Improvement of thickness tolerances for a two-stand aluminum cold rolling mill

The implementation of additional control loops to compensate backup roll eccentricity and harmonic hardness variation allows a significant improvement in strip thickness performance.

These measures were successfully implemented as an automation extension to an existing two-stand aluminum cold rolling mill.

An essential quality characteristic in the cold rolling sector is the minimum thickness deviation that can be achieved at final gauge, i.e. from the finishing pass. However, the need to maximize productivity requires that tight thickness tolerances have to be achieved even under sub-optimal mill and entry strip conditions. To meet this requirement there is a need for improved, intelligent control concepts.

Process-related disturbances during rolling

The analysis of a two-stand aluminum cold rolling mill has shown that process-related disturbances such as backup roll eccentricities and harmonic strip hardness variations can make it difficult to meet the target thickness tolerance.

Backup roll eccentricity is not only the result of grinding and roll assembly tolerances, but can also be thermally induced during work roll changes and other stoppages.

Strip hardness variation is less well understood, but an earlier ABB study has shown that for thin strip, cyclic hardness variations as small as 2% in the incoming strip can have a large impact on thickness deviation. Such hardness variations can easily occur in aluminum alloys as a result of uneven cooling.

Typically the hardness variation occurs as a soft (or hard) region on the circumference of the coil. The variation is thus synchronous with the rotational speed of the decoiler and the frequency increases steadily even at constant rolling speed, as the decoiler speed rises with decreasing entry coil diameter.

Concept for the compensation of harmonic disturbances

The key feature of the selected approach for compensating harmonic disturbances is the use of active controllers which automatically adapt to the changing conditions of the system.

While the use of active controllers to compensate harmonic backup roll eccentricities is well established, applying this concept to the compensation of harmonic hardness variations was a step in a new direction and presented new challenges.

Therefore it was decided to first analyze, verify and optimize these concepts within the framework of a simulation study before implementation on the plant.

Simulation study

Within the framework of the simulation study the new concepts for active compensation of thickness disturbances due to backup roll eccentricities (Rec) and harmonic hardness variations (Hdc) were to be tested and optimized.

For this purpose the two-stand mill, see cover picture, including decoiler, coiler and all relevant control loops was modelled and simulated.

The simulation platform in Matlab/Simulink® as used and developed by ABB enables a scalable, modular and dynamic simulation of single and multi-stand rolling mills for the development and analysis of new control concepts.

