-forward compensation
- modeling of position- and torque-loop

Strip module

- dynamic model with variable strip thickness and stiffness
- speed-dependable transport-delay generation for inter-stand distance
- internal modeling for tracking of head, tail and weld-seams

Disturbance module

- input thickness disturbance based on measurements from real plant
- disturbances from hardness and weld-seams
- eccentricity generation for top and bottom backup rolls including harmonics
- coil-bump generation for uncoiler and coiler
- coulomb friction in mill-stands

Control / sensor

- sensors for thickness, tension, speed, roll-force measurement
- speed dependant transport-delay for thickness-measurement
- thickness control, inter-tension control, disturbance rejection loops, decoupling loops, etc.
- bump-less changeover between different control concepts

For the process modeling as hardware-in-the-loop simulation in real-time all dynamic components are discretized and the complete multi-stand process model is executed on one AC 800PEC controller with a task sampling time of 1000 times per second.

The communication between the AC 800PEC with the process model and the AC 800PEC Controllers for the automation and application software is performed via high-speed optical links, providing fast and flexible interfacing and communication. Data-recording for analysis and evaluation can also be performed via optical link connection to an ibaPDA (PC-based process data collection and analysis system) [4].

Ghost rolling with HIL-process simulator

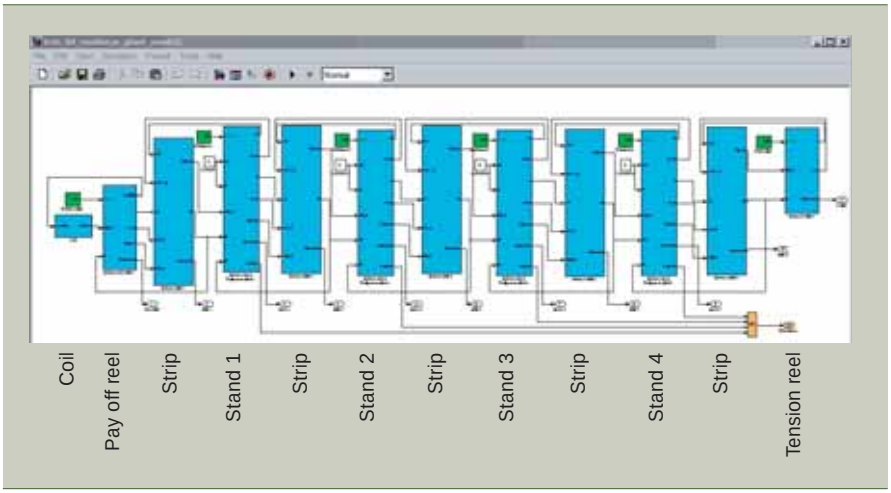
Referring to 2, the TCM Process Model on the AC 800PEC is acting as a replacement for the actual plant. Therefore the application controllers are operating against the process model instead of the real plant.

Different setups and observations can be performed with respect to the HIL-Process Model in on-line mode. Modes of operation can be selected for the HIL-Simulator, such as:

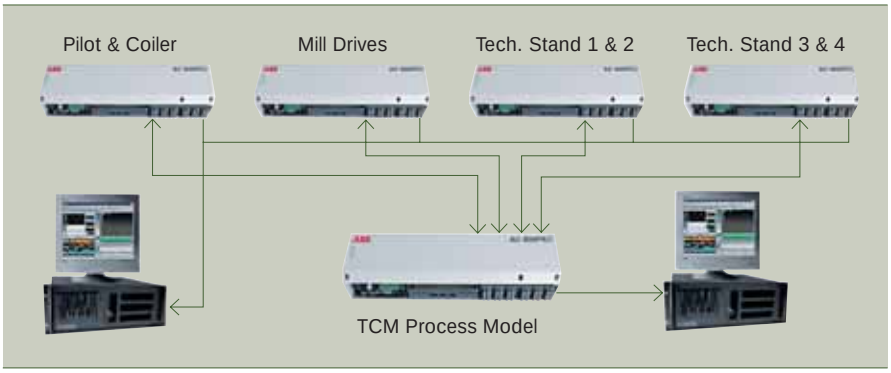
- selection of different test-coils
- selection / activation of different disturbances
- operation without strip
- operation with endless coil

Current process signals and trends during rolling can be visualized. These include speed, thickness, tension, roll-force, forward slip, position and torque.

