Industrial IT for cold rolling mills

The next generation of automation system and solutions

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Operating authorities of cold rolling mills face steadily increasing requirements regarding product quality from their customers: thickness and flatness tolerances are decreasing while surface quality must further improve. In addition, mill flexibility will have to increase to match growing product variety while high mill productivity (throughput and yield) is key to remaining competitive in the global economy. Therefore, to meet such demands a modern automation system is required with advanced technology products and solutions that can be seamlessly integrated into it.

To help manufacturers meet their business and technical objectives, ABB has developed and launched the next generation cold rolling mill automation system and performance enhancing technology solutions. The technology solution suite includes components for pass scheduling, mill set-up, simulation, control, product quality monitoring and diagnosis.

Initial tests at customer installations in Germany and Switzerland have shown significant improvements in throughput and thickness tolerance reduction as compared with state-of-the art technology.

With ever-increasing demands on mill profitability, productivity and product quality are pushed to the limit, while at the same time mill flexibility has to match the rising variety of products. Strip quality and mill throughput are influenced by various factors such as mechanical design, electrical equipment, auxiliary supplies and control strategy, and the very many associated variables have to be tightly controlled to meet product quality targets 1. In addition, pass schedules and set points must be optimally chosen to achieve the required productivity objectives. 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 *(table 1)*.

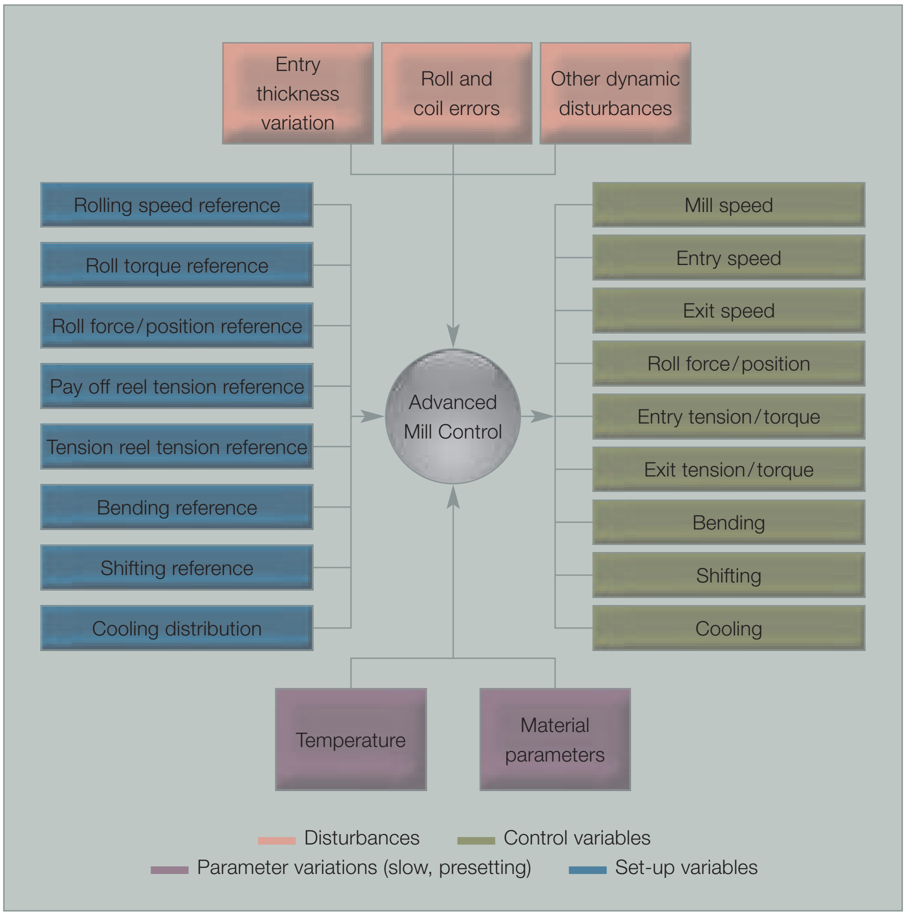
To exploit the full production potential of a rolling mill requires an overall and well-integrated approach to cold rolling mill automation, optimization, control, and decision-support tools. This approach has to cover:

