EMG HOTCAM: OPTICAL STRIP POSITION, WIDTH, AND CAMBER MEASUREMENT IN THE HOT ROLLING PROCESS[1]

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Abstract

In the hot rolling process the detection of slab/strip position and width is crucial with respect to an optimal positioning and movement of the processed strip between the rolling stands or on the roll out table. In an ideal scenario the slab/strip position and width measurement between each rolling stand allows to produce a perfect strip shape and avoids damages caused by strip contacts to the line's guide rail. In recent years Tata Steel Research & Development has developed a camera system for detecting the slab position in hot rolling mills. Tata Steel has chosen EMG as their partner for creating an industrial design of this solution. The result is a CMOS area scan camera based system detecting strip position (width) between the stands from a rather larger distance of 4-8 meters not requiring intensive cooling or protection. The system which is called EMG hotCAM is applicable for multiple stand hot rolling mills (finishing mills) or reversing mills. In finishing mills EMG hotCAM especially helps to avoid so called "cobbles" where the strip guidance between the rolling stands fails and the hot material breaks out of the mill, leading to time consuming and costly maintenance operations. In reserving mills the system serves especially for measuring and eliminating the strip camber due to feedback into the rolling process and adjustment of the rolling force. This paper concentrates on the system design, the industrial application experiences and results.

Key words: Hot rolling position measurement; Camber measurement; Optical systems; Width measurement.

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1 INTRODUCTION

During the hot rolling process the detection of slab/strip position and width is crucial with respect to an optimal positioning and movement of the processed strip between the rolling stands and on the roll out table. In recent years Tata Steel Research & Development has developed a camera measurement system for detecting slab position in hot rolling mills. Tata Steel has chosen EMG again as their partner for creating an industrial design of this system. The result is a CMOS area scan camera based system detecting strip position (width) between the stands from a rather larger distance of 4- 8 meters not requiring intensive cooling or protection. The system which is called EMG hotCAM is applicable for multiple stand hot rolling mills or reversing mills. In combination with a closed-loop control with an adjustment of the rolling force by the mill automation system it serves especially for avoiding costly “cobbles” in finishing mills and for measuring and eliminating the strip camber in reversing mills. This paper concentrates on the industrial application experiences and results of this new solution

2 MATERIALS AND METHODS

2.1 Application Scenario Hot Mill

The hot rolling process is typically a combination of a reversing mill (roughing mill) and a multi-stand hot rolling mill (finishing line). For the process reliability in a hot rolling mill it is crucial to keep a defined position of the strip between the hot rolling stands. The continuous measurement of the strip position between the stands or after the last stand allows an optimized adjustment of the rolling force and gap.

In reversing mills this leads to a reduction of the camber of the strip and thus prevents collisions of the strip with the mechanical strip guiding rail and improves the strip quality and the strip coiling.

One of the most critical sometimes disastrous events in finishing mills (2 – 5 and more stands) are so called “cobbles”. The strip leaves the center position between the stands to such an extent that it cannot longer hold in line and breaks out. The consequences are damages at the mill equipment, material loss, and long still stands of the mill.

Figure 1 shows a graphical representation of a cobble as it may appear in a typical hot mill production scenario.

