Plate mill automation

The restart of TKS Plate Mill, Duisburg

Jochen Bobbert[1], Thomas Kraxberger[2], Karl Schörkhuber[2] and Dietmar Auzinger[2]

The recent upgrading by VAI of automation equipment at the 3·9 m plate mill of ThyssenKrupp Stahl (TKS) in Duisburg-Süd, Germany involved the installation of new equipment during regular maintenance shut-downs and caused no additional loss of production. To maintain full production capabilities, a switch-over unit was used to provide a seamless transition to the new automation system.

In 1978, a new rolling mill stand with a new main drive entered operation at the Heavy Plate Mill of Thyssen Stahl AG in Duisburg Hüttenheim. With a rolling mill stand weight of 360 t and a backup roll diameter of 2100 mm at a width of only 3·7 m, the stand was extremely stiff and was also one of the first heavy plate stands in Europe to be equipped with hydraulic thickness control and a process computer, enabling tighter tolerances. However, the increasing implementation of laser welding in plate processing and the increased load capacities in mobile crane construction have led to ever higher requirements for flatness and thickness tolerances of plates. Installation of hydraulic work roll bending, intensive cooling systems and continuous adjustment and optimisation of the computer models allowed continuous improvement to be achieved. However, the limits of the original computer system eventually became a barrier to further progress.

The last stage of an extensive modernisation program, begun in 1999, which included new control systems for the reheating furnaces, modernisation of the stand hydraulics, etc., was the modernisation of the rolling process computer. This included the 'basic automation' (level 1) – i.e. the co-ordination of the roller tables and side guides, the electromechanical and hydraulic adjustment system, the main drive, the work roll bending, the intermediate cooling, the intensive cooling system for the final cooling – as well as the complete level 2 system for material tracking, PDI and process data handling, interfaces to level 3 – gauges, furnace model – and process models for the rolling process.

To make the transition to the new computer system as smooth as possible, a complex switch-over system was installed which allowed transfer from the old to the new computer and vice versa in less than two minutes. This involved the parallel installation of two independent control desks in the temporarily cramped control pulpit.

System outline

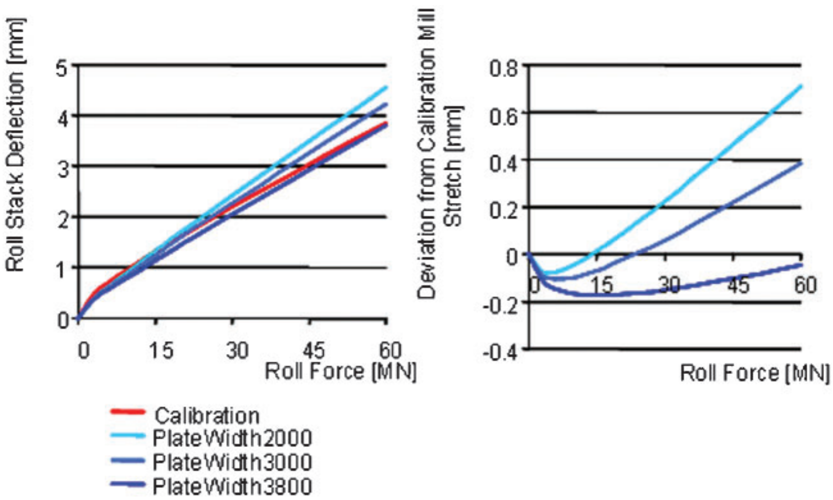
VOEST-ALPINE Industrieanlagenbau (VAI) – a division of the Siemens Group Industrial Solutions and Services – began planning the modernisation in August 2002. A major challenge was that past modernisations meant several automation systems had to be integrated to act as one production unit.

The 'heart' of the new automation is the technological control system designed for fast control loops. All equipment is designed for the mill environment.

The EGC SW package is used for electromechanical gap control. The electromechanical screws can be controlled individually in position control or in synchronous movement with closed clutch. To enhance the actual position reading of the screw-down drives, new position transducers have been installed, connected to the automation system via Profibus DP.

The automatic gauge control (AGC) uses Super AGC, which implements feed-forward compensation of pre-calculated thickness errors identified during the preceding pass.

