NLMK’s Upgraded Plate Mill Restarts at Clabecq

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Keywords: Revamping, Technological Packages, Profile and Flatness control

SUMMARY

NLMK’s Clabecq (Belgium) plate mill is composed of a quarto reversing mill and a four-stand continuous finishing mill. This unique configuration makes the plate mill capable of processing material in the same way as a semi-continuous hot strip mill; this carries obvious advantages in terms of process homogeneity opposed to a standard reversing plate mill. As a result, the company has been recognized as a specialist in thin to medium thicknesses. It covers the traditional markets of construction, shipbuilding and energy, as well as quenched and tempered products.

In 2020, NLMK decided to partner with Danieli again to implement all the necessary control packages in the finishing mill and gain the full advantage coming from this plant configuration. The revamping also involved the replacement of two descaling boxes. The results have made it possible to improve thickness tolerances, subsequently achieving benefits such as weight savings and improved bending performance for very high elastic limits. It also reduces the rate of second choice and revises the reheating programs downward, resulting in a reduction in terms of CO2 emissions.

INTRODUCTION

The NLMK Clabecq plant in Ittre (Belgium) produces medium and heavy steel plates in thickness from 3 to 64 mm. Unique in the industry, it includes the reversible quarto mill and the four-stand continuous finishing in the same line. This special layout allows for high productivity for low-thickness steel plates, together with superior high class surface finish and flatness. The modern quenching and tempering line, built with the latest heat treatment technologies, ensures the production of high added-value steels.

Market development and economic factors have led the company to intensify its presence in the more specialized products of quenched and tempered steels. Among others, the market for mobile cranes and the production of plates for very high yield strength booms (YS ≥ 1100 MPa) have led to consequent investments and modernization in the basic tools of the rolling mill: descaling and finishing mill equipment.

EFFECT ON PRODUCTS

Although amply justified by the strategy of growing in the plate sector for mobile crane arms, these investments have a direct impact on all our products, as described in Table 1.
### New Descalers Characteristics

The new primary descaler was installed in place of the old one and commissioned in August 2021. It is located upstream from the Quarto mill. It is fed by a new pressurized water station, designed and implemented by *SGGT Hydraulik GmbH*, to supply the high-water pressure of 250 bars (+ 175 % compared to the old one). The descaling box was designed and implemented by *Plakoma Gmbh* and nozzles are supplied by *Lechler*.

The top header height is automatically adjustable according to slab thickness to keep the vertical spray constant. Table 2 provides the main characteristics by comparing old and new descalers. The impact pressure is increased by 217% and the total water flow is decreased by 24%.

<table>
<thead>
<tr>
<th>Old primary descaler</th>
<th>New primary descaler</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max working pressure (bar)</td>
<td>90</td>
</tr>
<tr>
<td>Total flow rate (L/min)</td>
<td>6650</td>
</tr>
<tr>
<td>Type of nozzles</td>
<td>HP Superior</td>
</tr>
<tr>
<td>Max impact pressure (N/mm²)</td>
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</table>

Table 2 – Main characteristics – Comparison between old and new primary descalers

The new secondary descaler is located upstream from the finishing mill and was also commissioned in August 2021. Unlike the primary descaler, the water station was unmodified. *Plakoma Gmbh* and *Lechler* made the descale box and nozzles respectively. This descaler is composed of 4 headers (2 top/bottom entry and 2 top/bottom exit headers).

Top header height is automatically adjustable according to transfer bar thickness to keep the vertical spray constant. Table 3 gives the main characteristics by comparing old and new descalers. The impact pressure is increased by 20 to 50%.

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<th>Old secondary descaler</th>
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<td>Max working pressure (bar)</td>
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**INVESTMENT DETAILS**

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Finishing Mill (TFT) Revamping

The project main goal was to modernize the existing mill, while retaining as much as possible of the existing equipment.

Tasked with this target, Danieli devised a tailor-made modernization strategy, based on mill stands 3D laser tracking, new technological packages such as hydraulic actuators for gap control (HAGC) for stands 3 and 4, a brand-new hydraulic bending system as well as new interstand loopers, connected to a new hydraulic power unit.

The existing technological control system was replaced by the modern HiPAC automation platform and integrates the control functions related to the new HAGC, bending and hydraulic loopers.

The modernization strategy included improvements in the Level-2 process control system and the installation of a flatness gauge at the finishing mill exit.

The entire modernization project was implemented in different steps and was completed in February 2023.

The starting point of the project was the 3D scanning of the 4 housing stands. The targets of the scanning were to:

- Measure the current geometry;
- Evaluate the machining activity requested (not only for accommodating the HAGC, but also the accommodation of bending blocks);
- Evaluate the clearance requirement and liner addition/substitution to ensure a correct mechanical alignment of the HAGC and bending blocks during operation;
- Inspect the base plates, columns bottom, top column for any sign of issues or fatigue.