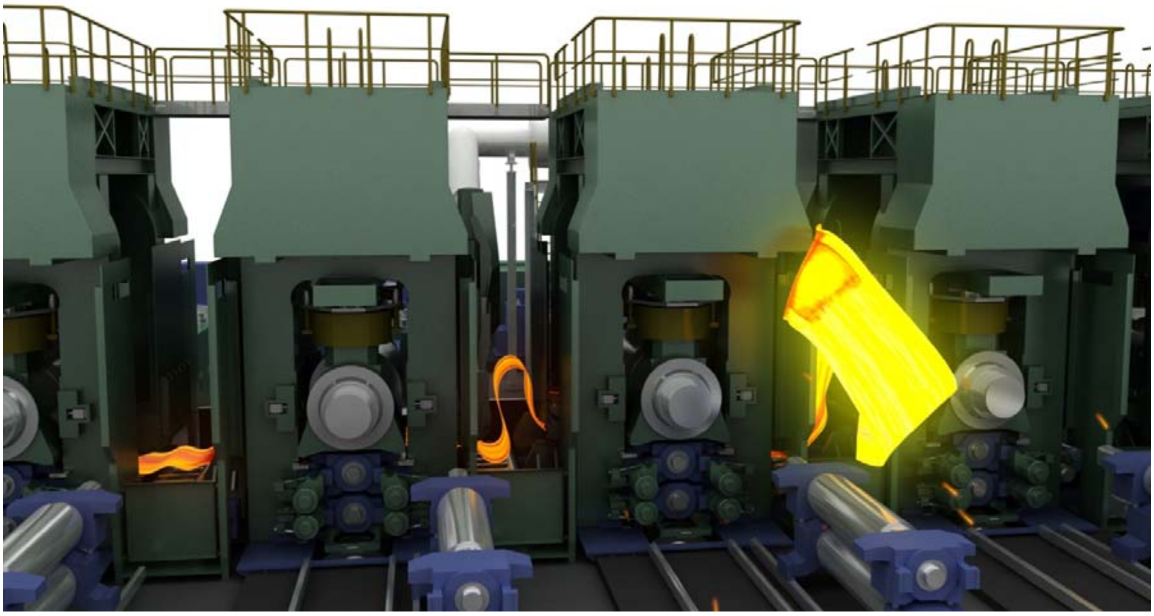

Figure 1: Simulated “cobble” in a typical finishing line.

For a complete simulation how EMG hotCAM is working and in which way “cobbles” emerge in a hot mill please refer also to the actual EMG hotCAM video at: http://www.youtube.com/watch?v=qjl6jYZJ_BM
Cobbles appear frequently at thin strips which are hard to control and to guide, most frequently the cobbles appear between the last rolling stands. Such kind of cobble leads to a complete scrapping of the coil and a line stop of about 1-2 hours since the lost strip has to be removed from the line.
Currently the strip positioning in a finishing line is performed manually. The strip is moved by the operator on all rolling stands by adjustments of the mill control system (this is one of the last tasks that the operator has to do manually within the rolling process, today). Possible alternatives to perform this task are today:

- The operator looks out of the window and pivots the strip based on his visual judgment
- Camera based supervision and pivoting based on operator’s visual judgment
- Differential tension measurement on the looper, alternatively measurement of the rolling force and guiding on the second but last or last roll stand, especially for thin strips

In both application scenarios the continuous online measurement of the strip position (and edges) would allow to optimize this positioning process, to improve the strip shape, and to avoid damages or disastrous events either by an operator based control or in future by a closed-loop control realized be the mill automation system provider.
Although the two applications are individually distinct with regard to some functionality and requirement aspects, they employ a basically equivalent system structure which hence is jointly described.

2.2 General Technical Approach

The EMG hotCAM system is based on a CMOS area scan camera which takes pictures of the moving hot strip in the near infrared range and measures the strip centre position between the roll stands in the finishing line on the one hand and the strip edges, position, and camber in the reversing mill on the other hand. In finishing lines the system can be scaled up with more cameras according to the number of mill stands to be equipped. Also a combined measurement of camber and strip position is possible for finishing lines. In this case an additional EMG hotCAM camera module needs to be positioned at the last rolling stand in rolling direction with a view towards the rollout table. The typical positioning of the CMOS cameras in a finishing line is shown in Figure 2.

