Slab curvature compensation in a Hot Rolling Mill by means of Fuzzy Control

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Abstract

In the flat products steel industry, the **hot rolling mill** transforms the incoming slabs in a thin coil which then can be processed to obtain the final products. Thickness is reduced by pulling the plate between two parallel rolls while moving the upper work roll. The effect of uneven thickness at both sides can produce deviations in the longitudinal direction of the slab, which have to be manually compensated for an human operator. In this paper a multivariable control system and a **fuzzy control** system are described and compared. Results are illustrated with real data from ACERALIA STEEL CORPORATION.

Keywords: Metal Industry, Rolling

1 Introduction

The purpose of this paper is to describe the design and implementation of a supervisory system for the real-time compensation of uneven thickness on both sides of a rolled strip. This supervisor systems is going to be used in the existing hot rolling mill at Aceralia Steel Corporation, in order to improve the rolling quality.

In a hot rolling mill the plate thickness is reduced by pulling the plate between two parallel rolls while moving the upper work roll, see Fig. 1. The unloaded roll gap is related to the plate output thickness. The total reduction is achieved in a series of passes. For each pass the unloaded roll gap is calculated and adjusted using mechanical screws.

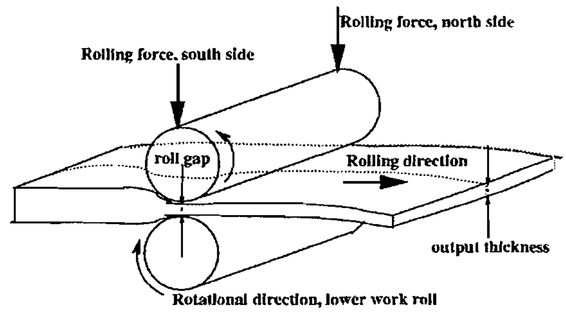

Figure 1: The rolling process, side view. The plate moves from left to right, and the upper roll moves up and down. The gage between rolls defines the output thickness of the plate.

While the material is being rolled, and in order to keep the output thickness on range, Automatic Gauge Control (AGC) systems are applied. The AGC corrections are implemented using hydraulic positioning systems. The objective is to correct deviations from the intended gauge objective; deviations which can be classified in two groups: related with irregularities in the material (input thickness, temperature) or with the equipment (roll eccentricity, rolls thermal deformation).

Most of operating hot rolling mills in industry are designed using single input–single output (*SISO*) models considering the mean value of the thickness. The effect of uneven thickness at both sides can produce visible deviations in the longitudinal direction of the slab, which has to be manually compensated for an human operator. Such correction is made by adjusting a *tilting* signal, in

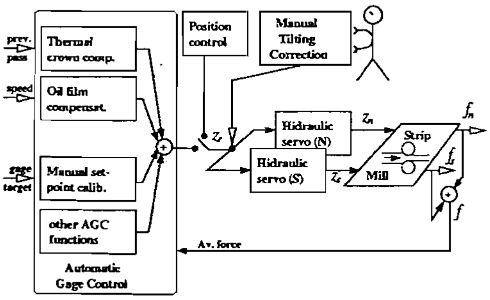

Figure 2: Building blocks of an **AGC**. The human operator controls the unevenness position of the rolling cylinders

order to produce a difference reference signal to the hydraulic actuators on each side of the mill. This manual correction is a tedious task and error prone, as is based on visual inspection in order to compensate deviations when they are big enough to be detected. This project was aimed to the design and implementation of a computer system to automatically generate the *tilting* signal from the mill operation data, leading to a reduction in the error rate, and an improvement in the final output strip quality.

2 Hot Rolling Mill

The *Hot Rolling Mill Train* transforms the bars coming from the Steel Mill in a thin strip coil. The incoming bar thickness is between 230mm and 250mm, and the final outgoing thickness must be between 1.5mm and 20mm. The process sequence begins when the slab is introduced in the **Reheating Furnaces**, in order to achieve an uniform temperature (1250°C). After the reheating the slab goes to the **Hot Rolling Mill** where it is reduced to only 5cm. The **Finishing Mill** does a final reduction, in this mill the critical point is the flatness control; and finally the process ends with the cooling and coiling of the strip.

