Application of Advanced Technology Packages For Improved Strip Profile and Flatness in Hot-Strip-Mills

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With the use of advanced process models the required settings of roll-gap actuators such as work-roll bending and shifting can be accurately calculated to ensure an optimum roll gap shape, taking into account the material cross flow in the mill and the influence of thermal stresses on the thermal crown of the work roll. This paper describes the latest technological packages and process models developed by VAI for improved strip profile and flatness in hot-strip mills.

INTRODUCTION

Significantly improved strip profile and flatness results in hot-strip mills can be achieved with the installation of new technology packages from VAI. These include the SmartCrown roll contour, an L-type bending and shifting block for reducing roll wear, an online roll-stack deflection model, a special mill stand design with reduced mill-housing nip, an optimised work-roll shifting strategy, dynamic work-roll cooling and a highly efficient profile and flatness-control model.
The key targets of these packages are to achieve a wide control range, easy-to-implement control characteristics, a flexible pass-schedule design, the suppression of all types of strip buckles and one single roll grind per mill stand.
Several of these technology packages, especially the control models, are currently being installed on the hot-strip mill of voestalpine Stahl, Linz, Austria. The clear target here is to improve the profile and flatness performance of the rolled strip by replacing the existing control system installed in 1995. The core of the new system is a highly accurate, online, 3D finite-element roll-stack deflection model, which is capable of executing calculations in 50 ms. In addition to higher profile and flatness accuracy, the new control system promotes greater flexibility in using the profile and flatness actuators of the mill, improves the interstand flatness results and reduces the degree of strip-shape changes per stand to assure safe rolling conditions.

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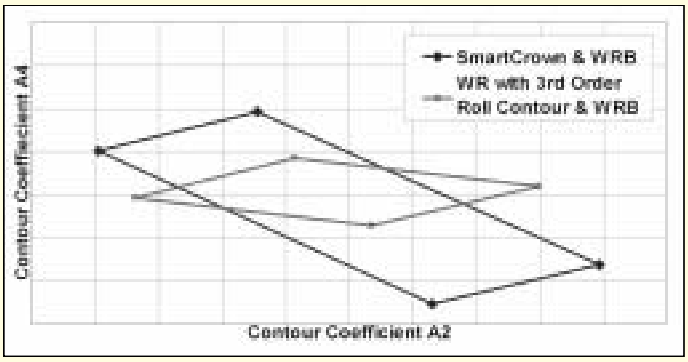
Figure 1: Comparison Between SmartCrown and Work Rolls with a 3rd Order Roll Contour Grind



AVAILABLE PACKAGES

VAI's Technology Package for improved profile and flatness in hot strip mills comprises the following components and features:

- SmartCrown Work-Roll Contour
- L-Type Bending and Shifting Block
- Mill Stand with Reduced Nip
- Optimised Shifting Strategy
- Dynamic Work-Roll Cooling
- Advanced Profile and Flatness Control System, including a 3-D Online Roll-Stack Deflection Model

SMARTCROWN WORK-ROLL CONTOUR

SmartCrown is a new type of roll contour[2] (patent pending)[3] introduced by VAI. The SmartCrown system employs lateral shifting of the work rolls to adjust the unloaded and thus also the loaded roll gap so as to adjust the strip profile or match the relative crown of the ingoing strip. The SmartCrown contour can be described as the sum of a sinusoidal and a linear function. Coefficients of this function are chosen so that at an arbitrary roll-shifting position the resulting unloaded roll gap profile is always cosine in shape. Therefore, continuous shifting allows for continuous adjustment of the roll gap profile.
The main benefits of the SmartCrown work-roll contour are:

- Achievement of a significantly enhanced profile and flatness control range – compared to just work-roll bending – by employing work-roll shifting in conjunction with specially profiled work rolls. SmartCrown is usually installed in combination with work-roll bending for profile and flatness control purposes.
- Replacement of all conventional roll crowns with one single roll contour. Due to SmartCrown's large adjustment capability, a single roll grind per stand can replace the different roll grinds in conventional mill rolls for satisfying the profile and shape requirements of various rolling programmes.
- Greater flexibility in the rolling programme and pass schedule design. SmartCrown allows a more flexible creation of the pass schedules and rolling programmes and thus helps to maximize mill capacity.
- Simple mechanical design. SmartCrown is a simple and yet powerful profile and shape control system. Axial roll shifting is performed by means of standard hydraulic cylinders. Figure 1 illustrates the performance range of control for SmartCrown compared to that of work rolls with a 3rd order grinding contour – both for the same roll crown range.