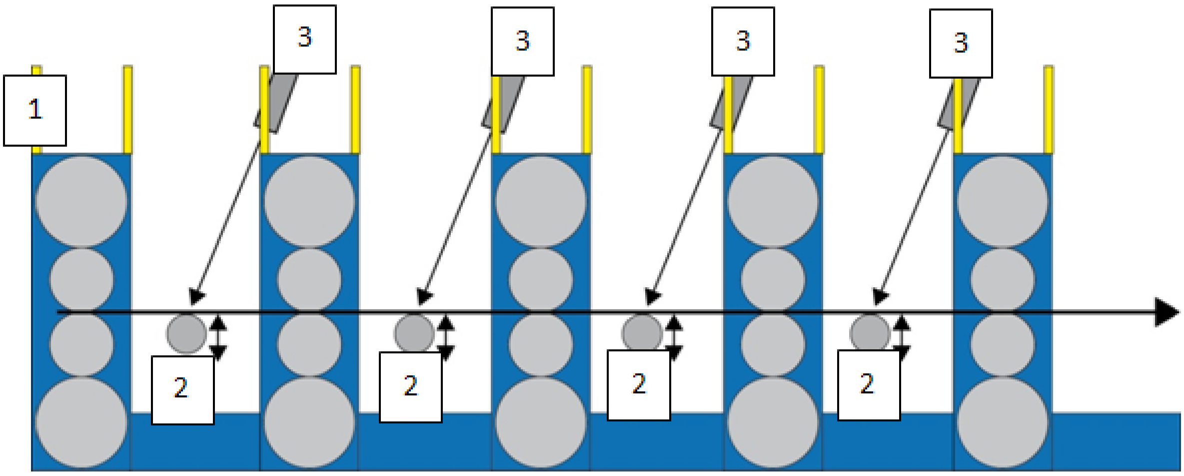

Figure 2: EMG hotCAM in a finishing line: mill stand [1], looper [2] camera position [3].

For a reversing mill, the camera location is at the top of the mill stand with a viewing area covering a larger part of the rollout table. A principal sketch is shown in Figure 3.

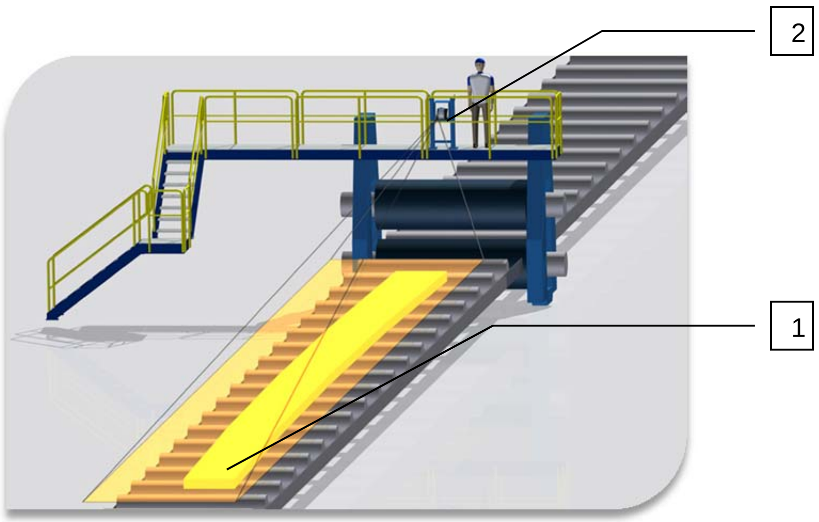

Figure 3: EMG hotCAM in a reversing mill: viewing area of the camera system [1], camera unit [2].

Based on intelligent image analysis the system delivers accurate values for the position of the strip edges, the center line position, the calculated strip width and for camber measurement the calculated strip camber.

3 RESULTS

3.1 Camera Technology

The system is equipped with a CMOS (Complementary Metal–Oxide–Semiconductor) area scan cameras as an alternative to CCD cameras (Charge Coupled Device). CMOS devices generally consume less power than CCDs, have less image lag, and require less specialized manufacturing facilities. Unlike CCDs, CMOS sensors can combine the image sensor function and image processing functions within the same integrated circuit. They have also been used in other fields including digital radiography, military ultra high speed image acquisition, security cameras, and optical mice. One main benefit of using CMOS cameras in this application is its immunity to the blooming effect where a light source has overloaded the sensitivity of the sensor, causing the sensor to bleed the light source onto other pixels.

EMG hotCAM uses the near infrared spectrum to detect the edges of the hot moving strip. This leads to an image of the strip which is clearly distinguished from the environment with high contrast: The environment is dark compared to the infrared radiation of the strip/slab (see figure 4). Furthermore the image is robust against non-thermal radiation (environmental light).

