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B. Description

1 Objectives

The European pilot & demonstration RFCS Roll-Prof project aims to develop and to implement a sensor system able to carry out on-line and real-time roll profile measurements for both cold and hot rolling.

With regard to hot rolling, this sensor system may be subjected to harsh mill environment such as radiation of rolled products, indirect heating due to roll contact with the strip, water cooling and presence of abrasive particles as well as important mechanical issues like vibration and positioning problems.

Furthermore, the sensor system must be able to:

- carry out roll profile measurement at roll speeds up to 20 m/s,
- assure the high measurement accuracy range of the finishing stand (in this case, for pinch roll),
- measure refined roll profile distribution over the roll barrel length.

In the case of Dunkirk's HSM, the measurement system should be implemented on the pinch roll with the purpose of measuring and controlling pinch roll's wear.

Thus, a real-time monitoring of pinch roll wear may help Dunkirk HSM to better:

- evaluate and quantify coiling & strip defects due to wear on pinch roll,
- correlate pinch roll wear distribution and type of defects
- and optimize rolling campaigns and pinch roll change (by improving pinch rolls life).

In cold rolling, an uniform reduction is aimed over the strip width. Non uniform reduction leads to bad strip shape (wavy edge, centerbuckle etc.). If the work roll profile is known, an optimum setting of other shape actuators can be found, so that strip shape is within tolerances.

2 HSM coiler application

Figure 1 gives a view of the coiler mechanism. The pinch rolls set consists of a top roll and a bottom roll mounted parallel to each other and perpendicular to the rolling axis. The top pinch roll can be raised by two pneumatic cylinders to allow the strip to pass through and be wound on coilers located downstream.

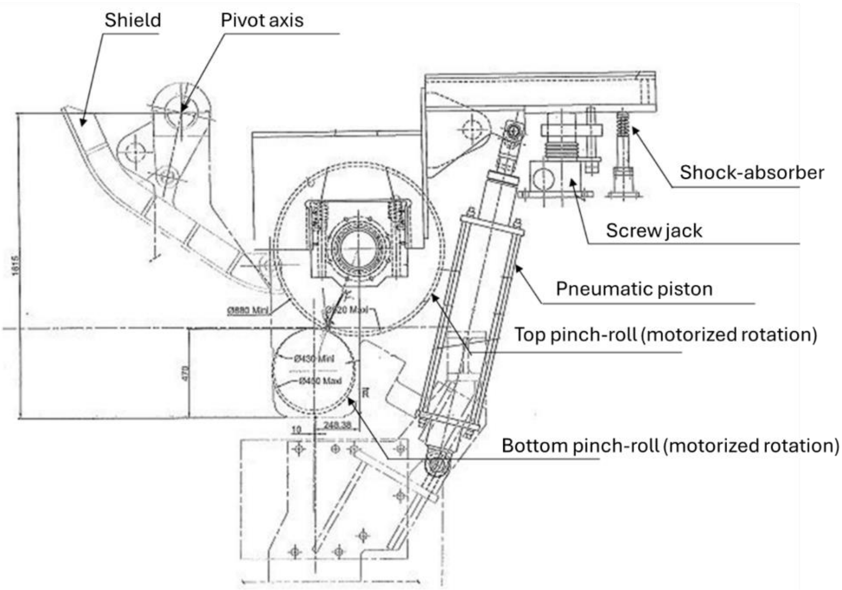


Figure 1 – View of the coiler mechanism.

At the grinding workshop, the pinch rolls are given a special grinding profile to reduce wear and maintain maximum contact surface with the strip, whose widths vary from 750mm to 1950mm. As illustrated in Figure 2, the pinch roll start profile comprises a flat area in the middle of one meter width and two straight chamfers on each edge.