One of the most disturbing defects with are caused by the hot rolling mill is the **camber** defect (see Fig 3), where the unevenness thickness profile causes a longitudinal deviation of the strip. This deviation causes stops in the rolling train, due to the clogging of the strip in the finishing mill. In order to correct this problem, the *rolling control system* must take into account the unevenness thickness profile of the slab [5].

Figure 3: The scheme shows the **camber** defect. The radius of curvature of the slab is the most usual measure unit of the camber defect.

The rolling mill includes three mechanical control elements: The lower backup roll axis can be adjusted using a set of **wedges** to assure an horizontal rolling line; the upper working roll is displaced by an **mechanical screw**, whose position is fixed according to the thickness reduction planning; and an **hydraulic system (SERMES)** adjusts the upper working roll position along the pass in each side, in order to achieve the expected thickness profile. This hydraulical control system (SERMES) can be divided into three main parts: 1) The servo-valves which command the oil flown to the system; 2) The oil cylinders which are tied to the common pistons; and 3) The grease cylinders which transfer the pressure to the roll pack.

3 Rolling models

The conventional AGC operation is based on the estimation of the deformation of the mill frame from the measured rolling forces, and the subsequent correction of the roll gap. To measure the plate thickness when it is rolled is quite complex. Instead, the thickness is estimated from the rolling forces f. The most simple example of a virtual sensor is $v = \frac{f}{K} + z$, known as the *Bisra gagemeter equation*. The principal limitation of this control is that it uses positive feedback and tends to amplify the effect of roll eccentricity and ovalness [3].

A multivariable model would allow to make a real independent control in each side of the rolling sides. A multivariable model has been developed on previous work from [4]. The models inputs are roll positions and rolling velocity, and its outputs are the deformations of the rolls.

The equations of the model admits the following parameterization:

$$(Ip^2 + a_{m2}\Gamma_1 p + EI\Gamma_2 + a_{m1}\Gamma_1)\,\vec{q} = = a_{m3}\Gamma_5 v_r - (pA\Gamma_3 p^2 + a_{m2}\Gamma_3 p + EI\Gamma_4)\,\frac{\vec{z}_d}{2} \quad (1)$$

being:

I, E, ρ — Rolls inertia, Young's modulus and density of rolled material

$\Gamma_1\,\Gamma_2\,\Gamma_3\,\Gamma_4\,\Gamma_5$ — Geometry matrix from plate and rolls

$v_r, \vec{z}_d, \vec{q}$ — Rolling velocity, roll positions and roll deformation normal coordinates.

The slab thickness $\vec{v}$ can be computed according to: $v(x,t) = \varepsilon(x)\vec{z}(t) + \vec{q}(t)\phi(x)$ being ε the sinuidal line with connects the vertices of the rolling cylinders $\vec{z}_d$; and ϕ_i the deformation functions. The parameters a_{m1}, a_{m2}, and a_{m3} must be adjusted with a real-time parameter identification process. in order to fit the model to our specific mill, and to capture unmodeled dynamics.

4 Automatic uneven gauge correction

The working control system in ACERALIA consists of an *Automatic Gauge Control (AGC)* which computes the mean actuators position, and an human operator who modifies it with the *tilting* signal. This *tilting* signal is intended to correct the problems caused by the uneven thickness, and the operator selects it by means of visual inspection. Due to this fact, the corrections can only be applied when the rolling of a slab has finished, and it is out of the mill.

4.1 Space-state compensation methodology

The proposed space-state model can be used in order to avoid the actual uneven thickness profile due to an single-input single-output AGC model. The state-space controller need feedback from the slab thickness. The thickness observer employs the position of the rolls $\vec{z}$ and the amplitude of the normal oscillation functions which are observed as $\vec{q} = F^{\dagger}\vec{f}$. The force model and the thickness

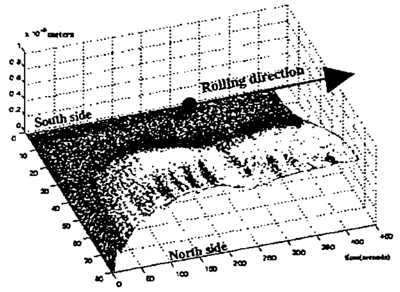

Figure 4: Representation 3D of the space-state computed thickness error

observer result in the system equations:

$$\Delta v_t = f_1(\vec{z}_t, \vec{z}_{t-1}, \vec{z}_{t-2}, \vec{v}_{t-1}, \vec{v}_{t-2}) \quad (2)$$

$$\vec{v}_{t-1} = f_2(\vec{f}_{t-1}) \quad (3)$$

$$\vec{v}_{t-2} = f_2(\vec{f}_{t-2}) \quad (4)$$

These equations give us the value of Δz which must be added to the *tilting* signal in order to avoid the uneven thickness profile. The equations can be solved in real-time, allowing the generation of a continuous *tilting correction* signal.