The system uses near infrared radiation emitted at approximately 820 °C and above because the strip emits approximately 250 times more light at 850 nm (near infrared) then at 640 nm (visual red). The camera sensitivity goes up to a wavelength of 1000 nm. A typical camera image is shown in figure 3 together with the region (ROI) of interest utilized for the image processing algorithms. The observation length in strip direction is approximately 20 cm.

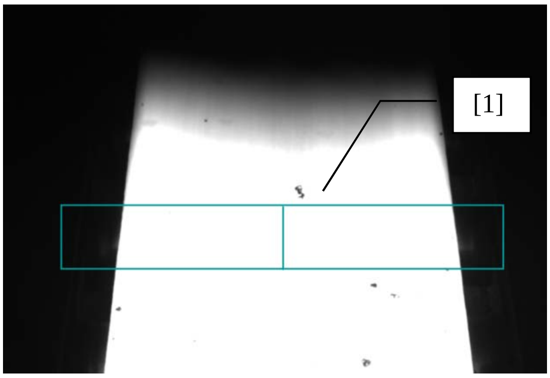

Figure 4: Typical camera image of EMG hotCAM with ROI [1] for the application between the mill stands.

3.2 Image Analysis and Software

For the position measurement, the region of interest (marked with „1“ in figure 4) is cut from the overall image for further processing. The image is divided into two parts, and the information is processed and filtered. After pre-processing of the image, intelligent mathematical algorithms are applied for robust and reliable distortion suppression in order to compensate e.g. for vapor and dust, and an edge extraction is executed on the images of the strip. After this correction and considering the actual

height position of the looper as well as considering the actual size of the rolling gap, hotCAM determines the strip position between the rolling stands and the strip width with high accuracy.
The image data are additionally corrected with respect to the viewing angle and the keystone distortion (trapezoidal distortion, see Figure 6).

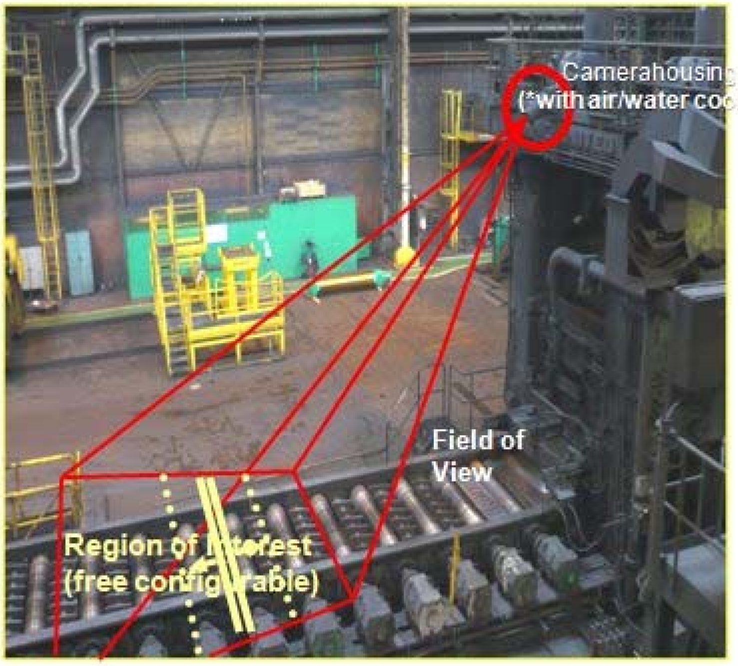

Figure 5: Viewing area and keystone distortion after the last stand in finishing line.

The calibration of the system is performed during a mill still stand with the aid of calibration marks and a calibration plate imitating the strip position. During production the position and adjustment of the camera is checked as well. Therefore some optical marks are placed in the viewing field of the camera. The position of these fixed marks is known. After each produced coil the position of the camera is checked based on these marks. Possible deviations from the initial calibration are automatically corrected by the software.
The software and algorithms have been developed by Tata Research &Technology, IJmuiden, the Netherlands and the productizing has been performed by EMG Automation GmbH. The system software is based on a real time operating system (Phar Lap), which guarantees consistency of the time signals and therefore a deterministic timing for the image analysis and the further processing.