Enhanced Shape Control

The contour of the roll gap can be expressed by a cosine function. The unloaded roll gap contour corresponds to a portion of a cosine curve around its vertex. The position of the roll barrel edge corresponds to a certain angle on this curve, which is called the 'contour angle'. By fine-tuning this contour angle, the transverse profile of the resultant roll gap (Figure 2) can be adjusted such that quarter buckles in the strip are avoided. This is because the local thickness reduction in the quarter-buckles sensitive area is decreased, since the unloaded roll gap is greater in this region. This smaller local reduction results in a reduced tendency for longitudinal compressive stresses to arise in the strip, which are responsible for buckling.

Figure 2: Deviation from a Parabolic Roll Gap as a Function of the Contour Angle

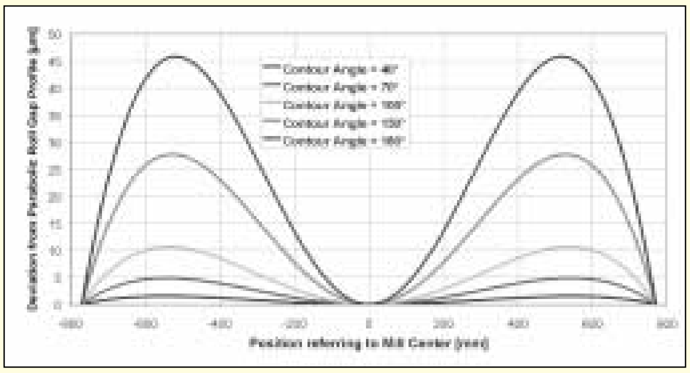


Table 1: Work-Roll Bending and Shifting Systems

Design	Bending Type	Shifting Type
Conventional	Positive	Short stroke
C-block	Pos./Neg.	None
T-block	Positive	Long stroke
L-block	Positive	Short stroke

L-TYPE BENDING & SHIFTING BLOCK

Modern profile and flatness actuator systems require a combination of work-roll bending and work-roll shifting. To use the capability of axial shifting of work rolls VAI offers a series of design options depending on the requirements of the existing mill stand design (Table 1).
A newly developed system by VAI enables positive bending in conjunction with the SmartCrown work-roll contour and is characterised by its simple design, low investment costs and maintenance requirements. The solution is 'L-pieces', which are guided along the longer side of the 'L', which is where the moment resulting from roll shift is introduced (Figures 3a, b & c). This moment results from the non-symmetric load of the chocks on the L-pieces. This simple design is characterised by the locally fixed bending block. The bending cylinders act between the two work-roll chocks and there is no need to shift the bending block. The clearances can therefore be reduced in comparison with other designs. Easy handling during work-roll change also brings another advantage of the L block (patent pending)4 during operation.

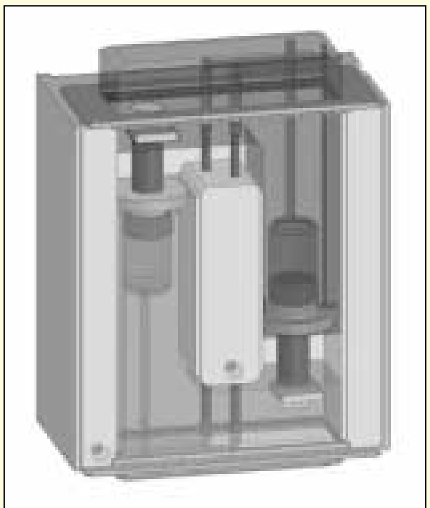


Figure 3a: Mechanical Principle of L-block

REDUCED NIP OF MILL STAND

Due to the nip of the mill stand housing during rolling, clearances between the housing and the chocks have to be considered. The required clearances can cause roll crossing, which will influence the roll gap contour. To reduce the possibility of roll crossing the clearances and thus the nip of the mill stand housing have to be reduced. The stretch of the mill stand is a significant portion that contributes to the formation of the unloaded and loaded roll gap contour. Therefore, optimisation efforts to reduce mill stretch and necking of the housing have been carried out. A reduction of about 60% of the stand necking in comparison to conventional mill stand designs has been achieved (patent pending)[5].