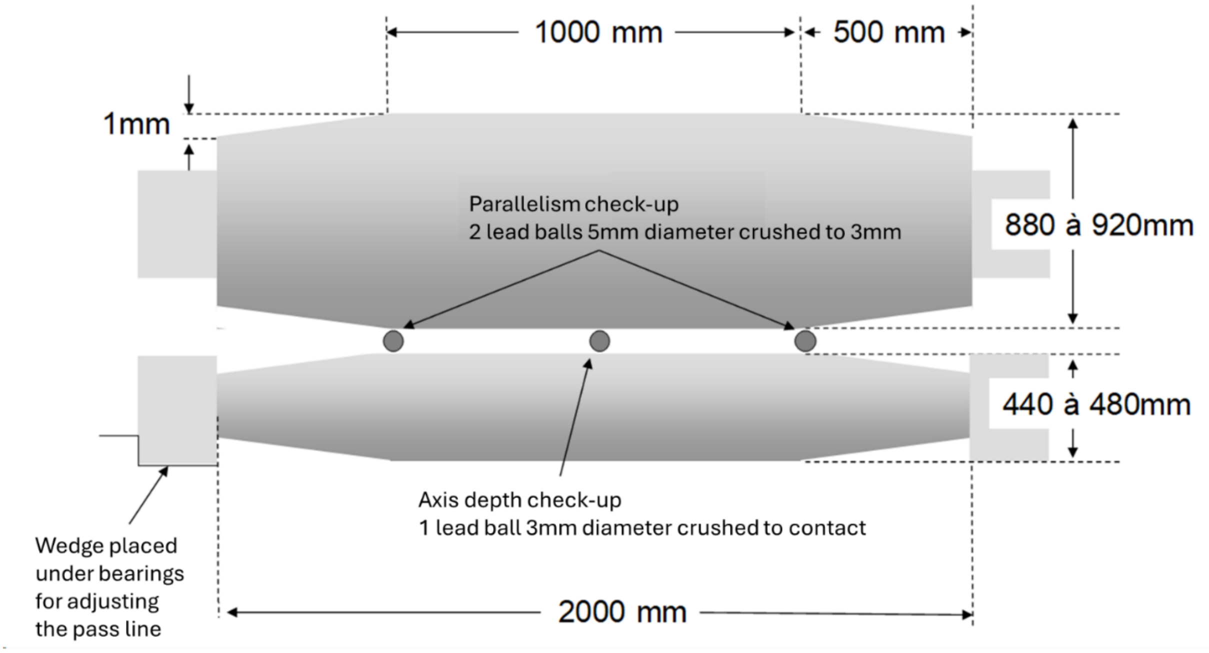


Figure 2 – Pinch-rolls arrangement and geometrical positions control.

The Roll Profiler measurement can be used to improve the grinding profile of the pinch-rolls, monitoring the progressive wear of it. This would allow for extended pinch-roll life.

Another possibility would be to reduce the slippage that can occur between the strip and the pinch-roll without going too far and deteriorating the wear performance.

It could also highlight the abrasive nature of certain product grades, just as the evolution of the wear profile compared to variations in coiled formats could lead to the reconsideration of grinding start profiles. The use of the wear model derived from the few campaigns exploited will make it possible to fine-tune the adaptation of the gap to the coils and to predict the change of pinch-rolls to be programmed.

Concerning the anticipated gain, as in Dunkirk, a coiler consumes from 2 to 4 pinch-rolls set per year, the replacement cost is around 40k€/year, an improvement of 10% on the pinch-roll consumption would produce an annual benefit of 4k€.

3 Principle of measurement

The Roll Profiler uses inductive sensor for measuring the distance to the roll surface. As illustrated in Figure 3, the inductive sensor generates a high frequency electromagnetic field producing eddy currents inside the metal. This resulting current flow sets up a new magnetic field that opposes the original magnetic field. The net effect is a change of the inductance of the coil in the inductive sensor. Inductive sensors are insensitive to water.

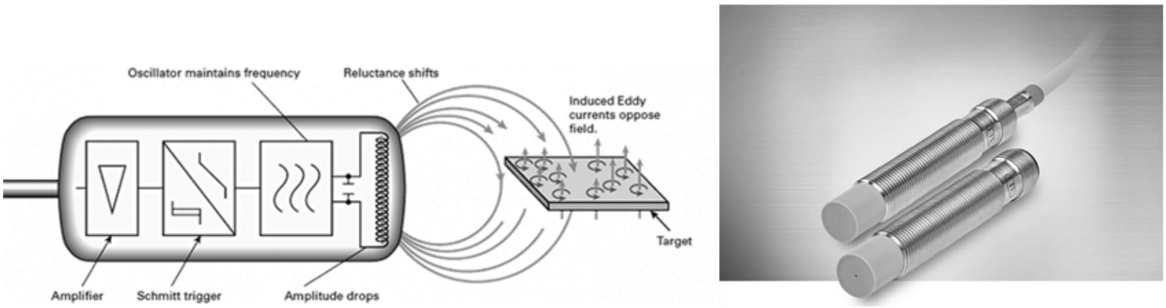


Figure 3 – Principle of inductive sensor

4 Design of the industrial prototype

The detailed engineering of the Roll Profiler system has been performed by CRM in close collaboration with ArcelorMittal Dunkirk. Figure 4 shows a view of the Roll Profiler without the front cover.

Figure 4 – Full size Roll Profiler for ArcelorMittal Dunkirk coiler

The 15 sensors are in front in red colour. Unused located are fitted with bold to fix the front cover. Additional sensors will be placed in these locations for the future CSM application.The water pipes (red colour) and the three cables connections are visible at the back.

5 Lab test of the industrial prototype

A final test of the complete system comprising the beam and the control cabinet has been performed in the full-size cooling platform prior shipping to Dunkirk plant. Figure 5 illustrates this operation.