3.3 Measured Data and Accuracy

Basically the system extracts the strip edges out of the acquired images. All other data are derived from this basic data set. Finally the following data are available:

- Position of the strip edges
- Center line position
- Strip width
- Strip camber (in case of camber measurement)

The accuracy of the center line position measurement is +- 1.5 mm for the measurement between the mill stands and +- 2 mm for the long viewing distance for camber measurement.

The normal operation does not require a graphical interface, because resulting data like camber or strip position are directly transferred to the process control level computers. However, for configuration, administration, or monitoring purposes a user interface is available. The user interface allows the display and monitoring of the relevant information. The resulting data (strip position and width) finally are transferred to the process control system. These values are available for automatic online or semi automatic control of the rolling stands. Storage of images or video sequences is also possible. Figure 6 shows a typical screen for position management. In the hotCAM position measurement the edge positions of the strip are displayed together with the calculated centerline position of the strip and the strip width value. By this the operator has direct indication about the rolling process and can decide to take measures if necessary.

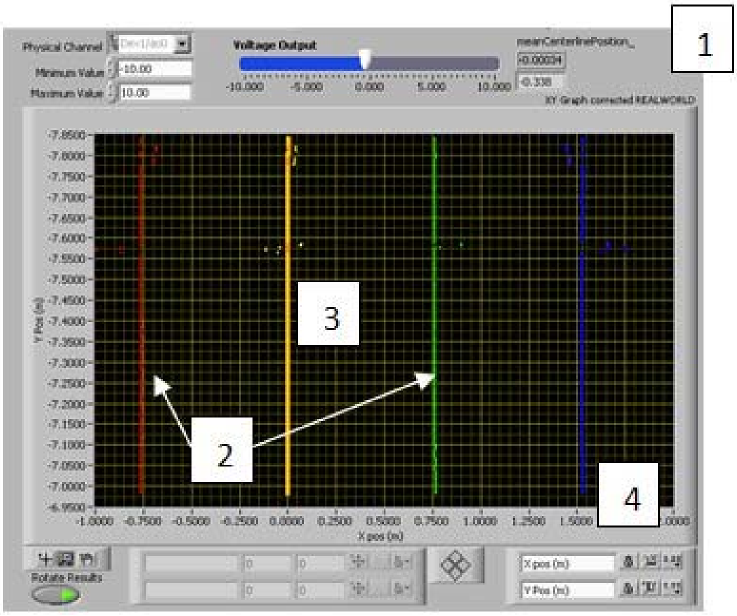

Figure 6: EMG hotCAM user interface position measurement [1], position of the strip edges [2], center line position [3], calculated strip width [4].

For the camber measurement, the user interface allows an easy recognition of the strip camber (Figure 7). The edges of the strip/slab are displayed together with the calculated centerline position and the camber value. The operator by this has a direct indication about the quality of the rolling process and can intervene accordingly.

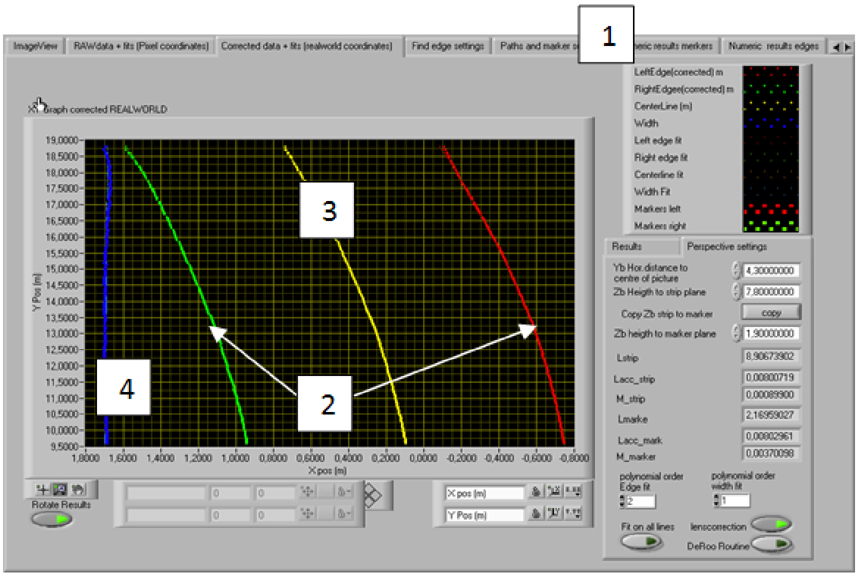

Figure 7: EMG hotCAM user interface camber measurement [1], position of the strip edges [2], center line position [3], calculated strip width [4].