OPTIMISED WORK-ROLL SHIFTING

The application of an optimised work-roll shifting strategy (patent pending)[6], targets the required profile and flatness performance while minimising roll wear

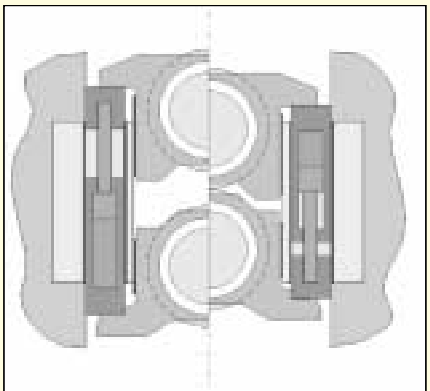


Figure 3b: Cross Section of L-Block and Work Rolls

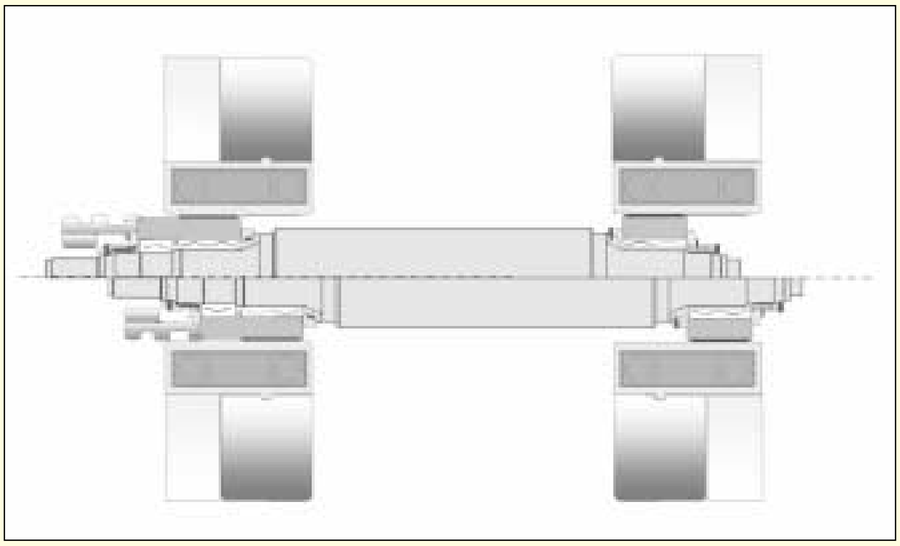
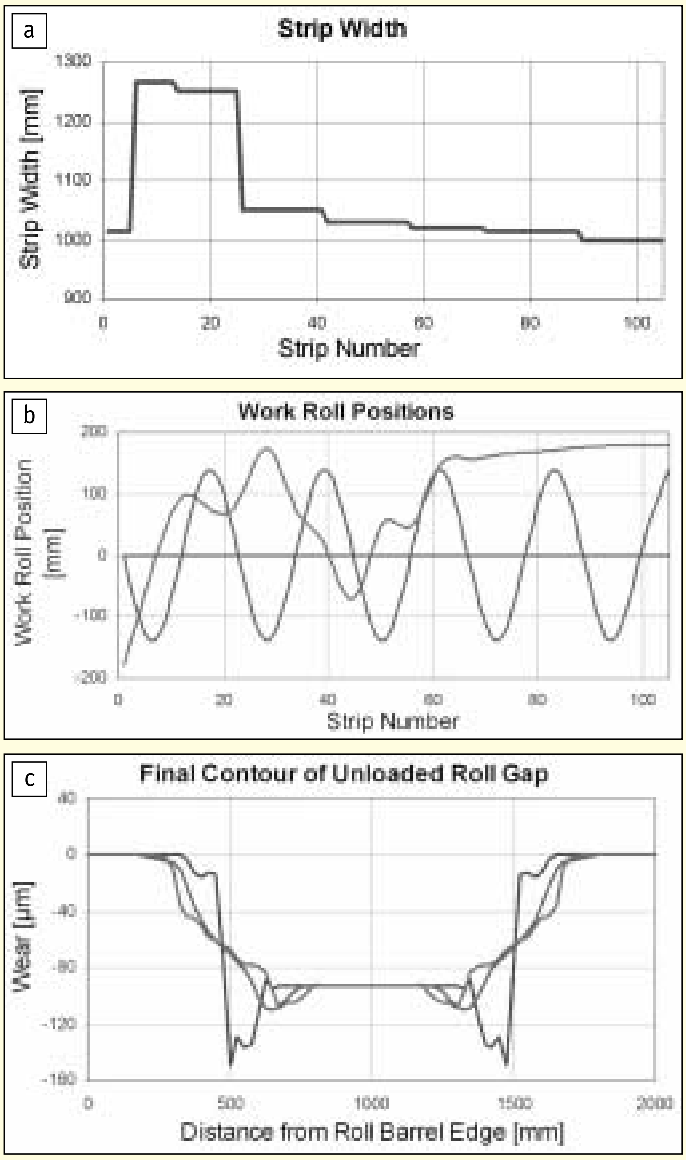