4.2 Fuzzy compensation methodology

The space-state model have problems to be correctly tested because of the sensors limitations. Without a correct thickness measure, the only reliable signal to check the proposed control signal are the human operator actions. In order to emulate this corrections, a fuzzy controller is a straight option.

According both to the engineers of *Aceralia Corporacion Siderurgica* and to the presented space-state model, the principal factor where the unevenness thickness can be reflected are the amplitude and variations of force unevenness and position unevenness. Using this knowledgement, and in order to build a controller which can replace the human intervention, the selected signals to be used as inputs in the fuzzy controller are: *Mean Force Unevenness*, *Mean Position Unevenness*, *Maximum Position Difference*, *Maximum Force Difference*, *Mean force*, and *Mean Position*, computed all them along one pass of the slab [1].

[1] The start an end point for a rolling pass, are fixed as function of the rolling force. ($F_m > 1e6N \rightarrow SlabIn$, $F_m < 1e6N \rightarrow SlabOut$)

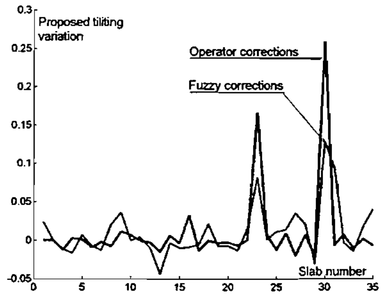

Figure 5: Comparative of the correction *tilting* signals proposed by the human operator and the fuzzy controller for a set of 33 rolling passes.

The output signal of the fuzzy controller is the value Δz which must be added to the *tilting* signal in order to avoid the uneven thickness profile in the *next* slab..

Taking into account the experience of the operators and the space-state results, a fuzzy controller if implemented. Each input has 5 ownership functions. The rule set is a Sugeno one, with 33 rules, and constant output. A set of states with different effects in the unevenness rolling thickness is selected according to the space-state model simulations, and each state generates one of the rules. The parameters of the ownership functions, and the output of the rules are adjusted according to the captured data, selecting passes with and without tilting operator correction, in order to catch all the relevant features of the model. The selected training methodology was *ANFIS (Adaptive Neuro Fuzzy Inference system)*, with a backpropagation algorithm. Three different data sets were used (training, test and check).

5 Results and Conclusions

In order to test the proposed correction methods, a PC computer with a data acquisition board has been installed in the *Tren Semicontinuo* N° 1 at Aceralia Steel Co. The acquisition board is directly connected with the mill's sensors: rolling velocity, rolling force on both sides, and hydraulic positions on both sides. This computer allows an acquisition frequency of 1KHz, with only 2.5μs of delay between the different signals. Due to the noise, all the signal must be filtered with a Chebychev filter. Data analysis shows that the maximum working frequency of the hot rolling mill variables is 30Hz. Then, the frequency selected for the input filters is 50Hz.

The state-space model can be used to get a estimation of the thickness error caused by the actual controller (Figure 4). The state-space approximation allows the implementation of a real-time unevenness controller, but it has one problem. the control system uses a methodology which differs of the current controller, so that testing the likelihood of the proposed control action is a complex task without making the feedback connections in the rolling mill.

The second option, the fuzzy controller, has an important advantage. The correction proposed by the fuzzy controller can be directly compared with the operator actuation in Figure 5. This comparative shows that the fuzzy corrections can replace the human operator without problems.

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References

[1] T.P. Adams and D.B. Collins. Properties of hot strip mill rolls and rolling. *Iron and Steel Maker*, 1999.

[2] Altan, Oh, and Gegel. Metal forming. *American society for metals*, 1986.

[3] Guo. Material damping effect in cold rolling process. *Iron and Steel engineer*, 1994.

[4] L.M. Pedersen. *Modelling and control of plate mill processes.* PhD thesis, Lund Institute of technology, 1999.

[5] C.C. Roberts. Mechanical principles of rolling. *Iron and steel maker*, October 1997 to February 1998.