3.4 System Architecture

The hotCAM system consists of four main components which provide the camber and position measurement functionality and the system monitoring and control tasks assuring the proper functionality of the overall system (Figure 8).

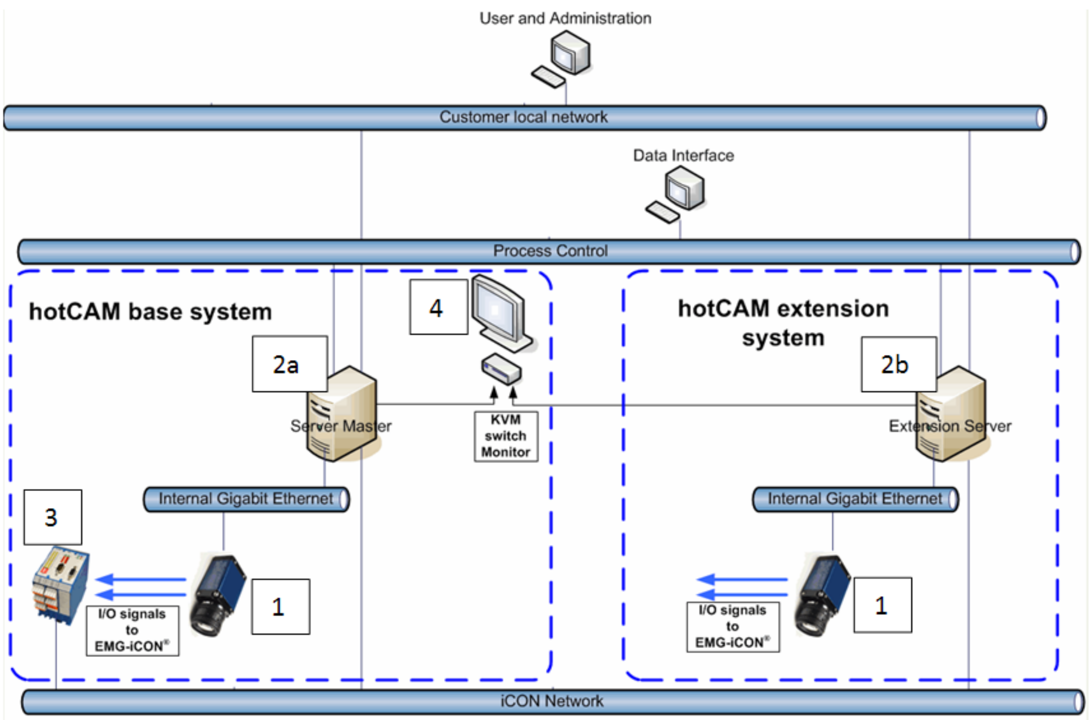

Figure 8: EMG hotCAM system architecture [1] Camera module, [2a] Server PC (Master) with software licence hotCAM operation, [2b] Extension server PC with software licence hotCAM connector, [3] EMG-iCON® electronic control unit, [4] KVM Monitor.

The hotCAM base system comprises all functional components necessary for the complete operation of the respective application. A camera module [1] takes the images and feeds them to a server PC. The EMG hotCAM operation software runs on the server PC [2a], processes the images and provides the resulting data like camber value or strip position to the process control level. A connection to the customer local network is provided for further visualization and monitoring of the resulting data or for administrative purposes. In principle it is possible to store the original images on demand.
The hotCAM extension system comprises the same main components – camera module and server PC with hotCAM connector software [2b] – as shown in figure 7. The extension system slightly differs from the configuration of those of the base system; however the general functionality regarding the position measurement application is the same. For each camera one server PC is necessary. In addition are monitoring components and control elements which are assuring the proper functionality of the cameras and of the overall system. The EMG-iCON® electronic control unit [3] is monitoring and controlling the overall system and the KVM monitor [4] is directly connected to the server PC for server administration and application viewing.
Due to the relatively large distance of the cameras to the hot strip the camera module [1] requires in most cases only simple cooling with compressed air. Water cooling can be applied optionally without changes in the housing.