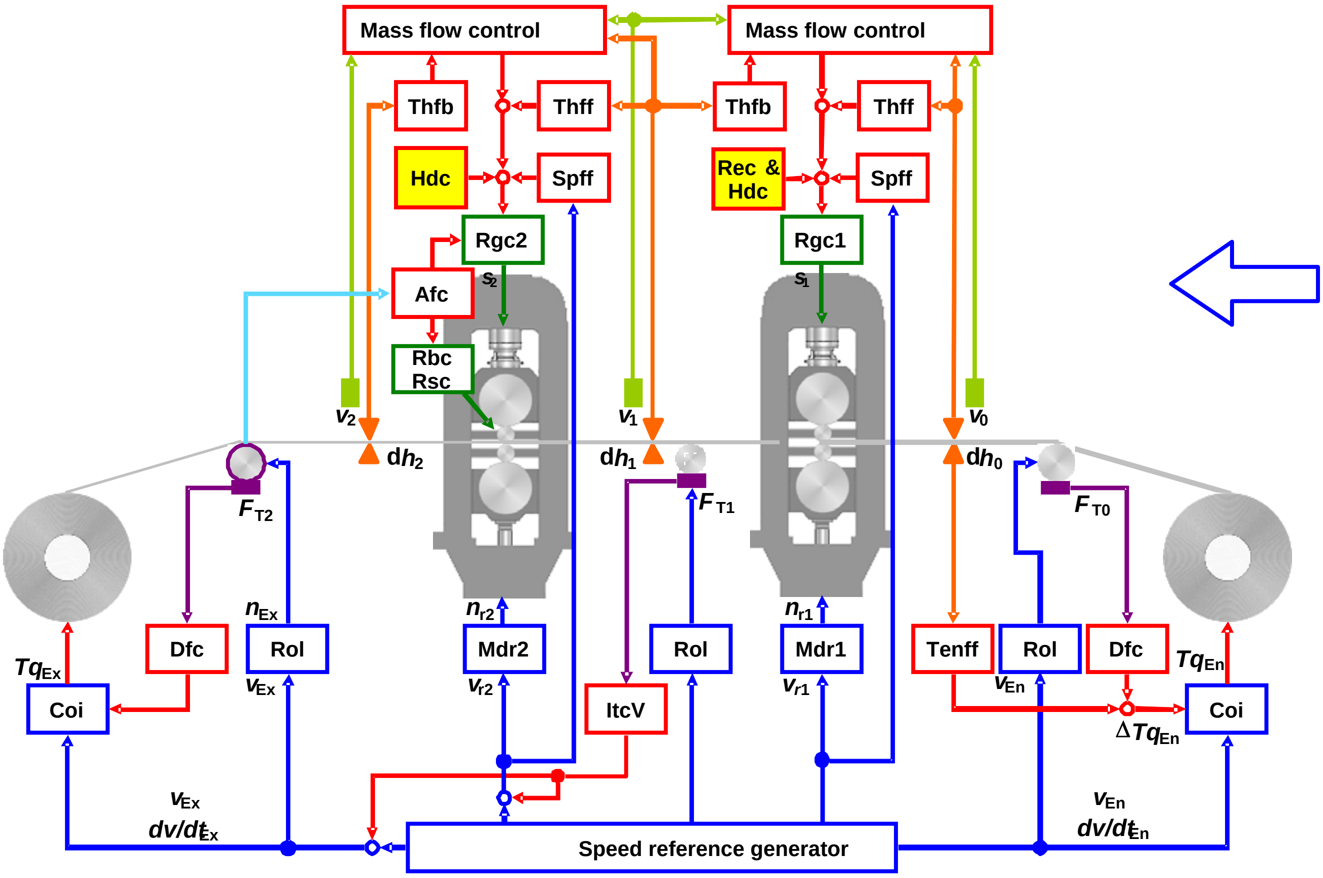

Fig. 1 Control concept with extension to include the functions for Rec and Hdc (yellow)

dh	Strip thickness deviation	En	Entry	Dfc	Tension control	Rsc	Roll shift control
F_T	Strip tension	Ex	Exit	ItcV	Tension control via speed	Spff	Speed feed-forward control
s	Roll gap position	Afc	Automatic flatness control	Rgc	Roll gap control	Tenff	Tension feed-forward control
Tq	Torque	Coi	Coiler control	Rbc	Roll bending control	Rec	Roll eccentricity compensation
n	Rotation speed	Mdr	Mill drive control	Thfb	Thickness feedback control	Hdc	Hardness compensation
v	Velocity	Rol	Roll control	Thff	Thickness feed-forward control		
dv/dt	Acceleration						

Fig. 2 Drive side, showing AC main drive motors

Fig. 3 Exit side with drive for flatness measurement roll, laser and X-ray strip thickness gauge

The plant to be simulated is configured on the basis of modules, such as drive and drive train, mill stand, decoiler and coiler, strip material, sensors, disturbances and control loops, and is parameterized with the actual plant parameters.

The control systems consist of drive control, position control (roll gap control), tension control and thickness control, including feed-forward control loops.

In the modelling of strip thickness measurement the speed-dependent transport delays are taken into consideration.

For the decoiling and coiling processes, the variation in radius and inertia over the strip length, the indirect tension control, the coiler drive trains (modelled as multi-mass and spring systems) and the drive controllers are all included in the simulation.