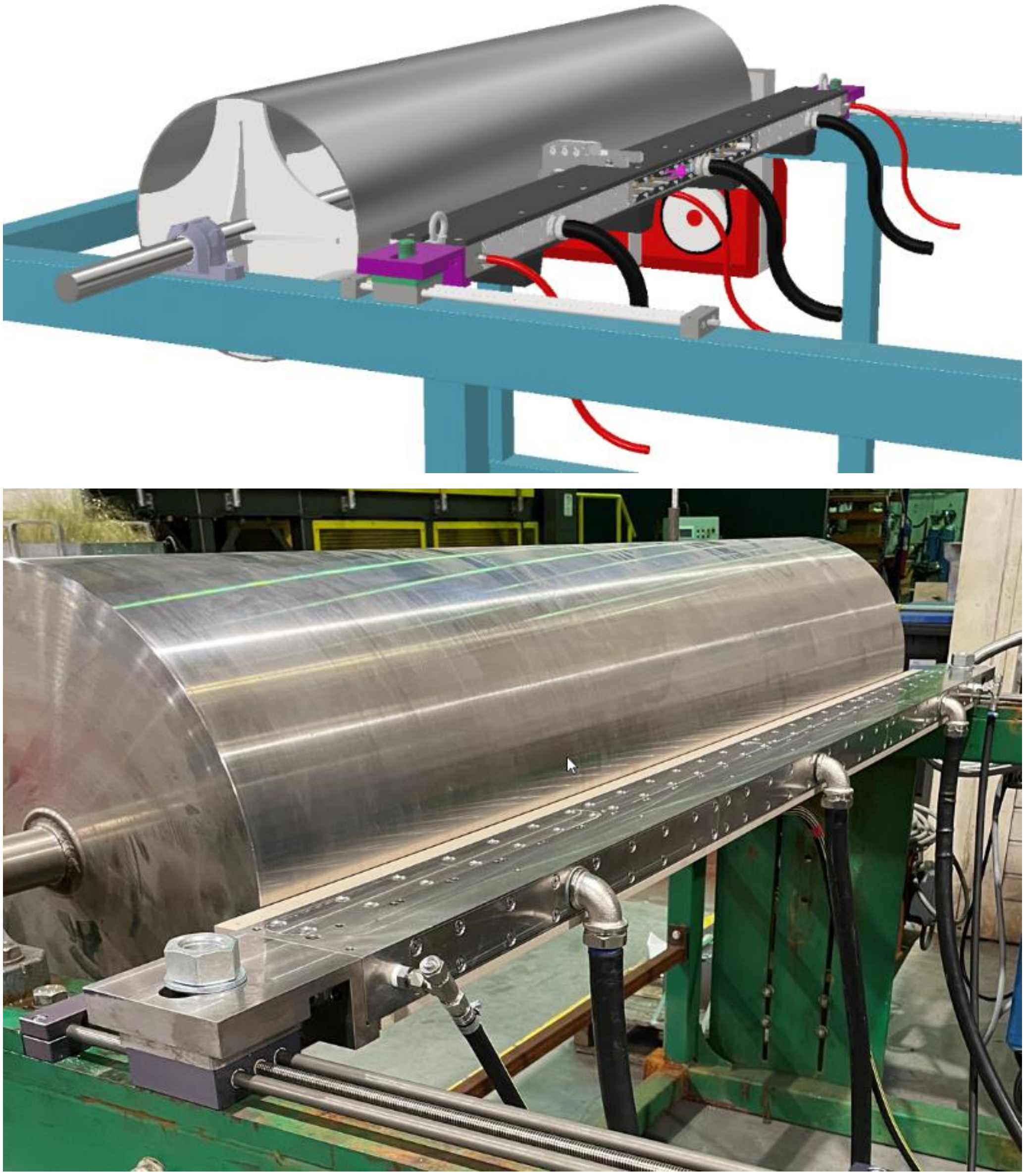


Figure 2 – Roll Profiler prototype for pilot lines implementation

The Roll Profiler is mounted in front of dummy roll. The correct functioning of the complete Roll Profiler system has been successfully tested, including the data acquisition software.

6 Implementation in the HSM industrial coiler

The roll Profiler implementation in the ArcelorMittal Dunkirk coiler was initially planned in summer 2022 during the annual stop of the mill. Due to various scheduling issues, the implantation has been finally performed in February 2023.

Before the final installation of the prototype with all the connections and cables, the mechanical mounting was evaluated with the beam alone. Figure 6 illustrates the check-up of the fastening system on each edge.

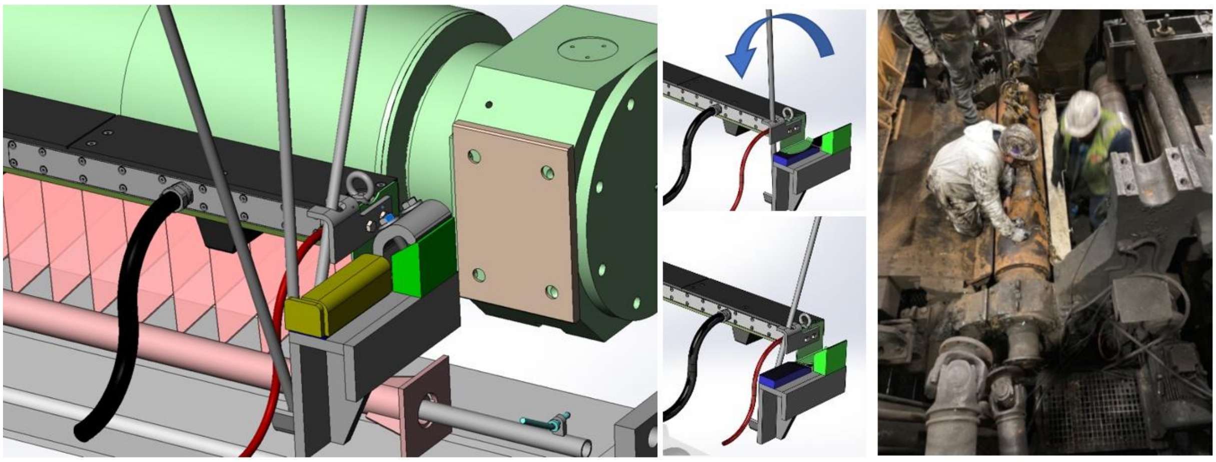


Figure 3 – Mechanical modifications on the hot rolling line before the installation.