- Mechanical systems
- Drive train
- Material flow
- Visualization and control system
- Modeling and simulation
- Pass scheduling and set-up
- Technological control
- Supervision and diagnosis solutions

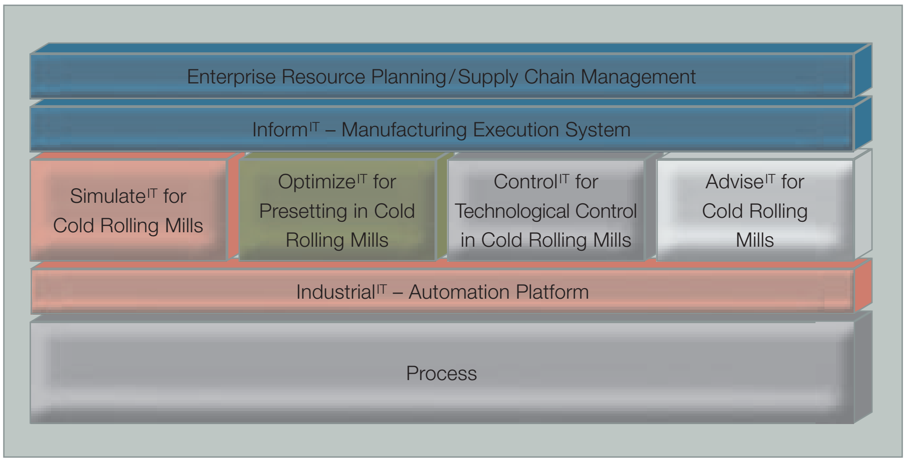
The design of such systems requires extensive knowledge and experience in the metals industry and with more than 650 projects in the field of cold rolling, ABB has developed the next generation of cold rolling mill automation. This new system, as illustrated in 2, consists of:

- *ABB's Industrial[IT] automation platform with Aspect Object™ technology* – the foundation.
- *Simulate[IT] for Cold Rolling Mills:* for nonlinear dynamic mill simulation.
- *Optimize[IT] for Cold Rolling Mills:* enables optimal pass scheduling and adaptive mill set-up.
- *Control[IT] for technological control:* for advanced thickness, flatness and tension control.
- *Advise[IT] for Cold Rolling Mills:* for monitoring and diagnosis of strip thickness and flatness quality.

1 Cold rolling of flat metals products involves controlling a multivariable process with couplings, which is subject to significant disturbances and parameter drift.



2 ABB's Industrial[IT] automation platform, technology solutions, and Manufacturing Execution System are all seamlessly integrated in the new ABB offering.



All components are seamlessly integrated with each other and with the Manufacturing Execution System (MES).

Industrial^{IT} Automation platform with Aspect Object™ technology

Automation systems for the metals industry consist mainly of human system interfaces, controllers and control network, drives, instrumentation, IO (input/output) boards, bus systems and other field communications. Integration of Manufacturing Execution Systems and third party products as well as connectivity to level 3 Enterprise Resource Planning (ERP) systems augment the system.

More than just data integration, however, is required from an automation system to match today's demands on quality, productivity, availability and flexibility. Mill management and personnel need the required information at the right time via a common user interface to make the correct business, operations and maintenance decisions. This can be achieved using *ABB's Industrial^{IT} automation platform with Aspect Object™ technology*.

Information Integration and Navigation

Operations and maintenance personnel have to deal with information from many sources such as measurements, applications and multi-media supervision 3. Even though information regarding single mill objects may vary in type, they are integrated using ABB's Aspect Object™ technology. In other words, a user does not have to deal with different files, folders, applications, operating systems and computers. Both hierarchical structuring and powerful search functions make navigation and information retrieval fast and easy. This is especially beneficial:

- When decision-making during operation is based on many information sources and types.
- For quick diagnosis in the event of abnormal situations.
- For quick and effective maintenance.

