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Optimization-based estimator for the contour and movement of heavy plates in hot rolling

F. Schausberger*, A. Steinboeck, A. Kugi

Automation and Control Institute, Vienna University of Technology, Gußhausstraße 27–29, 1040 Vienna, Austria

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ABSTRACT

This paper deals with the estimation of the contour of heavy plates during the hot rolling process. Asymmetric rolling conditions lead to a non-rectangular contour. The reasons for this effect, e.g., temperature gradients or non-homogeneous input thickness profiles, are hard to predict in a real rolling mill. Hence, feedforward compensation of these disturbances is difficult, whereas feedback control could be a suitable means for improving the plate contour. Feedback control essentially requires the actual contour of the plate, which has to be measured or estimated in real-time. The method presented in this paper suggests to capture an image sequence of the plate by means of a thermographic measurement device. In the considered application, an image sequence is required because the whole plate contour cannot be captured by a single image. An optimization-based algorithm takes into account the image data and the restrictions of the plate movement in the rolling gap and uses this information to estimate the actual plate contour. In addition, the algorithm estimates the angular velocity and the speed of the plate. Measurement data from a heavy plate mill is used to validate the effectiveness of the proposed method.

1. Introduction

1.1. Measurement of the plate contour

In heavy plate mills, the thickness of the incoming steel slabs is successively reduced to the desired final plate thickness in several rolling passes at the mill stands. A major quality criterion of the final product is the shape of the resulting contour, i.e. the shape of the plate from the top view. Ideally, this contour is rectangular to maximize the usable area of the plate. A deviation from the desired contour with respect to the vertical axis of the plate is called camber (cf. Fig. 1). This may be caused by asymmetric rolling conditions, e.g., temperature gradients of the plate or non-homogeneous input thickness profiles. Minimizing the deviation from the desired plate contour is one main objective of the rolling process.

An important aspect in the design of measures to prevent the generation of shape defects is the detection of the actual plate contour. A precise knowledge of the contour (longitudinal boundaries and shape of the head and tail end) can be used to optimize the adjustment of the rolling mill to reduce the camber. Simply measuring the whole plate contour at once, e.g., by means of edge detection of an image of the plate, is not possible in the considered application due to the following reasons:

- The contour of the plate is partly covered by plant components.
- The measurement should be performed during rolling in real-time.
- The length to width ratio of long plates is very different from the aspect ratio of common cameras.

Furthermore, the measurement of the contour should be carried out as near as possible to the rolling gap because:

- Short plates should also be captured.
- The time delay between the generation of a camber and its measurement should be kept to a minimum.

Therefore, the detection of camber must be conducted during the rolling pass itself and close to the rolling mill. At this position, the harsh environment may deteriorate the accuracy and robustness of measurements. Also the lateral and rotational movement of the plate, which is ignored in many published contour estimation procedures, makes contour detection difficult. In case of pure longitudinal movement, the contour could be obtained by simple integration of the plate velocity leading to the plate position and

* Corresponding author. Tel.: +43 1 58801 376231; fax: +43 1 58801 9376231.
E-mail addresses: schausberger@acin.tuwien.ac.at (F. Schausberger), andreas.steinboeck@tuwien.ac.at (A. Steinboeck), kugi@acin.tuwien.ac.at (A. Kugi).

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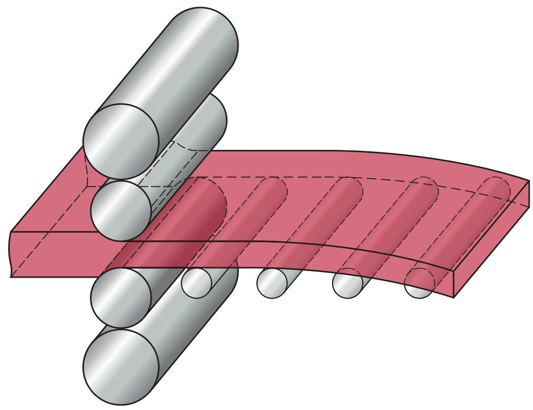

Fig. 1. Sketched rolling mill with roller tables and rolled plate with camber.