As shown in Figure 7, the ArcelorMittal Dunkirk maintenance staff people had to assist the installation to guide the wiring and the hoses below the pinch-roll towards the electrical cabinet.

Figure 7 – Mechanical installation on the hot rolling line with all electrical and cooling cables connected.

7 Industrial campaigns in the HSM coiler

Three industrial campaigns have been performed in the ArcelorMittal Dunkirk coiler n° 1. The follow-up has been performed by the "Support Process" staff of Dunkirk and by CRM, the data being acquired on-site, distributed in the plant network and also remote accessible.

First Campaign

The first campaign has been carried out from 10th February 2023 to 27th March 2023, it has been characterised by 21558 coils passing through the pinch-roll with 10695 coils processed in the coiler n°1. The coiler n°1 faced 4 coiling incidents.

Second Campaign

The second campaign has been carried out from 4th May 2023 to 23rd June 2023, it has been characterised by 23561 coils passing through the pinch-roll with 12171 coils processed in the coiler n°1. The coiler n°1 faced 3 coiling incidents including a major one.

Figure 8 gives a view of the major incident:

- The left picture shows the strip penetrating inside the coiler structure,
- The right picture gives a view of the Roll Profiler after dismounting of the shielding plates. The electrical connection cables were not damaged except one water pipe that had to be replaced.

Figure 4 – View of the coiler & Roll Profiler after the major incident

After detailed examination by the maintenance staff, it appears that the fastening on operator side has been damaged, the fastening bolds having acted as a mechanical “fuse”.

After replacement of the damaged water supply pipe and reparation of the fastening, the Roll Profiler has been correctly positioned in front of the new pinch-roll, ready to restart the measurements for the next campaign.

Third Campaign

The third campaign has been carried out from 21st July 2023 to 18th October 2023, it has been characterised by 30441 coils passing through the pinch-roll with 14449 coils processed in the coiler n°1.

At the end of this third campaign, AMMR performed a high accuracy measurement of the pinch-roll profile the end-life.

8 Results Analysis for the Industrial campaigns in the HSM coiler

In total, the three campaigns performed to date have been considered in the results analysis. They were nevertheless characterized by the following specific aspects:

- The first campaign got a normal production schedule with no major incident. Unfortunately, the end-life measurement of the pinch-roll could not be planned on-time.

- The second campaign got a poor production schedule with long stops. This campaign could not be considered a normal one and in addition a major incident occurred.
- The third campaign got a normal production schedule with no major incident. The end-life measurement of the pinch-roll has been performed. This last campaign was taken as reference for the results analysis and calibration of the wear model.

Consequently, the analysis of the results will not be presented in a chronological way but according to the following order:

- The third campaign with normal production schedule and end-life measurement,
- The first campaign with normal production schedule,
- And the second campaign with a poor production schedule.

*Results of the **third** Campaign*

Figure 9 gives the evolution of the raw distance measured by all the sensors as a function of time for the complete campaign.

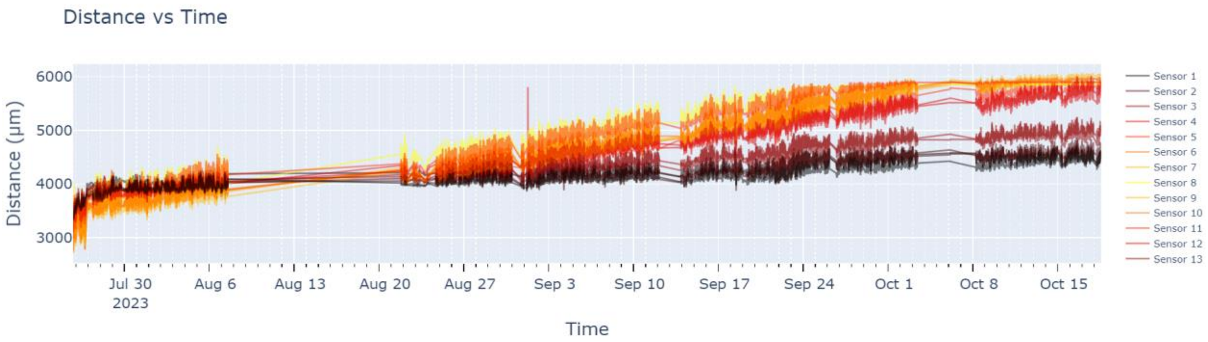


Figure 9 – Sensors response versus time (third campaign)

This time evolution highlights several production stops (straight lines on the graph) without possible measurement. During these idle periods, the pinch-roll cools down and consequently, at restart, the coiling of several coils is required to recover a steady thermal state and the corresponding thermal crown of the pinch-roll. To treat the acquired data, the raw distance measurements are preferably plotted as a function of the coil number passing through, so called “index”.