Human System Interface: Operate^{IT}

Operate^{IT} is the human system interface for complete process supervision, control, and diagnostics, 3, and it supports operations, optimization and maintenance of the mill. Operate^{IT} uses Aspect Object™ technology to integrate and manage data from different sources. It can interface directly with all ABB controllers and with many third party systems and applications by using the industry standard OPC (OLE for Process Control).

Process Controller: Control^{IT}

Control^{IT} consists of:

- A modular and scalable process controller family known as AC800.
- Control software programmed according to the IEC 61131-3 standard for a wide range of industrial control functionalities.

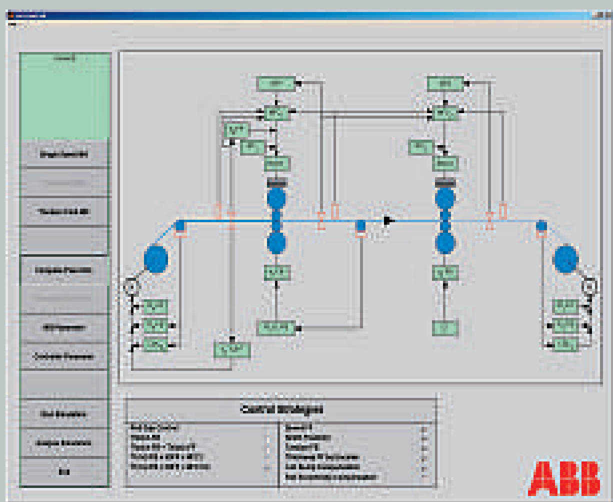
The controllers are well suited to low-level applications as well as advanced technological control of rolling mills. Fast control loops with cycle times of 1ms and below can be realized and it is possible to directly configure control loops from Matlab/Simulink™. All ABB solutions are equipped with simulation functionality so that testing can occur when disconnected from the process or the controller.

Simulate^{IT} for cold rolling mills

Whether manufacturers want a new mill or are seeking to revamp an old one, knowing if a proposed mill configuration

3 Operate^{IT}: Operator process data display

4 Simulate^{IT}: Graphical user interface of the nonlinear cold rolling mill simulation tool.



can meet specific requirements will heavily influence any investment decision.

Product quality depends on a range of different factors, including mechanical, electrical and hydraulic equipment, incoming material, lubrication and control strategy. Rigorous testing of many configured processes is recommended to analyze the overall system performance. Simulation capability must include acceleration and deceleration phases (which make up to 50% of a full pass depending on mill configuration and product).

For this purpose, ABB has developed an object-oriented modeling and simulation environment known as *Simulate^{IT} for cold rolling mills*. A library of rigorous model objects has been established and a graphical editor supports model assembly.

Up to now the industry standard was to use simplified models restricting simulation and analysis to a narrow region around an operating point. Simulate^{IT} uses nonlinear dynamic process models and this permits analysis of *full* passes including the critical acceleration and deceleration phases. More efficient model tuning and better prediction quality is gained by using the included parameter estimation algorithms and the aids for model validation.

The performance of different control strategies, mechanical configurations, sensor equipment and drives can be compared in simulation studies as shown in 4. From these, the most suitable setup can be selected and effective manufacturing process improvements identified. Dynamic simulation can also be used to analyze customer specific problems like oscillations, which have a negative impact on product quality.

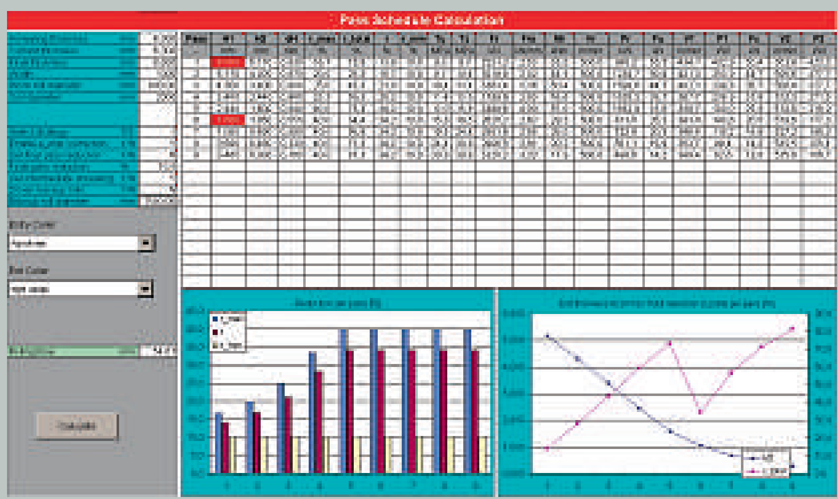
ABB's control solutions are equipped with process models to test customer specific software before commissioning, thus allowing the simulation of solutions in real-time without the necessity of being connected to the process or a controller.