![Figure 1 – View of Mill Upgrades](image)

Danieli’s engineering department designed all the components specifically adapted to the existing mill stands as measured by the 3D scan. This ensured smooth machining and installation activity on-site.

All the new equipment integration with the existing housings was tested with extensive FEM simulations.

Furthermore, the machined parts were FEM tested and compared to the prior situation in order to validate the safety and robustness of the new configuration.
The structural verification of the new machined housing is positive. It even allowed to safely increase the maximum separating force from 45,000kN to 50,000 kN.

Existing housing has been compared to new version with the proposed machining modification: stress distribution is equivalent, and stresses are well below the allowable limits. The verification of the machined chocks is positive as well.

The charts below show the calculated FEM stress and safety factors against the allowable limits of Stand 4.

- All the new components have been manufactured in the Danieli headquarters’ workshop in Buttrio, Italy.
- The hydraulic unit and valve stands were manufactured in the group center of competence located in Danieli’s workshop in Thailand.
Flatness Gauge

The flatness gauge is located downstream from the finishing mill and was commissioned by IMS Messsysteme GmbH in January 2023. Two projectors project a quadratic pattern of lines on the surface of the rolled plate covering the full width, as shown in Figure 8. The line pattern is detected by a CCD matrix camera. Then, a powerful image software analyzes the projected lines mathematically and determines the plate flatness by Phase-shift method.

A surface image of the plate is generated from an examination of the height progressions in the analysis window as given in Figure 9. Thus, the elongation of the plate can be calculated from it, see equations below (Pythagorean Theorem).

\[ l_i = \sqrt{\Delta x^2 + (h_{i+1} - h_i)^2} \]

\[ L = \sum l_i \]
Example: 10 I-Units correspond to a plate elongation of 0.1 mm over a length of 1000 mm.

Subsequently, symmetry and asymmetry are calculated. As shown in Figure 10, the calculated symmetry values provide primary information on the flatness type (center buckles or edge waves), while asymmetry is an indicator for edge wave. The values A, B and C correspond to the sums of the elongation inside the tracks and can be configured in the flatness gauge settings.

INVESTMENT IMPLEMENTATION AND COMMISSIONING

Finishing Mill (TFT) Technological Packages and Control

The new control automation imported many control functions that are proper and typical of the Hot Strip Mills. Adaptations have been introduced to consider the process differences between the Plate and Strip production.

The Gauge Feedback Adaptation model has been tailored for NLMK’s plate mill. Correction factors, time constants and parameters have been fine-tuned during the commissioning to adapt the control system to the plate process, as compared to the strip process. The gauge feedback control is based on the Smith Predictor method, see image below for a schematic of the control system. The underlying control used to compensate exit gauge deviations is the AGC system of the last active stand. However, a selectable number of stands prior to the last active stand, also receive additional filtered AGC thickness references.

Figure 11 – GFB Predictor Scheme with Force Sharing
Due to the dead time between the action in the last stand roll gap and the measuring position, the gauge deviation signal from the exit gauge will be processed using a predictor feedback control, which will generate corrections to the HGC position controllers to remove the gauge error.

**Major Level 2 Functions Implemented During Commissioning**

Besides the implementation of all new equipment in Level 2 (loopers, HAGC and positive bending), two major functions were implemented to improve thickness and flatness results:

1. **Optimization of Inter Stands Specific Tension**

   Load cells are mounted between the roll and the pivot of each looper to measure the plate tension. The constant tension over the entire length of the plate is achieved by changing the looper torque (as function of the looper arm angle), see Figure 12. It is done by acting on the servovalve of the hydraulic looper. Both position and tension references are calculated by Level 2.

   ![Figure 12 – Inter stand tension control](image)

   The stand outlet mass flow continuously changes because the HAGC function adapts the roll gap to control the plate thickness, producing variation in plate tension. A constant tension in each inter stand is recommended to avoid plate necking or breakage. In fact, a tension too low can lead to the formation of loops, while too much tension can lead to ripping of the plate. Moreover, too much tension can also lead to rolling instability when the plate head enters the next stand and when the plate tail leaves the previous stand. Thus, it can affect thickness results.

   During commissioning, it was noticed that too much tension was applied to each inter stand. The first modification was to set the position reference of each looper constant (25°), no matter what the inter stand thickness is. The second modification was to reduce the tension reference. Figure 13 shows the evolution. The blue curve depicts the results of tension reference for each plate produced before commissioning. The upper and lower limits (theory) are given by Danieli calculations. Many tests were performed during production to get the actual curve (the purple one on the graph), especially on thick plates (target thickness > 15 mm). The experimental approach was to minimize the head and tail thickness errors by modifying the tension reference in Level 2. This way, the inter stand tension was reduced by 75% (6.5 MPa vs 1.8 MPa) for plates with inter stand thickness > 15 mm. Then the equation was implemented in Level 2.