Figure 10 gives the distances profiles evolution at different “index” values.

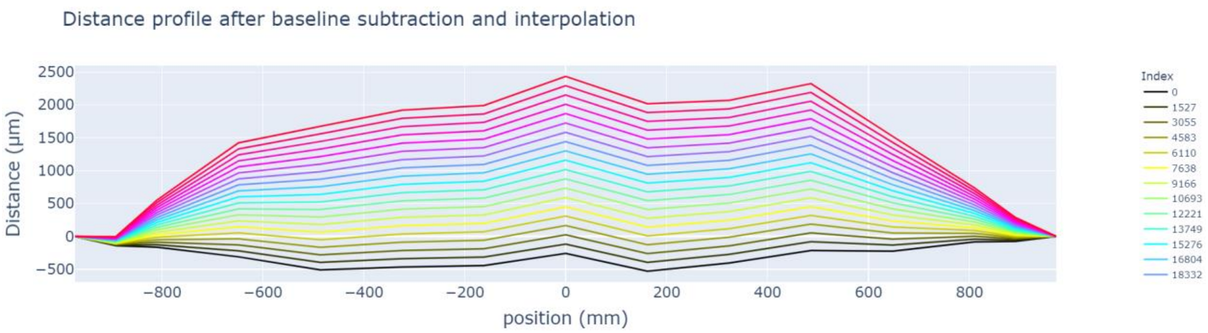


Figure 10 – Distances profiles evolution (third campaign)

By subtracting the first distance profile record from all the further ones, the evolution of the pinch-roll wear is obtained as shown in Figure 11.

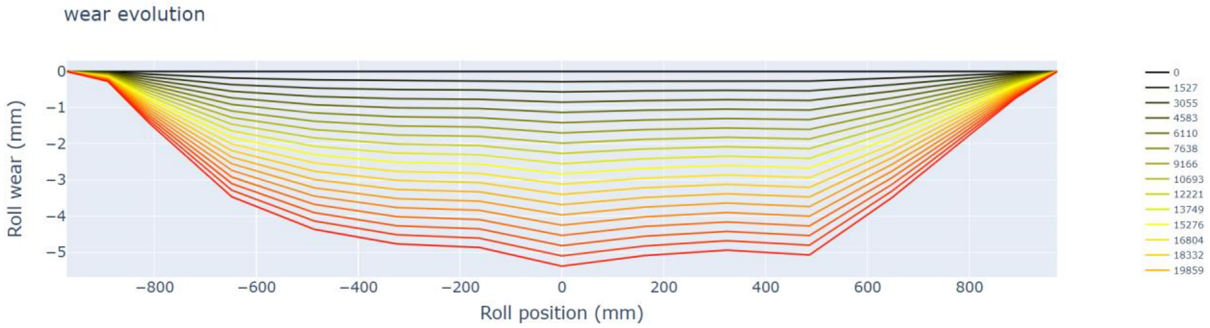


Figure 11 – Wear profiles evolution (third campaign)

On Figure 12, the high accuracy measurement of the end-life profile of the pinch-roll performed AMMR is plotted as a dotted blue line. A good correspondence with the Roll Profiler measurement is noticed. The wear evolution is also given (the plain lines represent the measured wear and the dotted lines the model).

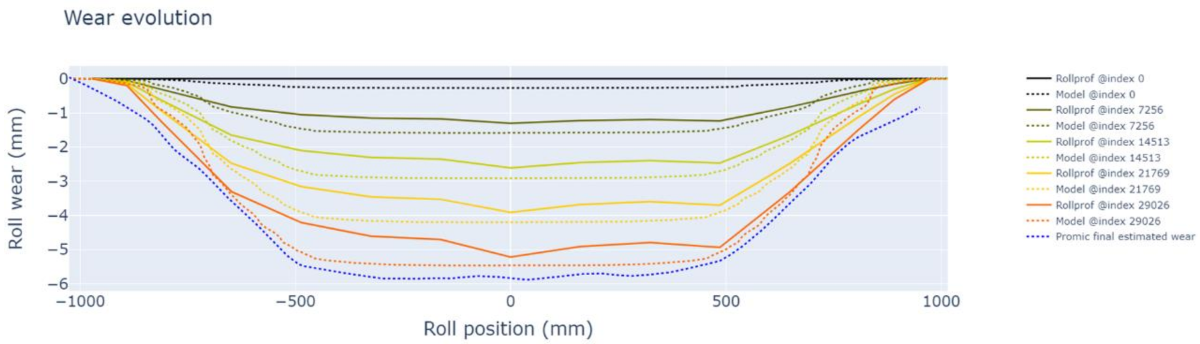


Figure 12 – Wear profiles evolution – model & end-life comparison (third campaign)

At the start of the campaign, the end-life pinch-roll is replaced by a “new” one which has been grinded at the plant workshop according to an initial profile illustrated in Figure 13. This initial profile comprises a flat central band, one meter width, and two chamfers on each edge.