Table 1 Extreme parameter ranges in cold rolling.

	CRM	Comparison
Max force	30 MN	11 kN (Sports car*)
Max mass	40 tons	1.7 tons (Sports car*)
Max acceleration	2 m/s²	7 m/s² (Sports car*)
Max sheet speed	120 km/h	305 km/h (Sports car*)
Number of drives	5–20	1 (Sports car*)
Min thickness	2 × 6 µm	30 – 150 µm (Human hair)
Min thickness tolerance	0.5 … 1.0%	
Min sample time	1 ms	

** Porsche 911 turbo, 309 kW*

5 Optimized schedule with 9 passes calculated with the offline pass schedule calculation tool.



These capabilities have been proven through simulation studies for different rolling mills and as a result, customers have been able to make the right decision for factory modernization schemes.

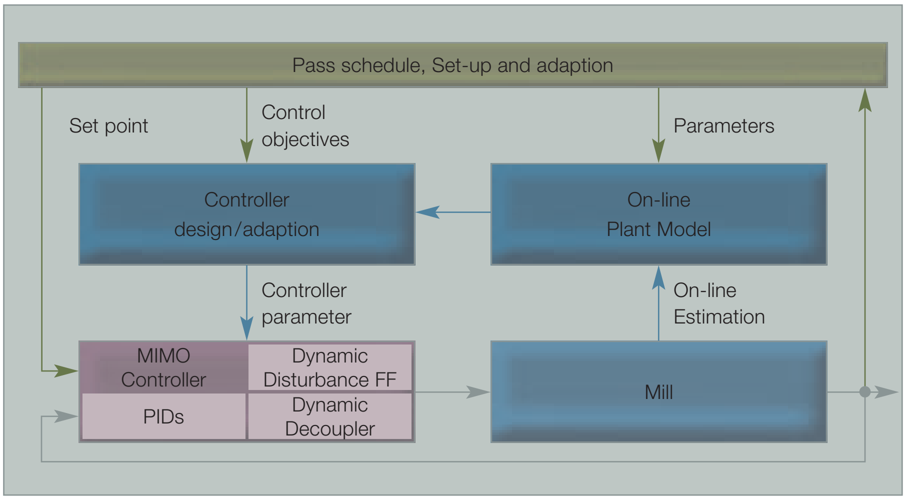
Optimize^{IT} for presetting

Optimize^{IT} for cold rolling mills calculates optimized pass schedules and adaptive mill set-ups and has been designed to meet the demands of increasing product diversity, mill throughput and yield for both new and existing mills.