The mill stand model includes the drive train with the rolls (as a multi-mass and spring system), drive controllers and the non-linear deformation in the roll-bite.

The simulation of the strip takes into account the varying stiffness depending on the material, strip thickness and width, the strip speed-dependent transport delay and the tracking of the coils and weld seam.

The disturbances that are simulated include entry thickness disturbances, disturbances due to hardness variations and backup roll eccentricities, coil bump from the decoiler and coiler as well as friction effects in the mill stand. The thickness disturbances are entered into the simulation based on real data measured in the mill.

For the intended investigations, in addition to the existing control, new control loops for eccentricity compensation (Rec) and hardness compensation (Hdc) were implemented, see Figure 1.

The effective control of mass flow in Stand 1 is decisive for the strip thickness tolerance at the mill exit. For this reason backup roll eccentricity is especially critical in Stand 1. Analyses have shown that for hardness variations, compensation in both stands may be necessary.

The harmonic disturbances from backup roll eccentricities and hardness variations are detected and separated while rolling using a real-time analysis of the (from mass flow) calculated strip exit thickness in each stand. In a second step the Rec and Hdc controllers actively suppress these disturbances by feeding correction signals to the position reference of the mill stands.

During this process, the compensation follows the changing frequencies as functions of both backup roll and decoiler speed. The hardness compensation presents a special challenge since the decoiler is constantly changing its rotational speed and therefore frequency even at constant rolling speed, due to the decreasing coil diameter.

Control loops for compensation were provided for the first three harmonics of backup roll eccentricity and hardness variation, with the first harmonic typically being dominant.

Plant characteristics

Material	Aluminum, Al-alloy
Strip width range	1600 - 2150 mm
Max. coil weight	29 000 kg
Max. coil diameter	2700 mm
Entry thickness range	0.7 – 3.5 mm
Exit thickness range	0.2 – 1.5 mm
Max. stand speeds	900 / 1500 m/min
Strip tension entry side	7 - 75 kN
Strip tension exit side	6 - 65 kN

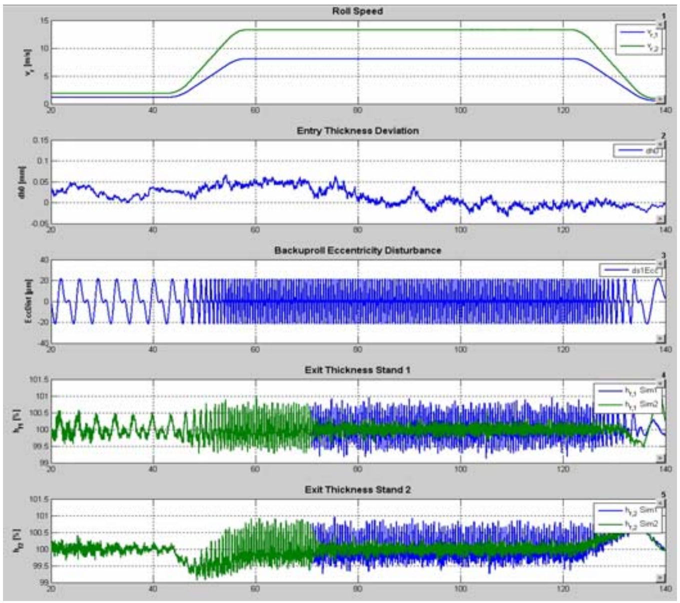

Fig. 4 Simulation run with activation of eccentricity compensation at T = 70 s

- Roll speed [m/s] of Stand 1(blue) and Stand 2 (green)
- Entry thickness disturbance based on actual measurement data
- Simulated backup roll eccentricity disturbance
- Exit thickness after the 1st stand (green: with compensation after 70 s)
- Exit thickness after the 2nd stand (green: with compensation after 70 s)