Figure 3c: Longitudinal Section of L-Block with Work Rolls



Figures 4a, b & c: Results of Optimised Shifting Strategy for a Coffin-Shape Rolling Schedule

and therefore increasing rolling campaigns. The following goals were considered during the development of the strategy:

- Improved strip contour by reduction of high spots
- Extension of rolling schedules
- Increase in mill productivity
- Decrease in roll wear
- Schedule-free rolling.

These targets can be achieved with a precalculation of the work-roll shift positions by means of mathematical optimisation for the whole rolling schedule. The model takes into account wear and the thermal crown so as to reduce contour anomalies for all strip. Comparisons of the optimised shifting strategy for a rolling schedule with equal width with schedules for totally free width distribution and one for a coffin shape campaign were prepared. Comparing rolling campaigns each of 120 strips of various widths, rolled in different sequences, the maximum wear difference over the barrel length could be reduced from 60 µm for rolling without shifting to about 40 µm for cyclic shifting and 20 µm for optimised shifting for a rolling schedule with strips all of the same width. For a coffin-shape schedule, it is possible to reduce the roll wear after 120 strips from 50 µm without shifting to 30 µm with cyclic shifting and to 10 µm with optimised shifting.

To find the optimum shifting positions, objective functions are used. An evaluation of the quality of work-roll contours caused by wear and thermal crown is carried out in the strip contact zone by quality functions for each pass of the rolling schedule. Restrictions used are the maximum work-roll shifting position and the maximum shifting distance between two consecutive passes (Figures 4a, b & c).

DYNAMIC WORK-ROLL COOLING

In addition to other targets, VAI's solution for work-roll cooling in hot-strip mills focuses on the improvement of strip quality through enhanced shape control. The adjustment of specific flow rates along the barrel length by a proper combination of cooling headers allows the control of the thermal expansion of the work roll and the control of the profile of the loaded roll gap. VAI usually uses three headers per roll and per side; one for basic cooling in conjunction with two additional headers for the control of the thermal expansion of the work roll. By using dynamic flow rates in each header, it is possible to extend the adjustment range of the work-roll shifting and bending system. If the thermal crown exceeds a certain limit, work-roll bending may not be able to compensate the expansion sufficiently and profile or flatness defects may occur. Dynamic work-roll cooling ensures that the bending forces can stay within a certain range and that the target strip profile can always be reached.