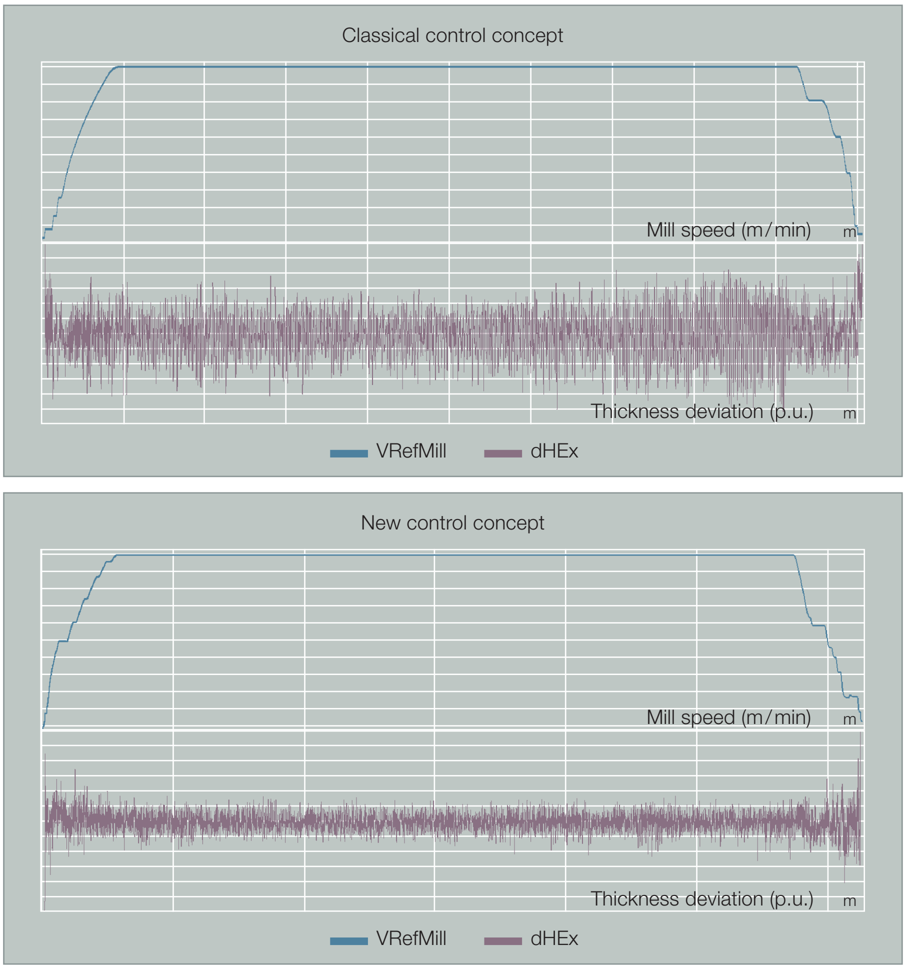
The task of pass scheduling is to find a suitable distribution of the total required thickness reduction to several passes. Raw material and product properties as well as mill constraints are considered. In order to forecast the process behavior, an adaptive mathematical model is used to determine mill set-up parameters such as roll gap position, roll force and flatness actuator references. The set-up for all operational phases, ie, threading, rolling and tail out must also be calculated. State-of-the-art approaches have been improved by:

- Enhanced roll gap modeling
- Consideration of the thermal chamber
- Rigorous profile (shape and flatness) modeling
- Improved adaptation algorithms

6 MIMO control concept with dynamically decoupled PID controllers, dynamic feed-forward and online parameter adaptation.



7 Results from the 4th full pass under normal mill operation: Length series of thickness deviation for the classic control concept (top) and for the new control concept (bottom); 3Sigma improved from 1.3 % classic thickness control (top) down to 0.7 % for new advanced thickness control (bottom).



These in turn have led to:
- Operator and production planning support with automated set-point references
- Optimized throughput rates
- Stable rolling conditions with respect to the process constraints
- Minimized threading, tail out and reversing times
- Reduced off-gauge length at strip head and tail
- Minimized strip breaks, downtimes and roll damages
- Improved strip surface quality

A gray-box concept is applied with intermediate parameters that have a physical meaning, thus enhancing the transparency and interpretability of the calculations. Enhanced parameter fitting functions have also been built into Optimize^{IT}.

The Optimize^{IT} components are part of ABB's manufacturing execution system and the application is available as off-line 5 and on-line versions. This new solution has already been applied in some Aluminium mills, resulting in some 10–30% throughput improvement (product dependent) over state-of-the-art solutions.