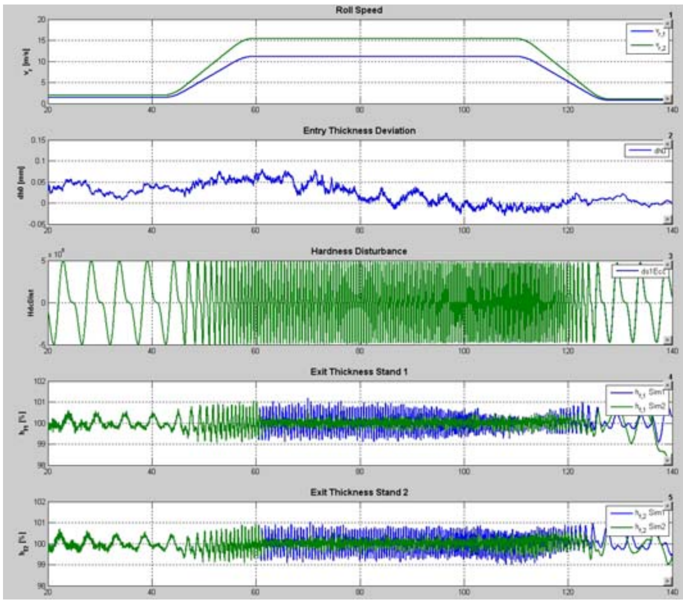

Fig. 5 Simulation run with activation of hardness compensation at T = 60 s

- Roll speed [m/s] of Stand 1(blue) and Stand 2 (green)
- Entry thickness disturbance based on actual measurement data
- Simulated harmonic hardness variation
- Exit thickness after the 1st stand (green: with compensation after 60 s)
- Exit thickness after the 2nd stand (green: with compensation after 60 s)

Results of the simulation study

Figures 4 and 5 show the results of some of the tests that were successfully performed within the framework of the simulation study for compensation of backup roll eccentricities (Fig. 4) and harmonic hardness variations (Fig. 5).

In order to demonstrate the improvements, the compensation was activated after a defined time.

Implementation on the two-stand cold rolling mill

After the successful simulation study, the control concepts were implemented on the two-stand cold rolling mill. For this purpose the new controllers for compensating eccentricity and hardness variations were programmed in the ABB Automation System 800xA (Controller AC 800PEC) and connected to the existing ABB Automation Platform MP200 (Master Piece 200) from 1994, see Figure 6.

The necessary process signals to be measured, such as strip speeds, entry/exit thicknesses and rotational speeds of the mill drives and the decoiler, were connected in parallel to the AC 800PEC controller to allow fast signal analysis with update times down to 2 ms.

The position corrections for compensation are sent to the existing MP200 controller and added to the position references.

Data collection is performed by an existing IBA PDA system, which was connected via an optical link to the AC 800PEC Controller.

Uninterrupted mill operation

In observation mode the functions for eccentricity and hardness compensation could be monitored and pre-optimized in parallel to normal operation with no effect on the current operation of the mill.

Additional monitoring functions were provided to safeguard against signal errors, e.g. to switch to a backup mode or deactivate the compensation should important signals fail or the evaluation or suppression of harmonic disturbances give implausible results.

If normal operation is detected again, the compensation loops are automatically and bumplessly reactivated.

Response to failure of strip speed measurement

A special case that was considered is the typical failure of the interstand laser strip speed measurement due to oil or oil mist. Since this signal is used for the calculation of the exit thickness based on the mass flow for each stand, a failure would lead to deactivation of the compensation loops and this is certainly not desired. Therefore an alternative interstand strip speed is continuously calculated based on an online estimation of forward slip.

The compensation loops are automatically and bumplessly switched to this estimated variable if the interstand laser speed measurement fails.

This method was first verified within the framework of the simulation study and then implemented and successfully tested on the mill.

The individual control loops for the compensation of harmonic disturbances were put into operation and optimized step by step, and here again it could be shown, as in the simulation study, that thickness disturbances due to eccentricity and hardness variations could be successfully suppressed and that the thickness deviation could be significantly reduced as a result.