4 DISCUSSION

4.1 Application Results

The system is applied in the finishing mill of the DSP (Direct Sheet Plant) at Tata steel IJmuiden, the Netherlands. The first installation took place at the exit of the finishing mill at the last rolling stand (see also: Figure 5). The following graphs show exemplary results of the measurement in different situations.

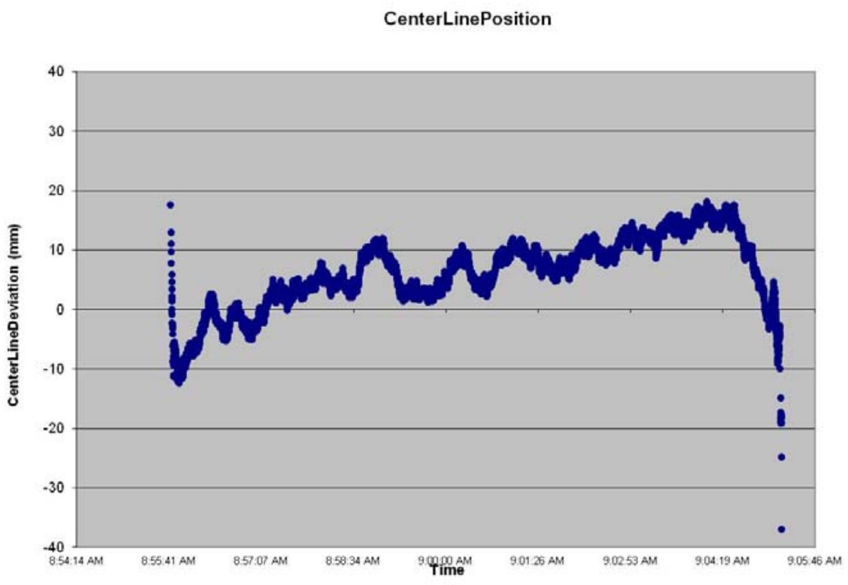

Figure 9: EMG hotCAM: center line deviation in mm of one slab / strip during processing.

The strip behavior with respect to the center line deviation is shown in Figure 9. The center line varies from -0.01 to 0.02 m with small variations around a mean value.

The big deviations at the beginning and at the end of the strip reflect head and tail of the strip and the normal variations of the strip shape in these sections.

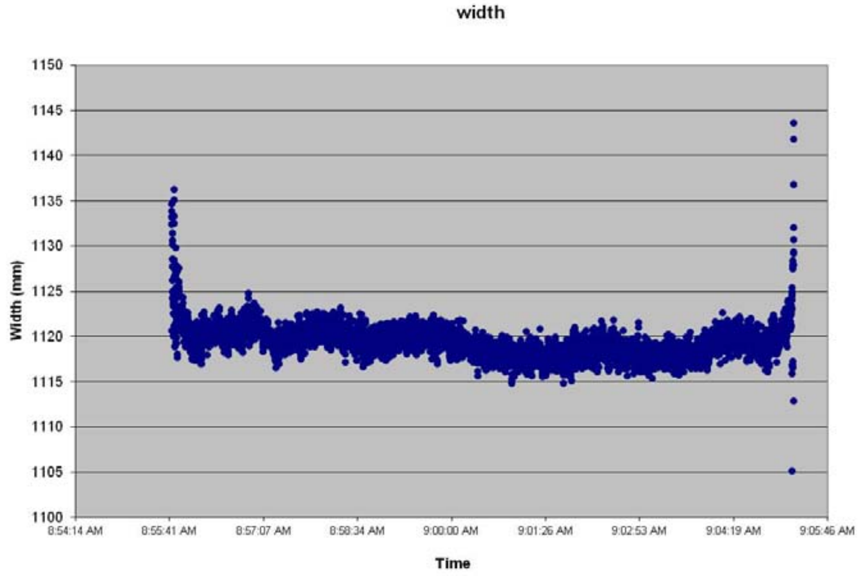

Figure 10: EMG hotCAM: width measurement in mm of the same strip.