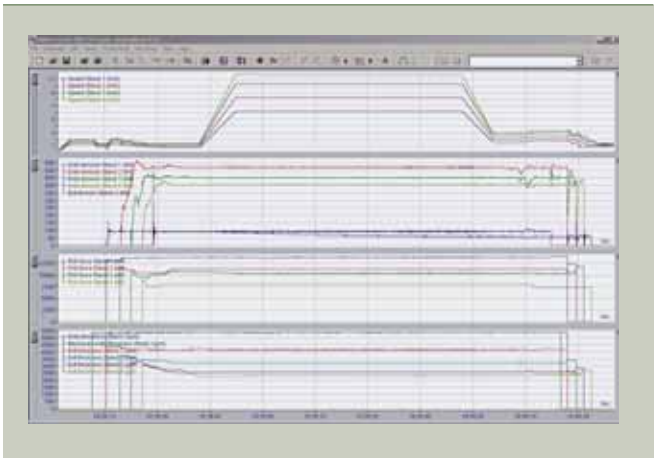
3 Modular process model for a four-stand tandem cold rolling mill



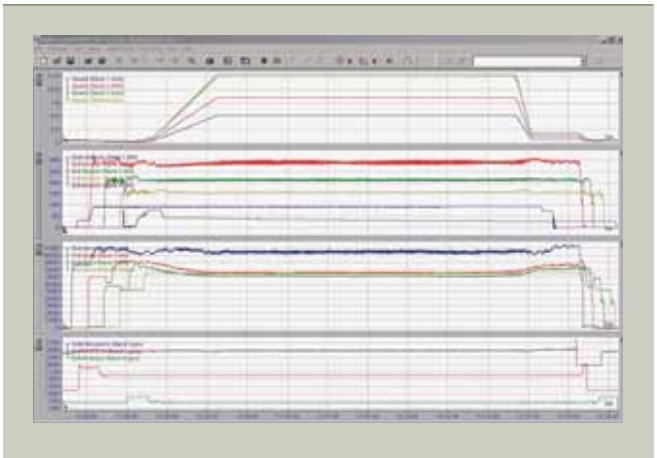
4 Interface between TCM process model and application controllers



5 Ghost rolling with HIL-TCM simulator for full coil



6 Process signals from coil rolling on real plant



For a more detailed analysis and evaluation the process signals can be transferred via optical link to an ibaPDA [4] 4, 5. This inside view allows a much better and straightforward performance and problem evaluation than on the actual plant. Various process signals are often not available on the plant. There are usually no thickness- and speed-measurements between every stand, and the actual thickness in the gap cannot be measured at all (since the sensor has to be placed after or before the stand). All these process signals are easily available while performing HIL-process simulation and can be used for fast analysis and optimization.

Factbox Various features can be pre-tested using HIL TCM Simulator

- model setup, adaptation and reference generator
- dynamic program change and head- / tail-tracking
- interstand tension- and thickness control including pre-optimization
- disturbance compensation and decoupling control loops
- bumpless changeover between different control modes
- full coil rolling including threading, dv/dt, constant speed and tail-out
- interface setup for communication between different AC 800PEC Controllers
- interface setup to Operator Interface and data-recording system (eg, ibaPDA)

Ghost rolling results with TCM HIL-simulator in real time

5 presents the results from performing ghost rolling with the TCM HIL-Simulator in real-time. The rolling of a full coil is shown for a four-stand cold rolling mill with uncoiler and coiler. The process performance is very similar to the one on the real plant as corresponding process signal recordings show 6.

The testing based on ghost rolling with the TCM HIL-simulator proved to be extremely efficient with respect to pre-commissioning and pre-optimization for the plant-related application and control software. The benefit results especially from the fact, that the testing and optimization can be done without the risk of damaging the real plant and without the need for any specific test coils. Also pre-commissioning can already be started long before the actual plant is available for any kind of testing.

Summary / conclusion

- The off-line simulation of the process allows flexible and straight forward optimization and development of new control concepts for cold rolling mills in order to meet future high demands on process performance, quality and reliability.
- The off-line simulator can be used for performance evaluations and plant optimizations already in the design phase.
- The HIL-simulator in real-time provides flexible and efficient pre-commissioning and pre-optimization of the plant related application and control software, without needing the actual plant and without risking damages to the actual plant.
- The HIL-simulator significantly reduces plant start-up time.
- The HIL- simulator can be applied for demonstration in real-time.
- The HIL- simulator can be used for operator training, without interference with the real plant or risk of causing any damages.
- The HIL-simulator can be implemented in the 800xA automation platform on a single high performance AC 800PEC controller, while operating at a sampling rate of 1000 times per second and communicating with the application controllers via high speed optical links.
- The modular design for process-modeling as well as control guarantees flexible and easy adaptation to different rolling mill configurations and provides realistic process modeling even in real-time.

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[3] The Mathworks, User Manual, In particular Matlab, Simulink, Real Time Workshop
[4] ibaPDA, PC-based Process Data Collection and Analysis System, www.iba-AG.com