PROFILE AND FLATNESS CONTROL

Voestalpine Stahl made a complete revamp of their hot-strip mill automation system in 1995, including a complete set-up and control system for the finishing mill. To satisfy the increased requirements on the hot band, voestalpine Stahl concluded a cooperation agreement with VAI in 2000 to improve the profile and flatness set-up and control. At this time, VAI had already developed an ultra-fast 3D online, finite-element program to calculate the deformation of the roll stack.

Pre-Study

To compare the actual performance of the existing process automation system with the new automation system, VAI's Advanced Profile and Flatness Control System was installed on a computer running in the background. For achieving flat strip at the exit of the final finishing stand, the roll gap shape and the strip profile must match. Therefore, the predicted roll gap shape was compared with the measured strip profile. Figure 5 shows a histogram of the difference of those two quantities for a number of strips.

A two-months trial not only showed very clearly the higher accuracy of the new system, but also clearly demonstrated the deficiencies of the roll-wear model and of the thermal crown model in operation at the hot strip mill.

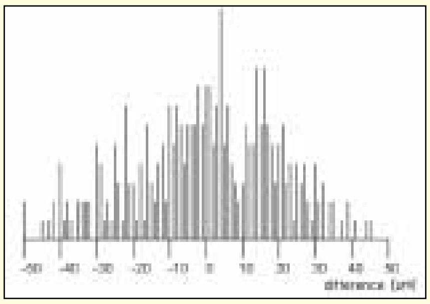


Figure 5: Difference Between Calculated Roll Gap and Measured Strip Profile

Concept

The core modules of VAI's Advanced Profile and Flatness Control System are:
- 3-D online roll-stack deflection model
- Thermal crown model
- Roll-wear model
- Profile and flatness set-up strategy.

3-D Online Roll-Stack Deflection Model

In most current online roll stack deflection models the rolls of the roll stack are modelled as beams and deflection calculated by means of differential methods based on simple solutions of elasticity theory (beam under transverse load, bar bent by couples, deformation of a half space by locally applied forces, etc.).
This approach has only limited accuracy. For this reason, VAI decided to use full mathematical modelling without simplifications for the online calculation. The main features of this approach are as follows:
- Fully 3-D elasticity theoretical modelling of the roll, taking into account the actual geometry of the roll barrel and roll necks
- Roll bending and flattening modelled without simplifications
- Precise evaluation of dimensions and material properties of roll core and shell
- Interactive calculation of the real, 2-D pressure distribution and the corresponding contact area on the basis of the actual contour of the rolls (crown, taper, thermal crown, wear)
- Efficient numerical methods based on Fourier Transformation and 3-D finite element methods in cylindrical geometry.

The model supports various actuators such as roll bending (positive and negative), swivelling, segmented roll cooling in combination with VAI's thermal roll crown model and roll shifting, e.g., with the SmartCrown work-roll contour.
To verify the accuracy of the model the results have been compared with a conventional offline 3-D finite element model. A comparison is shown in Figure 6, which shows an excellent matching of the two methods. Also, it is important to mention that for an online model a short calculation time is essential to determine the right parameters for each material. The typical calculation times using a 2GHz PC or similar computer is 50 ms. All the necessary calculations are automatically performed during roll change and during rolling.
To match the high accuracy of the roll-stack deflection model, the thermal expansion model for the work roll has been improved. Conventionally, to calculate the thermal work-roll crown the first step is to calculate the temperature field within the work roll and then the resulting expansion due to this temperature field.

Figure 6: Comparison of New Roll-Stack Deflection Model with Offline 3D Finite Element Model