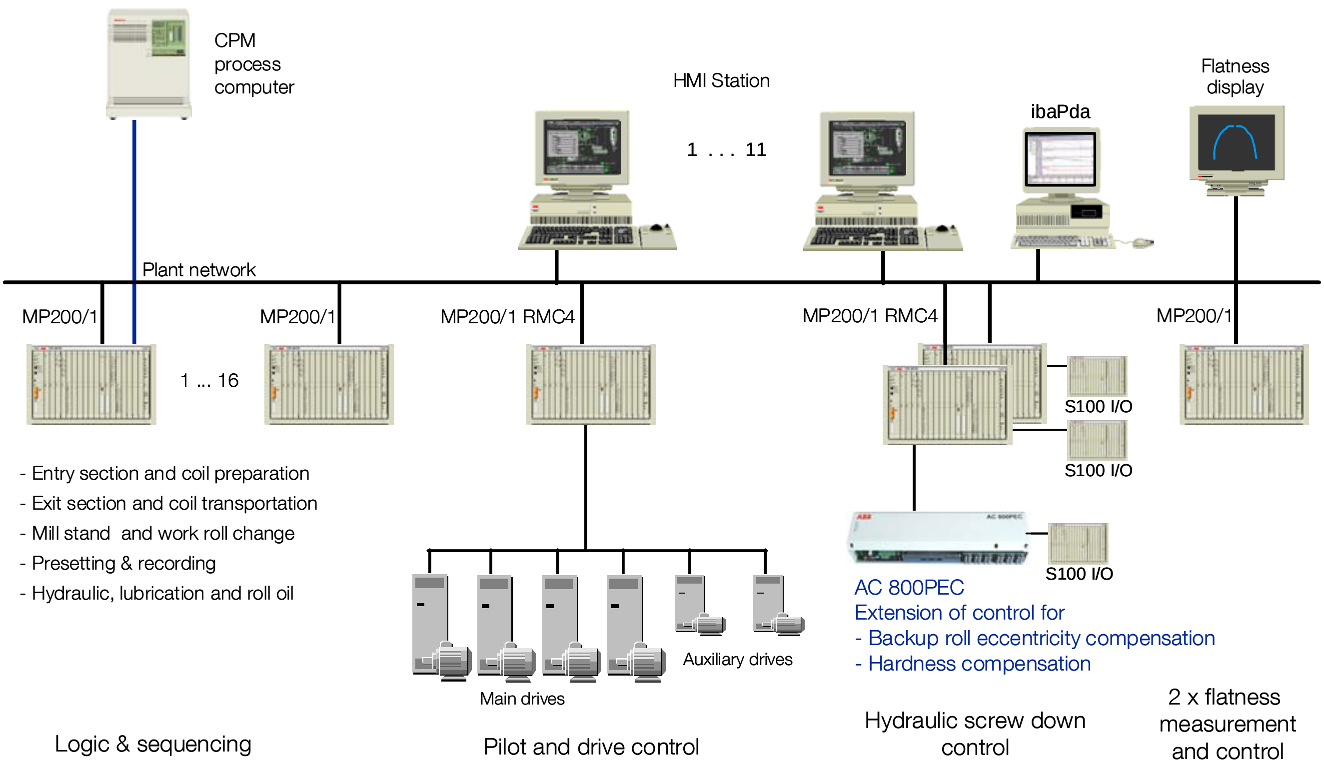

Fig. 6 Automation structure with additional AC 800PEC controller for eccentricity and hardness compensation