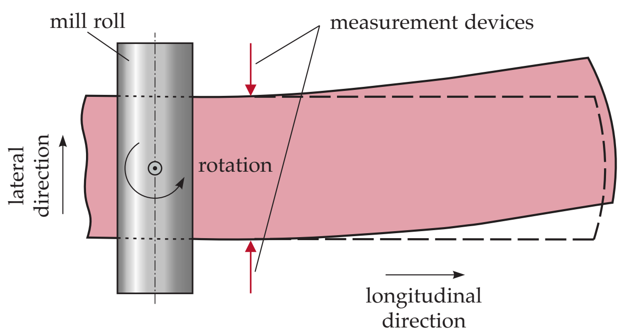

Fig. 2. Measurement setup providing insufficient data for the estimation of the longitudinal boundaries of the plate. The solid line represents a rotating plate with camber. A rectangular plate with pure longitudinal movement is shown as dashed lines. Both contours may lead to the same signals of the measurement devices, which are located at a spatially fixed position.

using measurement signals gathered at a spatially fixed position. Under real rolling conditions, this approach is infeasible because the plate is clamped in the rolling gap so that it may also rotate in addition to its main longitudinal motion (cf. Fig. 2). The possible rotation of the plate during the rolling process also complicates the detection of the contour.

1.2. Existing solutions

The use of three devices to measure the lateral position of the plate downstream the mill is discussed in [1]. Based on these measurements, a polynomial representation of the actual plate profile is estimated and used for feedback control to reduce the occurring camber by modifying the output thickness wedge.

Soaring computer performance enabled the usage of image processing techniques as proposed in [2], where three 2D-CCD cameras capture neighboring areas of the plate. In this camera configuration, the acute angle between the plate surface and the optical axis of the camera requires a precise calibration of the camera to accurately reconstruct the real image. After this preprocessing step, a customized edge detection routine is employed to estimate the edge of the plate. The detected edges of neighboring images are joined based on the longitudinal speed of the plate and to ensure C_1-continuity of the estimated plate edges. A very similar approach using just one camera to estimate the centerline of the plate is discussed in [3].

Also in strip rolling, 2D-cameras are used to track the lateral position of the strip during the rolling process. Carruthers-Watt et al. (cf. [4]) used measurements from several cameras between the mill stands to determine the lateral position of the strip in the finishing train of a hot strip mill. The edge is identified as maximum of the gradient of the intensity of the image in the lateral direction and parameterized using Bezier curves. A similar measurement setup and a mathematical model of the lateral position of the strip for steering control is discussed in [5]. In fact, an H_2 controller that is robust against heterogeneous properties of the different rolled products was designed using the tilts of several mill stands as control inputs.

An algorithm tailored to the stitching of several images of the plate was developed in [6–8]. Common feature points are identified on two consecutive images to determine the displacement between the images. They are captured by a CCD camera. Ollikkala et al. (cf. [9]) used a very similar approach. However, in this solution the inclined viewing angle of the CCD-camera requires a perspective correction of the recorded images. After this image rectification step, an edge detection algorithm is used to extract the boundaries of the plate.

1.3. Motivation and objectives of this work

The existing solutions for the detection of the plate contour are mainly based on adequate image processing. In most published works in this field, neither lateral nor rotational movements of the plate are considered. The knowledge of the restrictions of the movement of the plate during the rolling process is also not taken into account, which may lead to reduced accuracy of the contour estimation.

Additionally, the angular velocity is linked with the lateral movement (snaking) of the plate in the rolling gap. This movement may lead to an eccentric position of the plate in the lateral direction. Because of the resulting asymmetric loading of the rolls, the knowledge of the evolution of the lateral position of the plate is also vital for the necessary adjustment of the rolling gap actuators.

Furthermore, the estimation of the longitudinal speed of the plate, which is required for the detection of the contour, is not covered in many works. Usually, the speed of the plate is calculated using a mathematical model (forward slip model) and measurements of the angular velocity of the rolls of the mill, see, e.g., [10]. This in general results in an error prone speed of the plate due to inaccuracies of the slip model and therefore in an additional error of the estimated contour. Hence, a method to determine the plate velocity more accurately seems favorable in terms of the contour detection.

All these facts were the motivation to develop a new method to estimate the contour of heavy plates in hot rolling. The current work aims at:

- Accurate and robust estimation of the contour (longitudinal and lateral edges).
- Investigation of the influence and estimation of the movement of the plate (rotational and lateral motion).
- Precise estimation of the longitudinal speed of the plate.

The estimation of the plate contour has to respect several constrains:

- Harsh environment near the rolling gap.
- Real-time implementation of the contour detection algorithm.
- Small time delay between the generation and estimation of the plate contour.

The presented aspects and requirements make the contour detection a challenging task in terms of acquisition and processing of measurement data. This paper gives, in contrast to common image processing methods, an observer based approach utilizing