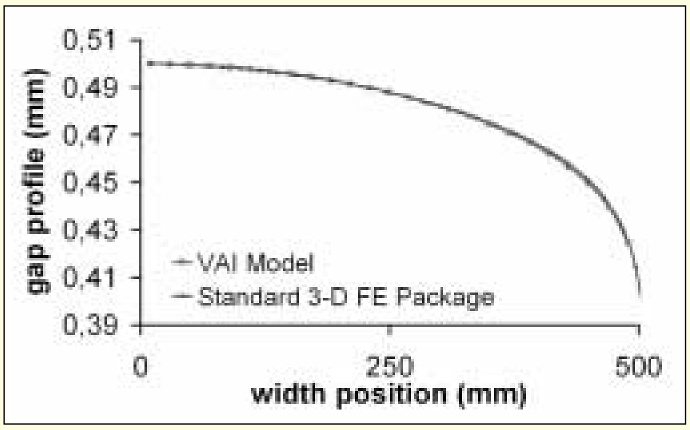
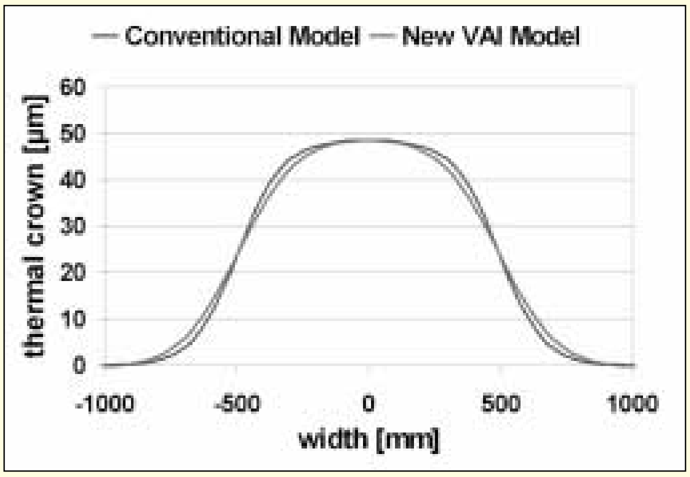


Figure 7: Comparison of Conventional and Enhanced Thermal Crown Calculations



In the VAI improved model the tensions inside the roll caused by temperature gradients and the effect of these on expansion are calculated with the use of the Lamé equation generalised for inhomogeneous temperature distributions in combination with a semi-analytical solution in cylindrical geometry (Figure 7).
Furthermore, it is very important to compare the results of the thermal expansion model with reality. For this reason a special measuring device, the roll-gap scanner, was used to measure the contour of the work roll in several stands.
Figure 8 shows the roll contour measured after 30 strips (a), at the end of a rolling campaign (b), and after an additional 5 minutes of water cooling (c).
The profiles also include the calculated contours, which show a good match with the measured values.
It should be noted that the measured values include the basic shape of the work roll from grinding, the roll wear and the thermal crown.
As part of the cooperation on improved profile and flatness control, voestalpine has developed a roll-wear model for the centre part of the rolls, which is based on extensive measurements.
A wear model especially for the edge parts is currently being developed.
First results of this model are also shown in Figure 8.

PROFILE & FLATNESS STRATEGY

The aim of the profile and flatness strategy is to establish a certain roll gap shape for each stand. For this reason the settings of the roll-gap actuators such as work-roll bending and shifting with or without SmartCrown are calculated. The target roll gap shape is calculated taking into account the material cross flow, which will be highest in the first stand of the finishing mill and which reduces to close to zero in the final stand. For the solution a mathematical algorithm is used to find the optimum target function.
With this new approach it should therefore also be possible to improve head-end thickness performance even for the first strip of a rolling sequence. Furthermore, the true mill stretch curve can be obtained for the rolling conditions of each individual strip so as to optimise the whole thickness control. This approach is especially important for a rapid start-up of a mill, improved performance of technological controls, changing mill conditions and changing products.
Currently, VAI is planning the next installation, which will be the application of the SmartCrown roll contour at the SHAGANG hot-strip mill in China.
To demonstrate the reliable design of the L-block and to check for possible improvements, the worst loading situations were simulated in an offline long-term test.