The mill stretch calibration can be selected by the operator via the new HMI system and runs in semi-automatic mode, whereby movements are initiated by the operator and all measured force and position values are transferred to the process optimisation system, where the mill modulus is calculated. Due to the fact that different load conditions prevail since the pressure distribution during rolling is restricted to the width of the rolling stock, the stretch curve has to be adapted accordingly, as shown in Fig. 1. The effective mill stretch, comprising roll stack deformation and



1 **Adaption of stretch curve for roll stack deflection**

[1]Profit Center Grobblech ThyssenKrupp Stahl, Duisburg, Germany
[2]Automation, VOEST-ALPINE Industrieanlagenbau (VAI), Austria
VAI is a division of the Siemens Group Industrial Solutions and Services

DOI 10.1179/174328106X113986

net elongation of the stand, is calculated individually for each pass.

During TruShape rolling, which is the last pass of the sizing and broadsiding sequence, a variable thickness profile is applied to the material. The thickness curve is calculated by the process optimisation system and forwarded to the control system as a polygon curve. During the previous pass, the actual length is measured by the tracking and the deviation between the actual and the calculated length is taken to adapt the thickness curve. For each supporting point of the polygon curve, a set of data (length position, forward slip, expected roll force and additional thickness) is part of the pass schedule. According to the plate position, an additional thickness value is sent to the stand AGC controller via a fast analogue signal.

The set-point for the work roll bending system and the sensitivities for roll force fluctuations are calculated by the process computer and forwarded to the basic automation system which calculates reference values for all four bending cylinders; these reference values are transmitted to the work roll bending control system.

The hydraulically operated side guides, in front and behind the mill stand respectively, have been equipped with new position transducers, connected to the new automation system via Profibus DP. For thin gauge rolling in particular it is important to design an optimised rolling and reversing sequence, so as not to lose time and therefore temperature of the piece, and to promote reproducible production. The centring of the piece is done automatically as part of the rolling sequence, whereby both side guide levers are controlled and supervised for symmetrical movement.

For TruShape rolling and for proper functioning of the Super AGC, accurate material tracking is mandatory. Several sensors are used to synchronise the calculated material position. For the length calculation, new incremental encoders for the main drives have been installed.

In thermo-mechanical rolling waiting intervals between passes are necessary in certain instances. To enable a second or a third piece to be rolled simultaneously, the automation system can track the position of the different pieces. In those cases the coordination function organises the rolling sequence, determining which material must be moved from and to the delay tables and decides which material will continue rolling at the rolling mill. Since the intermediate and finishing temperatures for these products are technologically very important, mill coordination is performed in close coordination with optimisation of the pass schedule.

To reduce the waiting time during thermo-mechanical rolling, intermediate cooling areas and fast cooling areas are installed. According to the target temperature, water may be applied to the plate, the necessary parameters being calculated by the level 2 system and forwarded to the process automation system. Many different cooling schedules must be considered given the range of materials and products processed.

The existing instrumentation for measurement of centreline thickness and temperature profile across the width has been completely integrated in the new automation system.

Two modes of plant operation are possible. In manual mode all movements and speed references are initiated by the operator; this mode is also used for roll change, calibration and light maintenance. The regular mode of operation for production is automatic mode where the complete rolling sequence and tracking is controlled automatically. The only manual intervention required is the turning of the piece, which is required because of the lack of geometrical position monitoring equipment.

To allow parallel operation of the plant during the switchover period, a new main control desk for the mill stand area was pre-installed in an elevated position behind the existing desk; after hot testing, the old desk was dismantled and the new control desk shifted to the final position.

For communication between the control systems a new plant network was established, making use of fibre optical cables outside the electrical rooms. The visualisation system has been redesigned for the entire process and the remaining automation systems have been incorporated for operators' convenience. For fast data logging functions a powerful PDA system has been installed, which is connected via fibre optics to the control systems. Different automatic data logging routines have been implemented to support commissioning, tuning and evaluation of non-standard incidents.

The new level 2 process optimisation system comprises material tracking, interfaces to level 3 for receiving PDI data and sending production reports, interfaces to the reheat furnace and accelerated cooling process models as well as to gauges, and the process model and mill pacing functions described below.

