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STRIP EDGE DETECTION IN HOT ROLLING MILL
Steering control at Arcelor EKO Stahl finishing mill

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INTRODUCTION

The lateral movement of the strip through the hot strip mill may induce rolling incidents such as edge damages, tail and pinching and as a consequence a decrease of the product quality and damage of the rolls. Hot strip mills (HSM) plans to reduce these defects to improve the reliability and the quality of the process. The strip off centring is characterized by a lateral displacement of the product versus the stand-rolling axis. This is the consequence of rolling asymmetries either linked to the stand, such as differential stand stretching or tilting of the work rolls or due to product asymmetries such as wedge (strip thickness profile) or thermal differential profile.

This paper describes a body strip steering control applied on the finishing mill of ARCELOR Eisenhüttenstadt. This industrial implementation is extended on the whole finishing mill using Strip Off-Centre (SOC) measurement in all inter-stands. Eisenhüttenstadt HSM is a 5-stand finishing mill with a transfer bar coll-box at the entry, which generates significant strip off-centre perturbations. Industrial tests of the control showed its very good performances. To reach this control efficiency, a Matlab / Simulink SOC model was developed, which was tuned for Eisenhüttenstadt HSM, linearised and simplified.

STATE OF THE ARTS

Before 1998, the major contributing papers describe steering control theories based on differential force measurements [ref 1]. The main advantages of this kind of control are the low implementation and maintenance cost. On the other hand, these types of strip steering controls are not reliable because the law linking the differential of force measurement and the strip off-centre is too complex to obey a simple command law. Industrial suppliers usually propose such a control using proportional controller. Also, the differential force is supposed to be the strip off-centre image and the stand tilting correction is proportional to it.

More accurate but based on the same principle, some interesting papers written between 1998 and 2004 describing steering control in hot rolling [ref 2] [ref 3] [ref 4]. These controls are based on strip off-centre model and the controller is PID type (Proportional Integral Derivative). In the same frame, a Japanese patent [ref 5] develops a non-linear command using the slipping mode control theory.

STUDIES AND TOOLS FOR THE BODY STRIP STEERING CONTROL

Various tools were developed to perform the steering control industrial implementation in cooperation with CRAN/ENSEM (Nancy, France). They were designed for the Eisenhüttenstadt HSM, but they can easily be adapted to another hot strip mill.

Today, the following tools under MATLAB/Simulink software are available:

- A strip off-center model which was tuned, linearized, simplified and validated for the Eisenhüttenstadt finishing mill;
- A strip off-center measurements treatment simulator;
- A stand tilting commands simulator that, through a user-friendly interface, enables to calculate offline the gain matrices that will ensure the control in the plant and to evaluate their performances;
- A full simulator which is the connection between the two previous ones;
- An EXCEL function, which gives indicators to evaluate the control industrial performances.

Strip off-centre model tuning, linearisation, simplification and validation

The strip off-centre model results from the superposition of various relations. The principle is shown in figure 1. For 1-stand, we take into account the coupling between the stand and the strip on the front side.
Figure 1: principle of the strip off-centre modelling

The used variables are:

- **SOC<sub>i</sub>**: strip off-centre at the stand i
- **SOC<sub>i-1</sub>**: strip off-centre at the preceding stand i-1
- **F**: lateral force at the support point i-1
- **θ<sub>i</sub>**: strip angle at the stand i-1
- **h**: strip thickness
- **w**: strip width mm
- **l<sub>i</sub>**: distance between two stands in mm
- **T<sub>AM</sub>**: mean of front stand strip tension
- **Δt**: differential of strip tension
- **l<sub>v</sub>**: distance between screw down actuators

The governing equations are:

- The mechanical equilibrium in the stand:
  
  
  \[
  \Delta F = f(\Delta P, SOC) \rightarrow \text{Mechanical equation}\quad (\Sigma F=0 \text{ et } \Sigma M=0)
  \]

  
  \[
  \Delta F = \frac{1}{l_v} SOC + \frac{w}{6l_v} \Delta P + \frac{2}{l_v} P SOC
  \]

  
  The differential rolling force (ΔP) is derived from the solution of the Sims roll gap model

- The stand stretch model to calculate the exit stand wedge: Δhs = f (ΔF, ΔS, ΔP, ΔK)
- The strip off-centre given by: SOC = f (Δt, Δhe, Δhs)
- The tension differential Δt results from an elastic beam calculation;

The main asymmetries taken into account are the following:

- The strip off-centre (SOC)
- The entry wedge (Δhe)
- The stand tilting (ΔS)
- The differential stand stretch (ΔK)
- The front/back stand differential of strip tension (Δt)
Today, a five-stand body strip off-center model is working under Matlab/Simulink (figure 2), which was tuned for Eisenhüttenstadt HSM, linearized, simplified and validated. The tuning is done by coefficients per stand, which are adapted to the plant, based on measurement campaigns. During the trials one or more stands were tilted and the reaction of the SOC and Wedge was measured. The tuned model gives a good agreement with the majority of Eisenhüttenstadt HSM products.