Backup roll eccentricity compensation

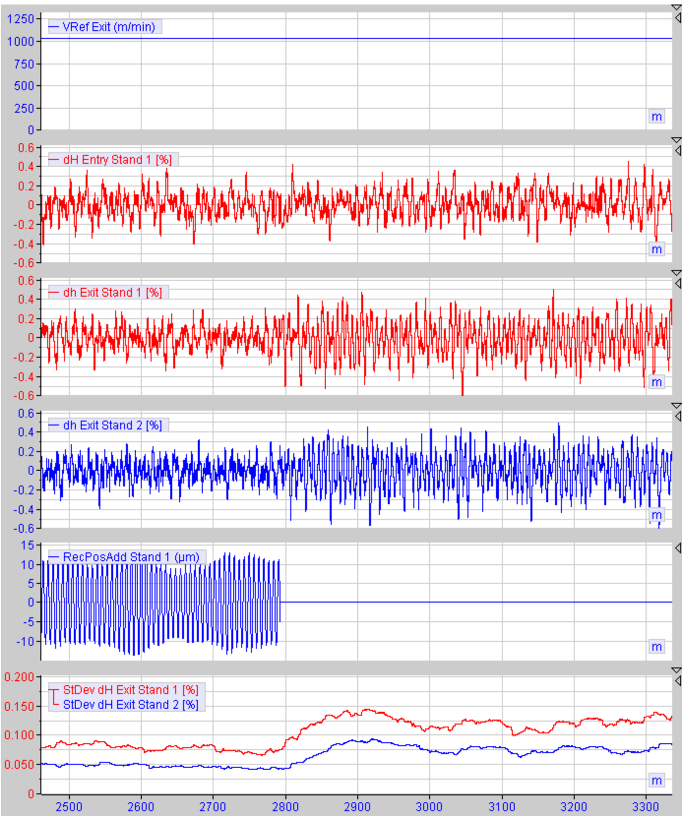

Fig. 7 Evaluation of the thickness quality with and without compensation of the backup roll eccentricities.
Exit thickness after the 2nd stand = 950 µm.
The standard deviation in exit thickness after Stand 2 is improved by approx. 38%.

- Exit speed [m/min]
- Entry thickness deviation before Stand 1 [%]
- Exit thickness deviation after Stand 1 [%]
- Exit thickness deviation after Stand 2 [%]
- Compensation signal Stand 1 for Rec [µm]
- Standard deviation exit thickness after Stand 1 and 2 [%]

Harmonic hardness compensation

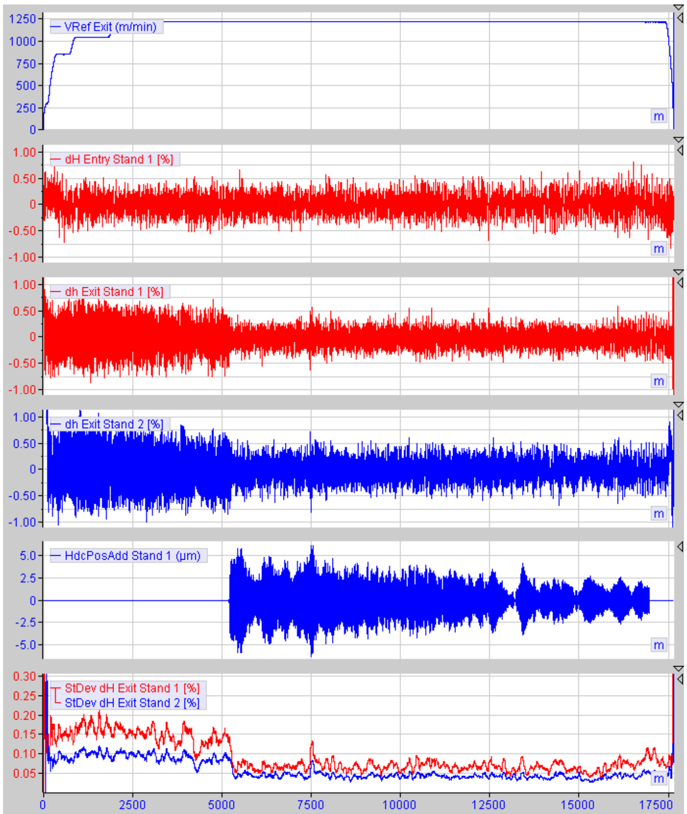

Fig. 8 Evaluation of the thickness quality with and without compensation of harmonic hardness variations.
Exit thickness after the 2nd stand = 249 µm.
The standard deviation of the exit thickness is improved by approx. 54%.