VAI.plate*plus*

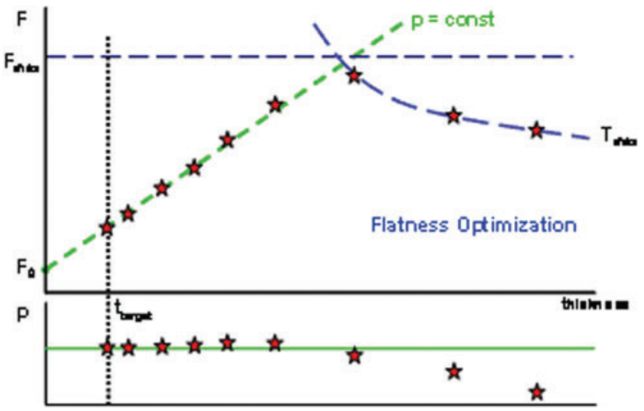
VAI.plate*plus* integrates extensive production and process know-how and experience. VAI, including the former Clecim and Davy, has been involved in plate mills since 1974. The current system, developed independently by VAI-Linz, was launched in 1999. In all, VAI has made nearly 40 installations at plate producers throughout the world.

VAI.plate*plus* is a real-time mathematical model designed to optimise the rolling process in a reversing plate mill. Its major role is to determine an optimal rolling schedule in terms of productivity and product quality, taking into account the mill physical constraints and rolling practices, and to calculate the presets for each pass (roll gap, force, speed, bending, etc.).

Calculating a pass schedule requires the initial product properties (dimensions, temperature and material properties), the final properties and plant parameters (dimensions, rolls and constraints). Basic physical models are used to predict the behaviour of both product (temperature, flow stress, rolling force and torque, shape and dimensions) and rolling mill (roll thermal crown and wear, mill stretch, roll gap shape) during the rolling process. A sophisticated rolling and optimisation strategy determines the rolling schedule, to meet the productivity and product quality criteria as a function of mill and product constraints and the imposed rolling practices. Finally, an automatic self-correction is applied, based on the measurements transmitted by sensors during rolling.

The particular features distinguishing VAI.plate*plus* include:

- **recalculation** during each pass and cyclically during delays makes it possible to revise a schedule during the rolling operation, taking into account deviations in the process and benefiting from **pass-to-pass adaptation** of the flow stress model and the actual plate temperature – the optimal schedule is *never* definitive and can be modified at each pass
- fast **optimisation techniques** make it possible to recalculate the

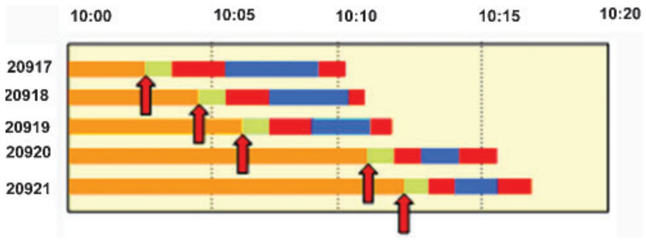


2 **Flatness diagram indicating roll force *F* and relative profile *p* for individual passes over pass exit thickness**

schedule fully on a real time basis, to make the presets available for the next pass. During the last phase, in which flatness and profile are important features for thin plates, a specific optimisation strategy ensures that the relative profile is kept constant to prevent waves on the plate (Fig. 2); mill restrictions (maximum force or torque) and other process factors must also be taken into account in the optimisation

- besides excellent thickness and width performance, outer shape (plan view) is a key factor for further improvement of yield, i.e. the ratio between customer plate mass and slab mass. To influence the shape that develops during rolling, a double-wedge longitudinal profile can be rolled during the last passes before the two standard 90° turns of the plate. Simple solutions calculate the height and length of this wedge profile, principally using the ratio between plate width and slab width. A further approach applies statistical methods to determine a linear regression formula for wedge height depending on dimensions, pass numbers, and other parameters. VAI.TruShape*plus* calculates the evolution of the outer shape during each pass, taking into account roll gap shape (cross-profile), transverse profile of the plate and the effect of using a vertical edger stand. A mathematical optimisation method is used to find an optimal parameter set within stand limits (AGC) for which the calculated final shape has the least deviation from the desired (mostly rectangular) shape. As a consequence, the longitudinal contour rolled in certain passes may show a more complex shape than the standard double-wedge curve
- a real time, fully three-dimensional calculation of the thermal crown and wear for the precise roll shape provides a precise input for the roll stack deformation model, ensuring precise mill stretch and roll gap profile calculation for each pass. VAI.rsd*3D* calculates the full roll stack deformation online without using simplifications to reduce computing time, in effect offering the accuracy of a detailed 3D finite element model
- improved **waiting time** and rolling speed optimisation during the last phase of rolling guarantees precise final temperatures and therefore optimal material properties.

In addition, the VAI.platePacer*plus* modules coordinate the passage of individual plates, taking into account heating, transport, rolling and waiting times (with and without intermediate cooling) and waiting positions (size and number of plates to wait on side of the mill stand), and predicts the discharging times for the next slabs in the furnace by arranging individual process phases on the time axis without collisions (Fig. 3). An optimum discharging sequence can be identified to maximise plant productivity.