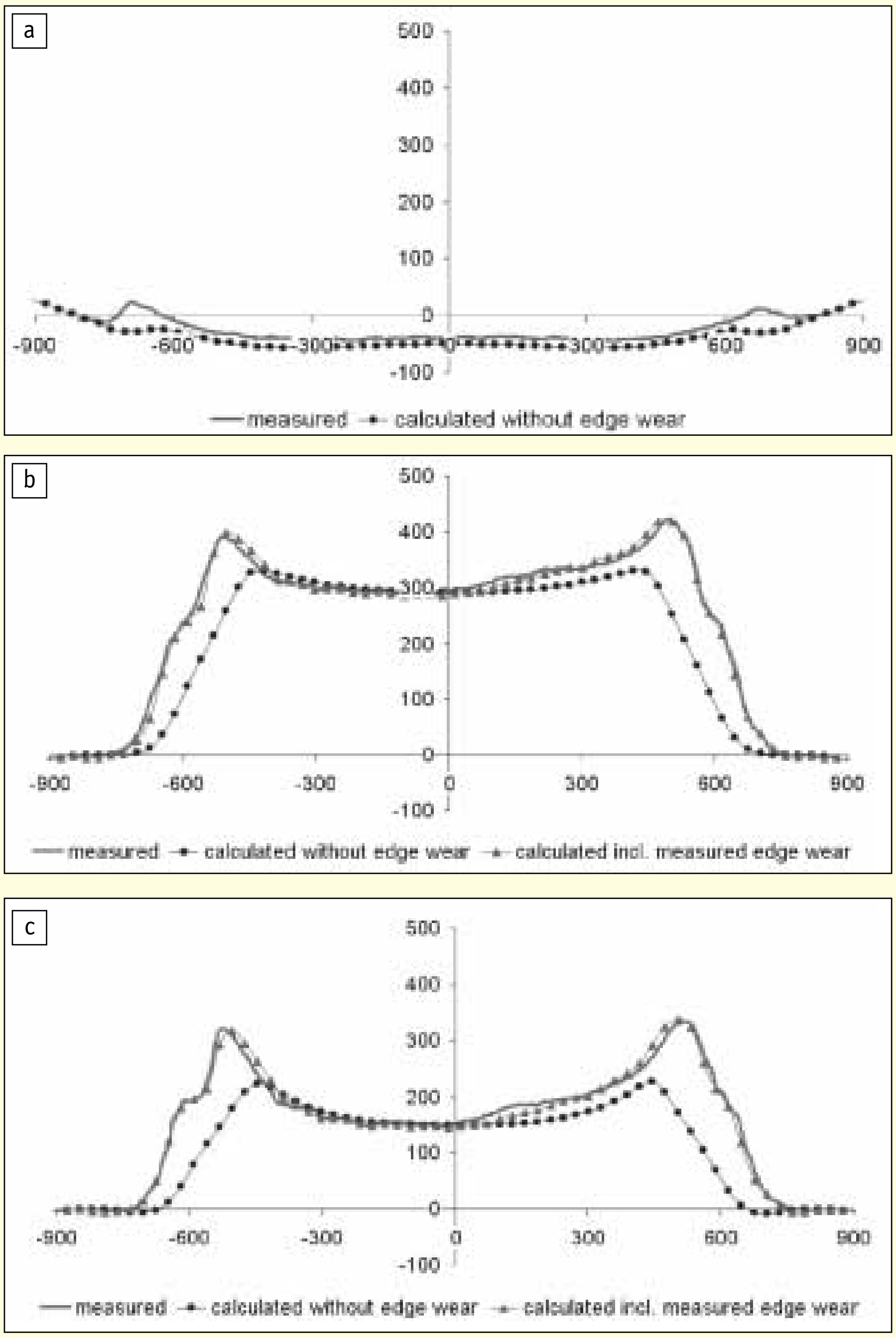


Figure 8a, b & c: Measured Roll Contours at voestalpine

Bending forces up to 640 kN were applied. During the test 52,000 tail end slaps were simulated. The block was then dismantled and checked. The L-block was in a very good condition, wear was almost negligible and the design proved to be ready for application in the hot-strip mill.
The mill stand with reduced is in use in the cold-rolling tandem mill of Bethlehem Steel, USA and will be used with the same type of improvements in the hot-strip mill.
The online roll stack deflection model is already in use in the hot-strip mill of ISPAT Annaba in Algeria, in the plate mill at voestalpine Grobblech in Linz, Austria, and at the EUROSTRIP® direct-strip production line at KTN in Krefeld, Germany.

The dynamic work-roll cooling system is in operation in the hot-strip mill of ISPAT Annaba, Algeria and will be shortly installed at the JISCO Steckel Mill in China.

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