- Exit speed [m/min]
- Entry thickness deviation before Stand 1 [%]
- Exit thickness deviation after Stand 1 [%]
- Exit thickness deviation after Stand 2 [%]
- Compensation signal Stand 1 for Hdc [µm]
- Standard deviation exit thickness after Stand 1 and 2 [%]

Results of disturbance compensation

The measurement plots demonstrate the improvements achieved in thickness quality with both backup eccentricity and hardness deviation compensation (Fig. 7 to Fig. 11).

The additional compensation loops were switched on or off while rolling actual coils to demonstrate the improvements due to the respective control loops.

Furthermore, statistical evaluations over a longer period before and after the changeover verify the significant improvements achieved in thickness quality (Figures 9 and Fig. 11).

It must be taken into account that plant- or product-related quality problems can always occur, that have other causes than backup roll eccentricity or harmonic hardness variation. It is also true that harmonic disturbances from backup roll eccentricity or hardness variations are not dominant or present in all coils, and when these particular problems are not present, no reduction in thickness deviation from the additional controllers can be obtained.

Fig. 10 shows an example of a coil with both backup eccentricity and hardness deviation errors:

- When activating the compensation for hardness variations (HdcPosAdd Stand 1), the lower-frequency components were suppressed in the exit thickness signal.
- When activating the eccentricity compensation (RecPosAdd Stand 1) the higher-frequency components were suppressed.
- Afterwards both compensation loops were switched off again.

Figure 9 shows improvements in 3-Sigma thickness quality after activation of the new control loops for compensation of eccentricities and harmonic hardness variations. The coils from 614 on were rolled with the additional new controllers active.

The 3-Sigma quality improvement can be clearly seen and rises by approx. 20%.

In Fig. 11 the thickness quality of coils after the finishing pass was evaluated over a longer period.

Here again the improvements achieved in the exit thickness quality are clearly noticeable. The number of coils in the < 0.8 UCL (Upper Control Limit) tolerance band was increased from 72% by approx. 20% to 92%.

Backup roll eccentricity and hardness compensation

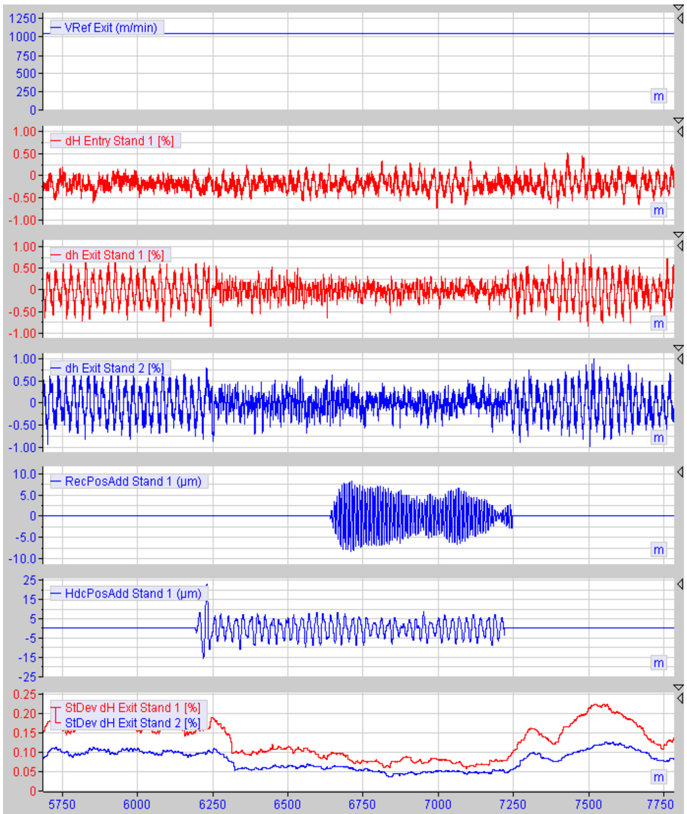

Fig. 10 Evaluation of thickness quality with and without compensation of backup roll eccentricities and harmonic hardness disturbances.