   ![Figure 13 – Finishing mill inter stand plate tension](image)
2. Bending Adaptation With Flatness Gauge

The flatness gauge is used for short-term adaptations. Figure 14 shows a diagram of the AFC system (Automatic Flatness Control), connected to the last active stand. The flatness gauge measures the plate symmetric and asymmetric flatness while rolling. The results are then transmitted by TCP/IP communication to the Level 2 server and stored in the database (head and tail ends are excluded from calculation).

For the next plate, the system takes input from the level 2 system and from the operator HMI bending corrections. It applies a filtered gain, a sensitive factor, and outputs trims to the WRB setup (Work Roll Bending) of the last active stand. The symmetric error is corrected by acting on the WRB of the last stand.

**Figure 14 – Flatness control system**

### Thickness and Flatness Results Evolution

The thickness measurement is performed by a Triple-Head thickness gauge (center, DS and NDS), located downstream from the finishing mill. The thickness tolerances given in Table 4 are valid for the full-length of the plate, excluding the out-of-width ends, that are cropped. The table also gives the sigma level for each mother plate, which is equivalent to the percentage of the measured points within tolerances. For commissioning, a plate was considered successful if the percentage of measured points are above or equal to the sigma level.

<table>
<thead>
<tr>
<th>Target thickness [mm]</th>
<th>Aimed th tolerances for customer plate [mm]</th>
<th>Sigma level for each mother plate</th>
<th>% of measured points within tolerances (mother plates)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.00 &lt; th ≤ 5.00</td>
<td>± 0.20</td>
<td>± 2.00</td>
<td>95.40%</td>
</tr>
<tr>
<td>5.00 &lt; th ≤ 8.00</td>
<td>± 0.20</td>
<td>± 2.05</td>
<td>96.00%</td>
</tr>
<tr>
<td>8.00 &lt; th ≤ 15.00</td>
<td>± 0.25</td>
<td>± 2.15</td>
<td>96.80%</td>
</tr>
<tr>
<td>15.00 &lt; th ≤ 25.00</td>
<td>± 0.35</td>
<td>± 2.20</td>
<td>97.20%</td>
</tr>
</tbody>
</table>

Table 4 – Thickness tolerances for each target thickness

The flatness performance is measured in I-Units by the flatness gauge. A plate is considered successful if 95% of the measured points are below the flatness limits, given in Table 5.

<table>
<thead>
<tr>
<th>Target thickness [mm]</th>
<th>Flatness tolerance [IU]</th>
<th>Flatness tolerance as wave height R (L = 1000 mm), see Figure 15</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.00 &lt; h ≤ 6.00</td>
<td>&lt; 30</td>
<td>&lt; 11</td>
</tr>
<tr>
<td>6.00 &lt; h ≤ 8.00</td>
<td>&lt; 20</td>
<td>&lt; 9</td>
</tr>
<tr>
<td>8.00 &lt; h ≤ 25.00</td>
<td>&lt; 10</td>
<td>&lt; 6.5</td>
</tr>
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</table>

Table 5 – Flatness tolerances for each target thickness

Figure 16 shows the evolution of thickness results per week during commissioning for product QUARD 450 3.3 mm 2500 mm width. There is a progressive stabilization of thickness results from week 21, with 94% of the points within tolerances in average.

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Figure 16 – Thickness results evolution during commissioning for product Quard 450 3.3mm 2500 mm width

Figure 17 shows the evolution of flatness results for the product S355 / DH36 5 mm 2500 mm width during commissioning. The results are also very positive, with 96% of the plates successful. It is also noticed that there is an improvement of the results plate by plate in the first batch, proving the right adaptation from Level 2 and flatness gauge.

After commissioning, when all Level 1 and Level 2 modifications were implemented, tested and validated, the capabilities for each thickness range were calculated (from September to November 2023). It concerns 163 plates with target thickness 3 and 4 mm. Figure 18 shows the thickness accuracy with all measurements plotted on the same graph. Distributions from Drive Side and Non Drive Side are shifted compared to the distribution from Centreline. It is due to the natural plate crown. Moreover, almost all the measured values are within the InThinity tolerances [-0.20; + 0.20] mm.

Figure 18 – Distribution of thickness accuracy (±μm) for 3 and 4 mm plates
Optimization of Nozzles Orientation – Secondary Descaler

After the secondary descaler was commissioned, global surface aspect for plates with high silicon content was not at a sufficient level. In fact, red scale remained at the surface, see example on Figure 19.