The width measurement results for the same strip are shown in figure 10. The measurement accuracy is influenced by the optical measurement accuracy, vibrations of the line, and temperature influences.

Finally Figure 11 shows a cobble event which in future could have been avoided by early interaction with the mill automation system.

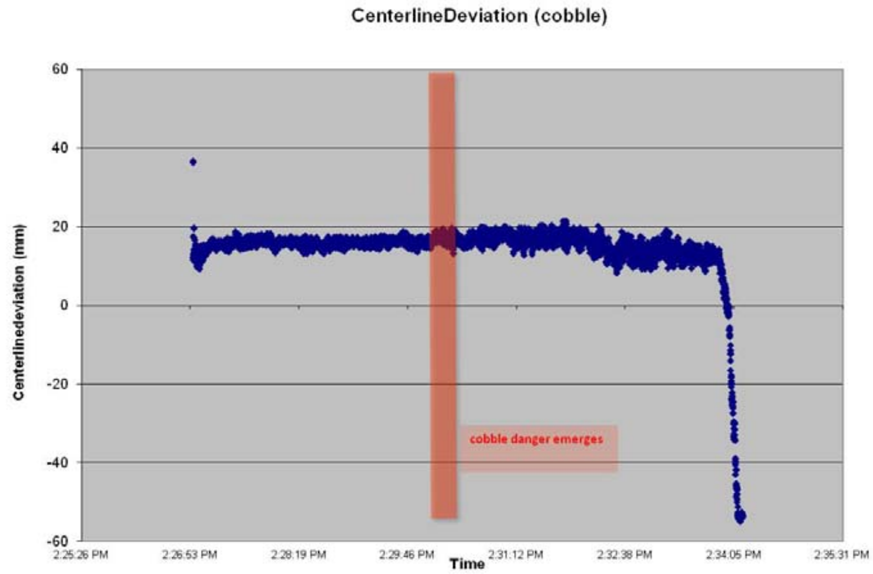

Figure 11: EMG hotCAM: measurement of the center line deviation and cobble formation.

Approximately 4-5 minutes before the cobble finally emerged the center line deviation became unusual. This would allow manual or semi-automatic control measures to prevent such an event.

The DSP mill at Tata Steel Ijmuiden is now equipped with 4 hotCAM extension systems (in total 5 systems) to allow a complete follow-up of the strip processing at each mill stand. During the first year of operation no manual cleaning of the base system was necessary. The system has been used also for successfully testing the camber measurement at the exit of the last rolling stand (see Figure 5 and Figure 7).

4.2 User Benefits

Based on the experiences so far the benefits of applying the hotCAM technology can be summarized as follows:

- The system delivers reliable and accurate position and/or camber data in hot mill applications
- It provides basic data which allow the mill operator or the automation system supplier to realize an automatic closed-loop control of the rolling mill
- It provides the necessary information for the operators to optimize the rolling process with respect to the avoidance of critical situations (e.g. cobbles or mechanical collisions with the guide rails) and to keep the strip in the center position between the stands
- It provides accurate camber measurement data allowing the operator to improve the strip shape and the coiling quality
- There was no need for maintenance or cleaning tasks during the first year of operation

5 CONCLUSION

EMG hotCAM has proven its stability and industrial suitability in extensive test at a TATA hot mill in IJmuiden, the Netherlands. The system can be applied in finishing lines for the position measurement between the rolling stands and for camber measurement after the last rolling stand as well as for camber and position measurement in reversing mills. It is scalable with respect to the number of rolling stands to be equipped. The installation of multiple cameras can be performed in one step or successively.

The system is easy to manage only low or no maintenance. With the utilization of CMOS cameras having superior image quality characteristics in comparison to CCD camera based systems, it provides a new, robust, and reliable alternative to CCD camera based systems in the described application scenario.

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