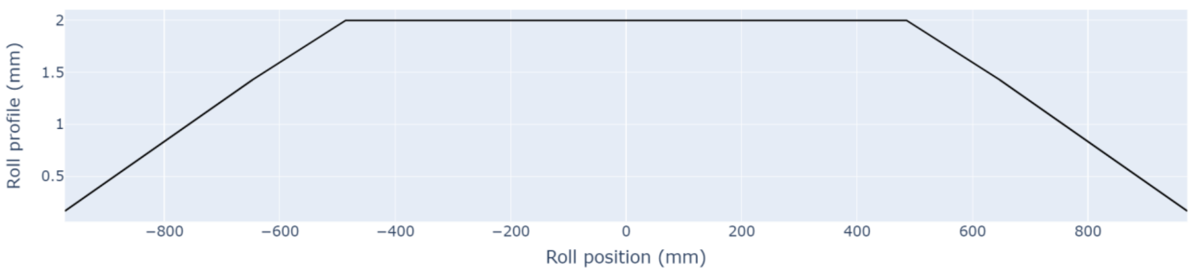


Figure 13 – Initial profile of the pinch-roll after grinding

Simply adding the initial profile to the wear profiles, the evolution of the pinch-roll can be obtained as illustrated in Figure 14.

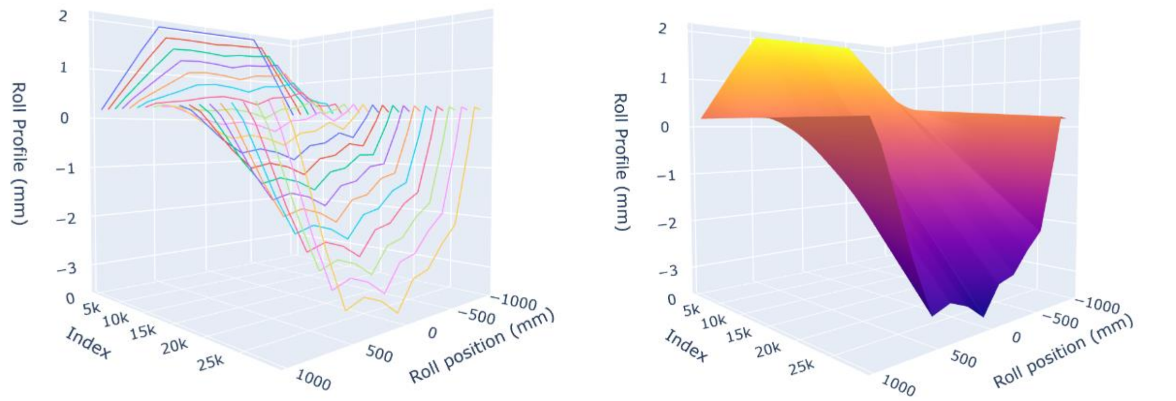


Figure 14 – Pinch-roll profiles 3D evolution (third campaign)

*Results of the **first** Campaign*

On the same way as for the third campaign, Figure 15 give the evolution of the pinch-roll profiles.

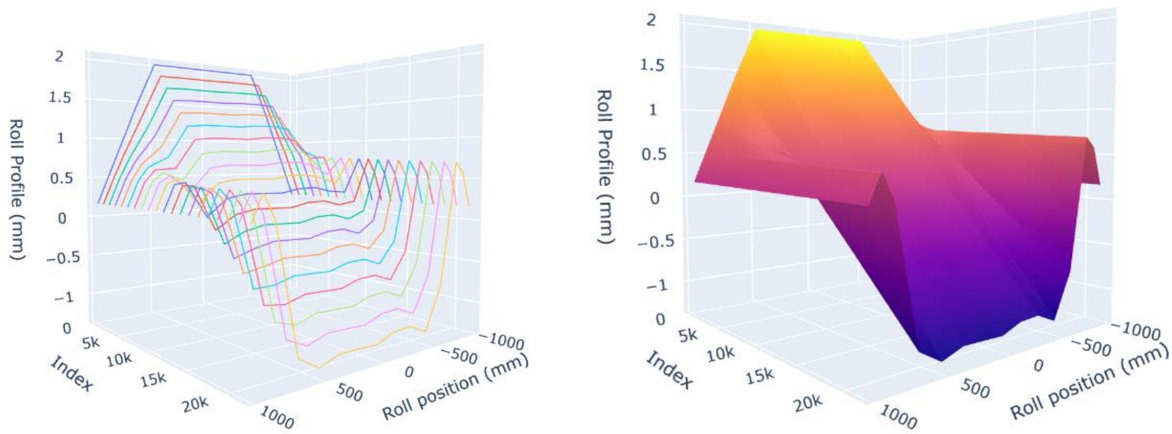


Figure 15 – Pinch-roll profiles 3D evolution (first campaign)