It is important to notice that this model is easily adaptable to any plant. However, its tuning will require industrial trials with one gauge per interstand region, and the development of a specific database to analyse them.

![Simulink schema of the SOC model (only the first two stands are represented).](image)

**Figure 2: Simulink schema of the SOC model (only the first two stands are represented).**

**Strip steering control for body part, simulations results**

The aim of the control consists in reducing the SOC through appropriate stand tilting commands taking into account the whole mill behaviour. It induces an improvement of the mill exit wedge and a decrease of incidents when the strip hits the side guides. To precede this work, the non-linear SOC model of Eisenhüttenstadt finishing mill was utilised to compute the appropriate tilting commands $u$.

$$ u = -Gx \quad \text{With} \quad x = (SOC_{11}, SOC_{12}, SOC_{13}, SOC_{14}, SOC_{15}) \quad \text{and} \quad G \quad \text{the control gain} $$

Then applying them to the simulator and observing their effects on the strip off-centre at the mill exit wedge the control law was evaluated. For all simulations real disturbances measured on plant were used.

Figure 3 shows the applied commands and the resulting strip off-centre in each interstand for a mean strip size and compares the results with and without control. The first five plots show the strip off-centre, and the sixth the mill exit wedge.

Notice that these simulations are realized with average gains, which are valid for the average product mix, and then that command saturations were inserted in the simulator in order to be closer to the plant reality (safety saturations).

For a majority of products (80% of them), it was possible to decrease the SOC and reduce the wedge below ten micrometers by applying unsaturated stand tilting commands. Furthermore, these corrections are small in stand 4 and stand 5 is not tilted, in order to minimize the effects on the exit wedge.
Figure 3: Simulation results for the mean product: the SOC is divided by more than two and the maximal mill exit wedge is almost null against 22 microns without control.

INDUSTRIAL IMPLEMENTATION

Body strip steering control implementation specifications

The following parts give all the steering control functions to implement at each plant level concerned (figure 4). An intermediate one was added at Eisenhüttenstadt HSM. It is composed of a personal computer (named SC), which is dedicated to the steering control. It receives and treats the SOC measurements, elaborates the stand tilting corrections and sends them to the stand PLC for application on the mill.

The implementation at Eisenhüttenstadt HSM

The system consists of four cameras, the controlling computer and the data connection between the different parts. For the selection of the cameras, the experience learned during previous trials at the Dunkirk HSM, was considered. The main requirements for the cameras are: tough mechanical design, especially the mounting of the lens and the sensor and a suitable case for the camera as well, aperture correction and gradient-based edge detection. Several camera systems were tested. Finally system DAC004 delivered by Fife was chosen. The number of the camera-pixels is 7500 and provides a solution of approx. 0.24 mm per pixel.

Different installation positions of the cameras were tested. It was important to install the camera outside the operating area of the crane and preferably behind existing mechanical protection shields. The mounting at cantilever beams should be avoided, in order to avoid oscillation. The position should be approximately orthogonal to the strip surface. The viewing area of the camera has to be considered as well, because good brightness contrast to the background is necessary, which means no illuminated objects such as rolls or side guides in the region. A suitable location was found at the cross bar at the mill stand entry, behind the cobble shields, where some additional windows were
installed. The cameras are mounted on dedicated vibration absorbers to protect the device from high accelerations. A water-cooled housing protects the cameras.

![Steering Control System Diagram](image)

Figure 4: Information global processes at ARCELOR Eisenhüttenstadt HSM.

The camera is connected by Profibus for the data exchange with a cycle time of 5 ms. For service functions an additional RS422 connection is used. The Control system is linked to stand PLC by means of Profibus as well, utilizing a DP/DP connector, which is running in a 100 ms cycle. This speed may be increased, which might be necessary for the tail out control.

The controlling system consists of a 3 GHz Intel-P4 standard personal computer with integrated PROFIBUS interface and four RS422 service interfaces. The system was developed in the C++ language and is running at the Operating System Windows XP. TCP/IP using an Ethernet connection realizes the communication to Level II system.

Filtering, active pixel selection and edge detection are done by FPGA, which are located directly in the cameras. The main advantage of this principle is the reduction of the data transfer. The edge detection algorithm is based on the gradient analyses where the detection direction is symmetric for both sides.

The algorithm is only working on predefined regions of interest, which are derived from the set up data of the mill. Non-linear deviations of the optics are corrected using calibration data. The exposure time is automatically controlled depending on the contrast in the regions of interest.