3 **Mill pacing overview: heating times (orange), transportation times (green), rolling times (red) and waiting times (blue) for a sequence of plates. Predicted optimum discharging times are indicated by arrows**

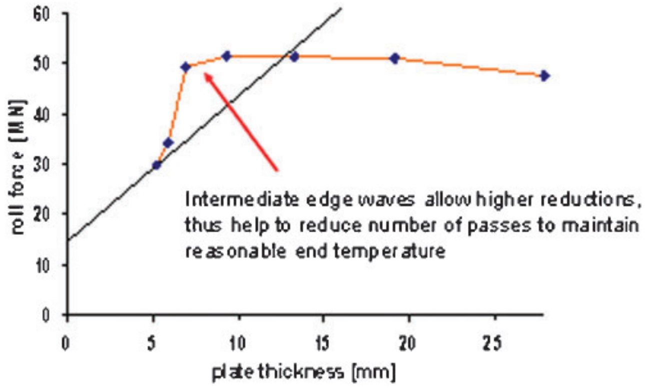
Thin gauge rolling

Implementation of new optimisation techniques makes rolling of complex products possible by exploiting the full capability of a mill and giving much more precise predictions. Thin plate rolling (down to 4 mm) is an important application worth describing in further detail.

Thin gauge rolling in plate mills is a major challenge for the mill model and control system – plate flatness is difficult to achieve, but is of crucial importance for both process stability and product quality. During thin plate rolling the plant and the process limits are often used to the maximum. Those limitations are largely defined by maximum roll force, plate temperature (rapid temperature loss in the final phase due to the thin product, strongly depending on plate length), roll set stiffness, roll grinding contour, thermal crown and wear of the rolls, roll diameter, product width, steel grade and maximum force for unloaded roll gap.

For optimised fully automatic thin gauge rolling, a precise setup for the entire final phase is required. Any significant deviation in the final rolling phase causes problems for thin plate, as there is usually little room for compensation in later passes: for instance, an error in the roll force prediction, e.g. due to incorrect temperature prediction, will accumulate from pass to pass, and any attempt to compensate it will result in flatness problems, if no powerful actuators for profile control such as heavy bending are available. For this reason, not only must the model be precise, but the entire process must be predictable and – to widen the product range towards thinner, wider, longer, harder plates – fully optimised, i.e.:

- predictability of the rolling process requires high process robustness, without rolling interruption, especially during the last phase



4 **Effect of permitting intermediate edge waves**

- the automatic gauge control must be very stable, based on an exact mill stretch curve
- precise temperature and roll force prediction
- a precise roll gap shape and plate profile and flatness model is required.
- fully dynamic recalculation helps to adjust the remaining pass schedule in the case of deviation
- simple to use, easy to understand operator intervention must be supported for rapid process feedback to the model via the operator, as there is usually no flatness gauge available for automatic flatness feedback
- although intermediate lack of flatness may result in process instability (e.g. plate centring problems), controlled intermediate flatness deviation (edge waves) may be required to extend the existing product limits. Centre waves are usually more critical for process stability than edge waves and should be avoided where possible. Allowing intermediate edge waves to some extent makes higher intermediate reductions possible; thus, an increase in the number of passes required for a certain product may be avoided, which helps to maintain a reasonable final rolling temperature (Fig. 4).

Switchover

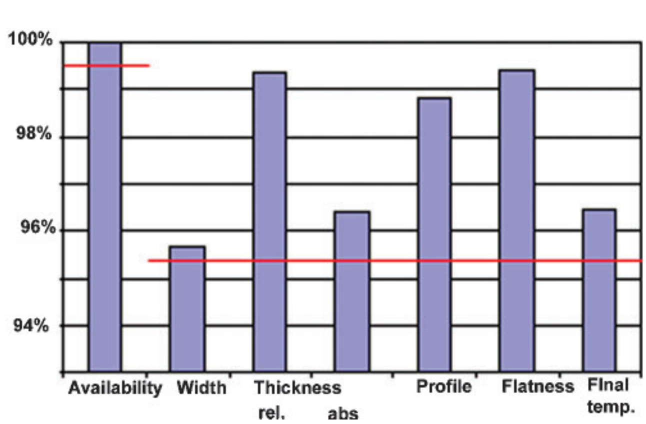
The demanding implementation time frame of only 12 months from the contract signing to the first plate rolled, required thorough planning of engineering and installation activities. The interface with the existing control systems required particular attention, including site visits, to locate all interconnections and integrate the remaining automation equipment seamlessly into an overall control concept for the plant.