Control^{IT} for technological control

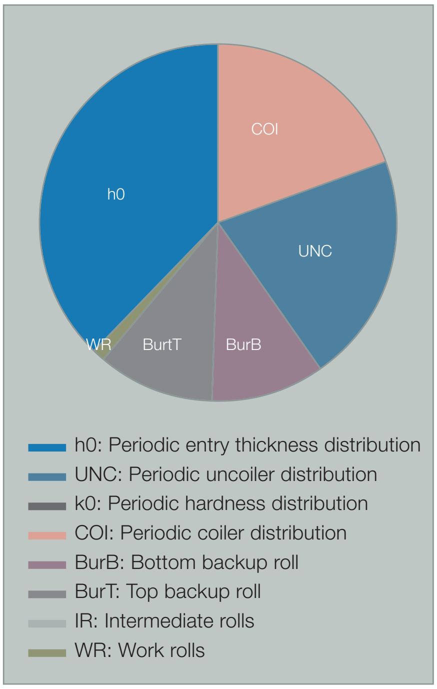
Keeping the strip thickness within a tight tolerance band is one of the most crucial jobs in cold rolling. Deep drawing of aluminium and steel sheets for cans or car body sheets sets the benchmark. The more the thickness variation can be reduced, the closer the minimum permissible thickness the mill can be operated at. In return, material usage is reduced and overall cost-efficiency is improved. To achieve effective control of the rolling process, mechanical, electrical and hydraulic systems, instrumentation, as well as the lubrication and the control strategy must all fit together.

State-of-the-art thickness control algorithms are composed of single control loops and feed-forwards. They are limited in their achievable thickness performance because these algorithms do not take the connection between thickness, roll position and tension fully into account. In contrast, the new ABB technology control solution is based on a Multi-Input Multi-Output (MIMO) control concept, 6 whereby the existing mechanical/metallurgical couplings at a mill stand are dynamically decoupled. The decoupled loops are controlled with Single-Input Single-Output PID control algorithms. Dynamic feed-forward strategies support disturbance rejection.

> ABB's Industrial^{IT} system for cold rolling mills permits uniform plant automation with a suite of seamlessly integrated performance solutions.

The MIMO controller is adapted online to the actual process state to ensure constant strip quality and robust control performance for different materials and operation points. Suitable adaptation parameters are calculated online using a process model. A supervision component monitors and tracks the quality of the changing parameters.

8	Offline analysis showing source and variance contribution of periodic deficiencies.



In the example shown in 7, the improvements that are possible with ABB's new control concept as compared with a state-of-the-art control concept are illustrated. The improved bandwidth of the new thickness control method ensures that tolerances during acceleration and deceleration can also be significantly improved. First tests at customer installations show a thickness deviation improvement of up to 50% (product dependent).

Advise^{IT} for cold rolling mills

Modern human system interfaces such as Operate^{IT} include standard visualization and analysis features like alarm and event filtering. Increasing requirements regarding product quality and process yield, however, demand more enhanced supervision, diagnosis and decision support. Therefore, to match these requirements, ABB has developed Advise^{IT} for cold rolling mills. This application provides online and offline strip thickness and flatness quality analysis, which in turn enables the optimization of mill operation modes and procedures. Advise^{IT} will detect problems with quality and identify their root causes. Features such as a length-based display of product quality parameters make visual inspection much easier.

Thickness deviation problems are commonly due to periodic deficiencies in:

- Strip entry thickness
- Strip entry hardness
- Roll eccentricities
- Uncoiled or coiler tension (by coil bump or coil eccentricity)

FFT analysis and correlation methods are used to identify and quantify contributing factors, 8, which support:

- Predictive maintenance practices such as changing rolls at the right time or identifying problems with a grinding machine
- Optimization of operation modes and procedures for hot and cold mills, for example, using different speed profiles at the beginning or the end of a coil or changing the cropping practice to reduce the impact of coil eccentricity.

Advise^{IT} for cold rolling mills is available as offline and online versions. The online version runs on Control^{IT} AC800 controllers and uses Operate^{IT} for visualization.

Conclusion

In conclusion, ABB's Industrial^{IT} system for cold rolling mills permits uniform plant automation with a suite of seamlessly integrated performance solutions. It offers outstanding performance and includes components for pass scheduling, mill set-up, simulation, control, product quality monitoring and diagnosis. By its design and by the demonstrated performance, Industrial^{IT} for cold rolling mills sets the standard for automation in the metals industry.

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