After transmission to the controlling system the measured data will be plausibility checked and the measurement error coming from the strip height variation is compensated. In parallel, several checks are applied to the data, e.g. the monitoring of the linearity of the device characteristic and the observation of the edge gradients sharpness. Based on this information the parameters of the edge detection algorithm are adapted in order to compensate environmental influences, for instance vapour or water drops. This allows us to get realizable results even within highly polluted environments.

During the operating phase of the controller the SOC values are multiplied by the corresponding gain values. In order the get the tilting command. After applying security functions, the commands are sent to the stand PLC, where the additional tilting is added to the initial tilting signal. If the operator manually changes the tilting, the additional tilting command is forced to zero, using the same ramp as
the tail end. This is a security measure in order to return to a known working set up and should be unnecessary after final commissioning of the controller.

The material tracking system, which is based on strip position signals coming from stand PLC, manages the controller operation.

In order to prevent sudden changes in the stand levelling, for the on and off switching of the controller, predefined ramps are used. These ramps are considered as a temporary solution, till the 2nd step of the project is working, the steering control until tail out.

For the evaluation of the controller some indicators are calculated and stored in a database, together with a pile of other data, which should help in the implementation and tuning of the algorithm, for instance the set up values and the used controller gains. For the observation of the operation and to adjust the controlling parameters, a HMI was designed.

BODY STRIP STEERING CONTROL ON-LINE PERFORMANCES

In June 2005, industrial trials were started at Eisenhüttenstadt HSM. They aimed at demonstrating the industrial feasibility. For safety reasons these trials were made gradually, stand-by-stand. Later on, in September and October 2005, three trial campaigns were realized to test the steering control actuator and evaluate its performances. The main results are:

- 151 controlled strips of different sizes and grades were rolled,
- No rolling incidents occurred;
- The operators confirm the good control effect in terms of SOC.

The results are striking:

- The strip lateral movement of about 80 mm was decreased by more than 70%,
- The body strip wedge was confined between ± 10 micrometers;
- The standard deviation of the wedge was divided by two.

Decreasing the body strip lateral movement

In order to illustrate the operational results, figure 5 shows the peak-to-peak SOC magnitudes in each interstand for two consecutive strips of the same size (1574 x 4 mm) and steel grade. The first strip was not controlled whereas the second was. The initial SOC in the first interstand was roughly the same. Therefore the results can be compared.

Two distinct behaviours are clearly demonstrated: for the uncontrolled strip, the SOC increases from stand to stand and the decrease observed after stand 5 is due to the big distance between the last gauge and the mill exit and also to the effect of the run-out table which centres the product. On the contrary, when the strip is controlled, the SOC decreases from stand to stand to reach a magnitude of 17 millimetres instead of 59 mm without steering control in the last interstand. The strip off-centre is reduced by more than 70%.

![SOC magnitudes](image)

*Figure 5: Strip off-centre results behaviours with and without steering control.*
The link between SOC reference and wedge

During industrial trials it was shown that the SOC reference of the controller and the average wedge at the exit of the finishing mill was linked. Indeed, according to figures 6, we must impose a reference around 3 mm to get a zero wedge at the finishing mill exit.

**Average wedge - Thickness classes matrix**

![Diagram](image)

SOC reference

*Figure 6: A reference around 3 millimetres provides a zero wedge.*

**CONCLUSION**

An original Matlab/Simulink strip off-centre model has been developed and tested in Eilsenhüttenstadt HSM of ARCELOR. Very good operational results have been obtained:

- Decrease of the body strip lateral movement by more than 70 %
- Restriction of the strip wedge between ± 10 µm
- Reduction of the wedge standard deviation by 50 %

Several robust and user-friendly tools was developed that can easily be adapted to any plant. They can even be handed over to the plants to let people update the controller themselves.

The most critical point is that stand tilting trials are required in order to tune the model. Such trials are not difficult to conduct but require the implementation of one off-centre gauge per interstand. For instance by using portable gauges.

**BIBLIOGRAPHY**

[ref 1]: Application of steering control in hot strip mill
Furukawa,Y
Tetsu to Hagane, Vol 78 (1992) T141-T144

[ref 2]: State feedback control of the strip steering for aluminium hot rolling mills
Yoshihide Okamura, Ikuya Hoshino

[ref 3]: Development of steering control system for reversing hot mills
Steeper MJ, Park GD
Iron and Steel Engineer (USA), vol. 75, no. 11, pp. 21-24, Nov. 1998

[ref 4]: Advanced control method of steering on the hot rolling mill
Yoshihiro Marushita & all
IFAC, 10th conference MMM2001, Tokyo, septembre 2001

[ref 5]: Method and device of plate steering control on rolling mill
Nobuyasu OKADA, KAWASAKI STEEL CORP.