VAI committed to use planned shutdowns and maintenance shifts for installation of the equipment. Since this period is not long enough for a revamp of this size, pre-installation work was also done during normal plant operation. To open the existing control circuits and connect the new automation system in parallel, two regular multi-day shutdowns (3+2 days) were utilised: all interconnection work and signal-testing after re-connection of the old and the new system took place during this time. All other activities where interruption of production was necessary took place during regular maintenance shutdowns every 2 weeks.

To ensure a secure start-up without disturbing regular production VAI implemented a switch-over facility, which provided the possibility to go back to the old automation system within a few minutes. Simply turning a key changed the source of the outgoing signals in several switch-over relay units and enabled the new automation system to take control. Input signals from the plant were split, in parallel, to serve both old and new automation systems. At suitable positions in the wiring, signals were branched off to isolation amplifiers in the case of analogue signals or via relays in case of digital inputs. To save cables and cabling work the signals were led to ET200 remote I/Os which were retained after dismantling the old automation system. Output signals were converted to a suitable voltage level before entering the switch-over relays. After actuation, the new automation system had exclusive control of the actuators.

The switch-over equipment was one of the first items installed, successfully commissioned less than 8 months after contract. Before hot commissioning, a **listening mode** proved valuable for offline tuning of the new model and controls. All process signals were collected and transferred to the new model computer as if under real operation. Relevant model parameters for plant and material conditions had been tuned in advance, reducing the learning time during hot commissioning and guaranteeing a shorter start-up period. Certain control loops were also tested offline. Since incoming signals were available and the control loops were enabled, but not connected to the actuators, principal controller behaviour had already been tested and adjusted.

During production gap times, the new automation system was deployed to perform cold test procedures, e.g. electromechanical gap adjustment or tests with the main drives and roller tables. The interfaces and signal exchange to the neighbouring systems were also tested. The cold test finished with a complete ghost rolling simulation of the plant with interaction of all automation and measuring systems. During ghost rolling the sequence control, pass schedule distribution, application of cooling water, gap adjustment, speed guidance and tracking were tested and the result verified on the new HMI system. The



5 **Performance values during four week test period**

6 Thickness record during four week test period

7 Redesigned main control desk

comprehensive cold testing allowed hot commissioning to start with full confidence.

The first successful rolling in manual mode took place almost exactly 12 months after contract. From that point, the new automation system was switched on part time for optimisation of the process control, gradually taking over more and more of the production until the old system was used for stand-by only. The obsolete system was dismantled in autumn 2004 following final acceptance tests over a period of four weeks with 72 shifts.

An impression of the tests is given in Fig. 5, which shows final results of the most important test values; the red line indicates the guaranteed values. A thickness report showing excellent consistency is shown in Fig. 6.

An important objective of the project was to implement the new control system without additional shutdown. While the switch-over module is a valuable tool, providing a redundant control system that enables production to fall back to the old system, it does require a somewhat longer commissioning time than a straight-forward start-up. In this instance, the high season of the steel market caused a reduction of net testing time and shifted the final performance tests. The frequent change of workplace was an additional requirement for operators and it took more time for them to feel comfortable with the new automation.

Customer experience

The implemented models represent state-of-the-art of modelling and rolling technologies. TKS experts were present during the planning, programming, start-up and performance test phases, and are able to maintain the models and, if necessary, make adjustments for new market requirements.

Generally, the quality of the heavy-plate production was improved and stabilised at a high level. The target temperature accuracy of normalised formed or thermo-mechanically rolled materials improved noticeably, which contributes to uniform mechanical characteristics of the final product. The flatness of the rolled material improved; failure and re-machining rates were also noticeably reduced. TruShape thickness profiling during the stretching and spreading phase, which is implemented to optimise the end scraps, led to a noticeable reduction of the number of plates that were too short. 'Too thin', 'too thick', 'too narrow' or 'too wide' plates were practically eliminated.

The control pulpit was completely modernised and redesigned according to ergonomic principles during the 14 day shutdown at the change of the year 2004/05. Operating personnel were involved right from the start, in determining the optimal positions of the operating elements using a 1:1 cardboard model. They also actively influenced the design of the visualisation system and even the colours of the walls of the control pulpit. This resulted in a modern workplace that was accepted by all (Fig. 7).