- Exit speed [m/min]
- Entry thickness deviation before Stand 1 [%]
- Exit thickness deviation after Stand 1 [%]
- Exit thickness deviation after Stand 2 [%]
- Compensation signal Stand 1 for Rec [µm]
- Compensation signal Stand 1 for Hdc [µm]
- Standard deviation exit thickness after Stand 1 and 2 [%]

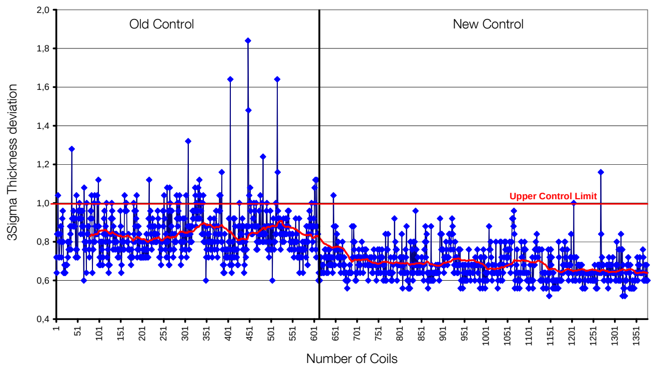

Fig. 9 3-Sigma thickness quality improvement after activation of the new control based on evaluation of coils after the finishing pass (normalized to UCL = Upper Control Limit).

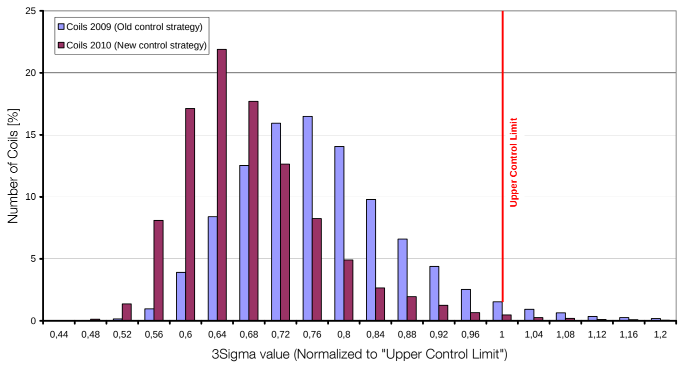

Fig. 11 Statistical 3-Sigma evaluation of coils after the finishing pass over a longer time period (normalized to UCL = Upper Control Limit).

Summary

Two new control concepts for the active suppression of typical harmonic disturbances in single and multi-stand rolling mills were successfully implemented and tested.

The concepts for backup roll eccentricity compensation and for the suppression of harmonic hardness variations were first analyzed and verified within the framework of a simulation study and then implemented and tested under real plant conditions.

The additional technological controllers have been in successful operation for more than a year and statistical evaluations have demonstrated a considerable improvement in the exit thickness deviation achieved.

Authors

Lawrie Witham
Aluminium Norf GmbH
41403 Neuss
E-Mail: lawrie.witham@alunorf.de

Axel Brickwedde
ABB Automation GmbH
68309 Mannheim
E-Mail: axel.brickwedde@de.abb.com

For more information please contact:

ABB Automation GmbH
Industrials Plants – Metals
Kallstadter Straße 1
68309 Mannheim, Germany
Phone: +49 621 381 2596
Fax: +49 621 381 8055

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