![Figure 19 – Red scales remaining at the surface – Plate with high silicon content](image1)

![Figure 20 – Presence of remaining red scale striations on the surface](image2)

To optimize the surface aspect, a study of nozzles parameters was conducted in collaboration with Lechler. The first study regarded the headers (entry top/bot headers VS exit top/bot headers). Statistical analysis showed that entry top/bot headers are more efficient than the exit headers. It is probably due to a perturbation of water while descaling (water layer at the surface) and a temperature drop at the surface.

The second study regarded the header height. Once again, a statistical analysis was performed to compare different header heights (85, 80, 75 and 70 mm). Header height of 70 mm gave better results since the impact pressure increases by 25% (1.95 MPa with 80 mm, while 2.45 MPa with 70 mm). However, the presence of red scale striations was noticed with header height at 70 mm, see figure 20. It is due to an inadequate overlap.

To keep the header height at 70 mm and avoid red scale striations, a study about offset angle was carried out. Different configurations on test bench were tested with the same nozzles (Mini Scale master HP Superior), with a constant header height at 70 mm and pressure = 120 bars, but with different offset angles (0°, 5° and 15°). Results are given on Figure 21/Figure 22. An impact pressure drop is clearly visible in the overlap area with an offset angle of 15°. Moreover, a previous study demonstrated that the in-line nozzle configuration improves surface aspect in term of scale, particularly in the overlap/washout area [1].

Based on the obtained results, nozzles with in-line configuration (offset angle 0°) were implemented on the entry top/bot headers. The surface aspect was significantly improved with a decrease of remaining red scale estimated at 80% by surface inspection analysis. Moreover, no more striations were observed, see Figure 23.

The next improvement will be to upgrade the water pressure station of the secondary descaler. This will allow to produce plates with high silicon content at a lower temperature and to keep a perfect surface aspect after descaling and rolling.

![Figure 21 – Impact pressure test – Water pressure 120 bars, total water flow rate 96.7 L/min, vertical spray height 70 mm, offset angle 15°, inclination angle 15°](image3)
RESULTS – IMPACT OF INVESTMENTS FOR CUSTOMERS

The effects of the investments for our customers can be summarized as follows (Figure 24).

![Figure 22 – Impact pressure test – In-line nozzle configuration – Water pressure 120 bars, total water flow rate 96.7 L/min, vertical spray height 70 mm, offset angle 0°, inclination angle 15°](image1)

![Figure 23 – Surface aspect of plate with high silicon content after implementation of nozzles with in-line configuration](image2)

![Figure 24 – Effect of investments](image3)
Reduction of Rejection Rates

Descaling:

![Comparison of rejection rate (incrustation)](image1)

Finishing mill upgrade:

![Comparison of rejection rate (rolling mill)](image2)

**Table 6 – Key Performance Indicators after the revamping**

<table>
<thead>
<tr>
<th>Rejection Causes</th>
<th>Rate Before Revamping [%]</th>
<th>Rate After Revamping [%]</th>
<th>Variation [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cobble</td>
<td>0,64%</td>
<td>0,46%</td>
<td>– 18</td>
</tr>
<tr>
<td>Thickness</td>
<td>0,44%</td>
<td>0,35%</td>
<td>– 20</td>
</tr>
<tr>
<td>Flatness</td>
<td>0,93%</td>
<td>0,40%</td>
<td>– 57</td>
</tr>
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</table>

Thanks to the improved control systems and the new technological packages, all the quality performance indicators show a substantial improvement, as per Table 6.

Reduction of CO2 Emissions

Thanks to improved efficiency of descaling process, it was possible to gradually reduce reheating temperatures. Between 2022 and 2023, taking into account these new programs as well as the increased proportion of plates produced by the direct quenching process, it has been possible to reduce the mill's CO2 emissions by 12%.

CONCLUSIONS

NLMK and Danieli partnered once again for an important transformation project of the key asset at the Clabecq plate production site.

Thanks to the close cooperation between the teams, the project that required detailed tailored solutions was concluded with successful results. All the key quality parameters show a substantial improvement after the intervention.
Following the implementation of these new investments, it has been possible to accelerate the industrialization of new products (in particular those linked to the production of plates for the booms of mobile crane).

Thickness tolerances can be offered at a new level with InThinity branding.

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<tr>
<td>8.00 &lt; h ≤ 15.00</td>
<td>± 0.25</td>
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The next possible improvement step will be to make better use of the stand reduction capacity after revamping by using higher transfer bar thicknesses. This will enable a further gain in efficiency by reducing the number of passes during roughing mill operation.

REFERENCES

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