*Results of the **second** Campaign*

The evolution of the pinch-roll profiles is also given in Figure 16

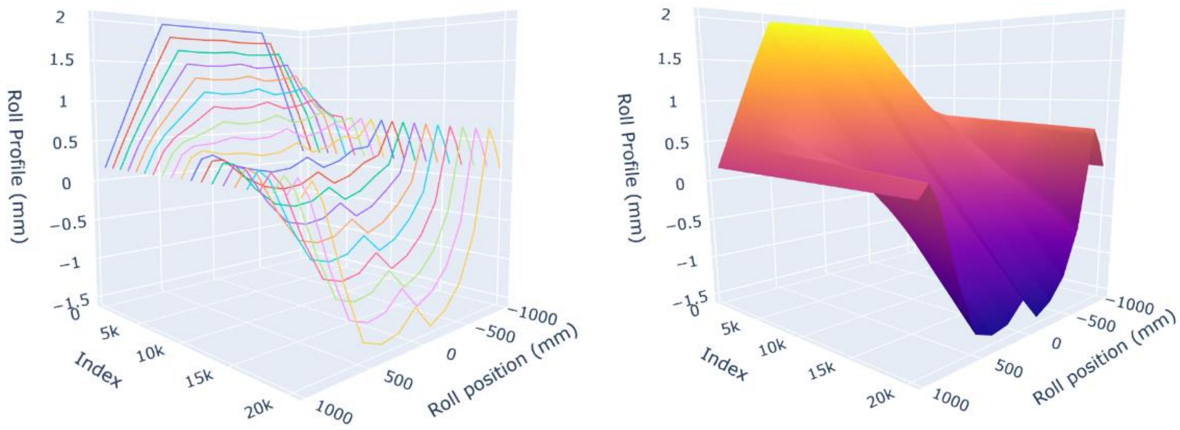


Figure 16 – Pinch-roll profiles 3D evolution (second campaign)

As a conclusion, the Roll Profiler system gave the evolution of the pinch-roll profiles for three industrial campaigns in the ArcelorMittal Dunkirk coiler. The intervention of the maintenance staff was limited to the positioning of the beam at pinch-roll change. The system survived to a major coiling incident that tend to prove its robustness and its industrial reliability. The comparison with the wear model was satisfactory as well as the end-life measurement for the third campaign.

9 Improvement of the wear model of the coiler pinch-rolls

AMMR developed a wear model of the coiler pinch-roll. The pinch-roll wear model proposed here corresponds to a contact-mechanic based equation inspired from the main principle that wear (volume loss) is proportional to the normal force by the sliding length. The model accounts for the 3 coiling phases.

The pinch roll wear model has been calibrated by using the coiling campaign n°3. For this campaign, an optical measurement of the pinch roll at the end-life (at the end of the campaign) has been performed in the grinding workshop in ArcelorMittal Dunkirk by using a “PRO-MIC©” contact measurement device which measures roll profile change in diameter across the roll barrel length with high precision.

Figure 17 shows the initial and final pinch roll profiles measured by the Pro-Mic system device respectively before starting and after the end of the campaign n°3. The starting profile corresponds to a flat grinding shape with roll chamfers of 500 mm width and 2 mm depth (in diameter) at both pinch roll edges. While the final profile corresponds to a classical worn roll shape with progressive material consumption from the roll edges to the central zone (which usually corresponds to the smaller strip widths coiled).

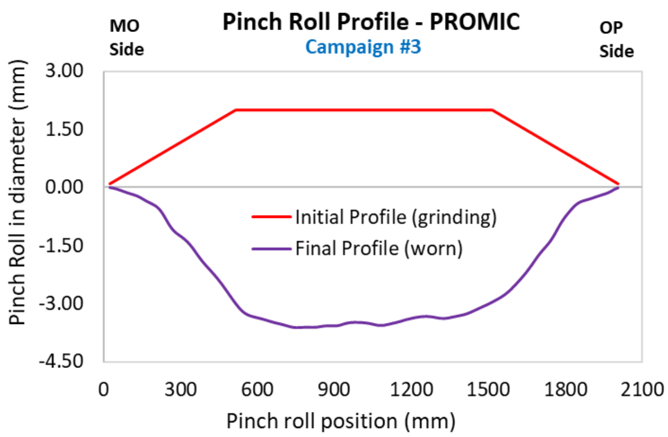


Figure 17 – Initial and final pinch roll profiles of coiling campaign n°3 measured by “Pro-Mic” device.

Figure 18 shows this wear profile coming from both “Pro-Mic” and Roll Profiler measurements as well as from calibrated pinch roll wear model calculations. The wear profile results on this figure reveal that:

- it can be seen a similar trend between both Roll Profiler and Pro-Mic measurement acquisitions. So, it can be concluded that Roll Profiler online system is able to provide reliable measurements.
- The pinch roll wear model developed seems to be able to predict well the pinch roll wear profile both in terms of shape and amplitude.

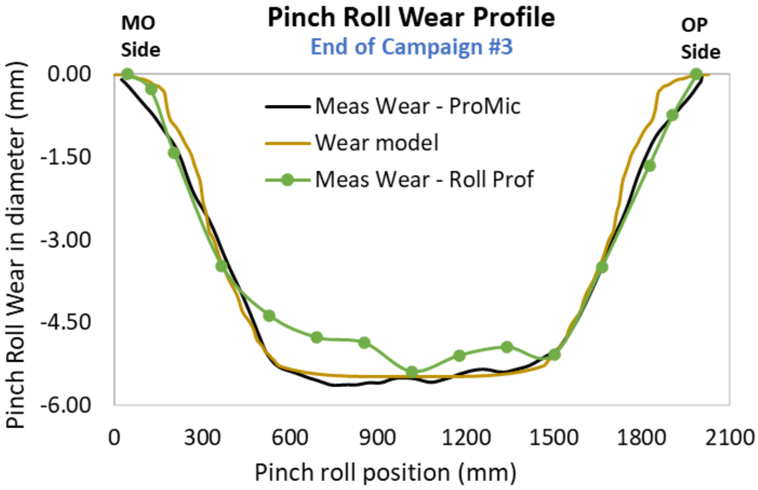
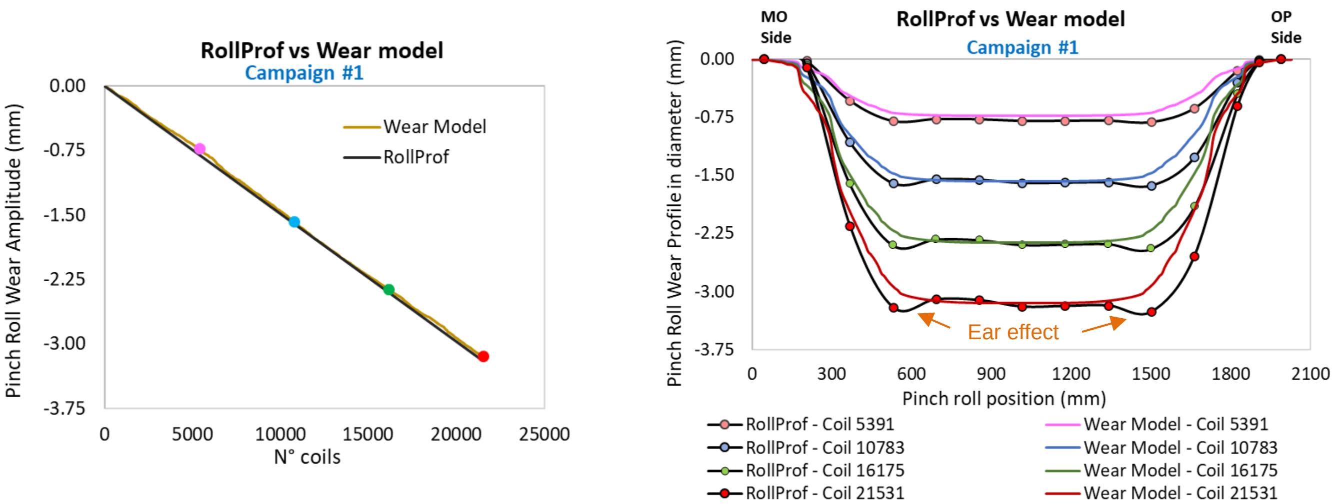


Figure 18 – Pinch roll wear profile i) measured by Pro-Mic device, ii) measured by Roll Profiler system and iii) calculated by the wear model with calibrated coefficients.

Figure 19 shows comparisons for the coiling campaign n°1. For the wear amplitude over the full campaign as well as wear profiles at different stages along the campaign, there is a general good agreement between the between Roll Profiler measurements and model predictions.



a) b)

Figure 19 – Pinch roll wear a) amplitude over the full campaign and b) profiles at different stages of the campaign obtained by both Roll Profiler system and wear model for the coiling campaign 1.

The pinch roll wear model developed can be applied for appraising the wear state of the pinch-roll in case of malfunction or withdraw of the Roll Profiler system. The combination of Roll Profiler system and wear model will also allow the coiler operator to continuously assess online the wear shape of the pinch roll and consequently better determine its end-life and better estimate the optimum time to replace the pinch rolls.

This combination could also be used to optimize the initial grinded shape of the pinch roll with the purpose of enhancing the pinch roll behaviour over next coiling campaigns. Such optimization aims at reducing pinch roll consumption while assuring strip flatness requirements.

C. Conclusions

The Roll Profiler system has implemented successfully in the ArcelorMittal Dunkirk coiler and operated up to four coiling campaigns. It has proven its robustness and reliability to sustain the environment of the down-coilers.

The Roll Profiler has been compared satisfactorily to an end-life profile measurement performed out of the coiler.

It can be used to follow-up the wear of the pinch-roll, a wear model having been developed to assist the prediction of the Roll Profiler.

This measurement could be used as a tool to master the wear. The benefits will be in the optimisation of the start profile and in the change of the pinch-roll. A reduction of the slippage is also anticipated due to a better mastering of the pinch-rolls wear.

In complement for mills with hydraulic pinch-rolls, it can be used with other actuators (tilting, force per side).

Concerning the cold rolling application, the pilot line tests performed in Tata Steel Ijmuiden gave an insufficient accuracy that impended the industrial implementation.