ESTIMATION OF THE EDGER'S INFLUENCE ON THE STRIP-WIDTH WITH THE DEFORMATION ENERGY AND THE IMPLEMENTATION IN THE ACRONI STEELWORKS

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Abstract

The production of hot-rolling strips of prescribed dimensions requires planning and tracking of the steel's dimensions along the production line. This paper is focused on a determination of the edger's influence on the final strip width on the basis of existing measurements on the edger. Steel slabs are rolled (top and bottom) several times on reversing rougher mill (RM) to prestrips, while edger synchronously with RM rolls slab widths (left and right). Beside initial slab width, edger provides additional influence on final strip width. Edger's influence on final strip-width is estimated by combination of energy consumed for slab-width rolling (the deformation energy) and edger's roll gap, observed through all the passes through RM and edger.

In order to calculate the deformational energy for the slab-width rolling a mathematical model of an unloaded edger was built, which uses velocity as an input. Model of unloaded edger provides estimation of power needed for accelerations of edger's rolls and other rotating parts. The edger total power is measured by current and voltage on the driving motor. Subtraction of unloaded edger power, obtained by simulation of mathematical model, from measured total power, yields power used for rolling (deformation) of slab width. Integration of this power yields deformation energy. Deformation energy is determined for every pass through the RM and edger. The acquired information is instantly written in a database and, at the same time, is used in a charge-width report. The generated charge-width reports are stored in pdf file format, and are then distributed to the end-users using a web server.

Keywords: edger model, strip width, deformation energy, rolling, report

Presenting Author's biography

Franci Vode. He is a Ph.D candidate in the Faculty of Electrical Engineering, University of Ljubljana, Slovenia. He received his B.Sc degree from the Faculty of Electrical Engineering in the Process Control Department in 2002. His main research interest is control and optimization of complex multivariable processes. Currently he is working on continuous reheating furnace control systems and optimizations as a young researcher at the Institute of Metals and Technology, Ljubljana, Slovenia. He is a member of the SLOSIM society.

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1 Intoduction

The production of hot-rolling strips in Acroni has the following stages: the prepared melt is cast on a continuous caster, the slab surface is cleaned and wetted (optional), the slabs are reheated and hot-rolled on a reversing rougher mill, and the transfer bar is rolled on a finishing mill (steckel mill) to the final thickness. In order to reduce production costs the final width of the hot-rolled strips should be as close as possible to the desired customer-dependent width.

During the process of continuous casting the slab dimensions are difficult to control, and the dimensions of the cast slabs vary depending on several variables. The most influential for an individual material are the casting speed, the melt temperature and the ferrostatic pressure of the melt. The slab width and the slab thickness are slightly different for each slab and this is more evident through the whole charge. Unfortunately, due to the high temperature of the slabs, measuring the width of the slabs is difficult and expensive.

A vertical edger roller mounted on a rougher mill is a device for rolling of the slab sides synchronous with the slab top and bottom rolling of the rougher mill. The edger is the only device for adjusting the slab widths in the production line. The transfer bars made on the rougher mill are rolled to the final strip on the finishing mill. Here, the strip-width measuring device is mounted.

The strip width is influenced by the two most important factors. The first is the initial slab-thickness/slab-width ratio, which is not measured. The second factor is the use of the edger.

The purpose of this work is to numerically estimate the influence of the edger on the strip width. The estimation of the edger's influence can then be used to optimize the continuous casting process to ensure a slab width within the prescribed tolerances and to optimize the operation of the edger. The influence of the edger on the strip width is estimated from the energy consumed for slab-width rolling.

2 Analyses of the edger measurements

The following measured signals are available from the edger: the edger velocity *v(t)* / m/s, the voltage *U(t)* / V and the current *I(t)* / A of the edger's motor and the edger roll gap *d(t)* / mm. A sample of the signals is presented in Fig. 2, diagrams 3 and 4.

The basis for the extraction of the desired information from the edger measurements is a mathematical model of an unloaded edger. The unloaded edger model describes the rotational movements of the edger only, without the influence of the transfer bar. The idea can be seen in Fig. 1.

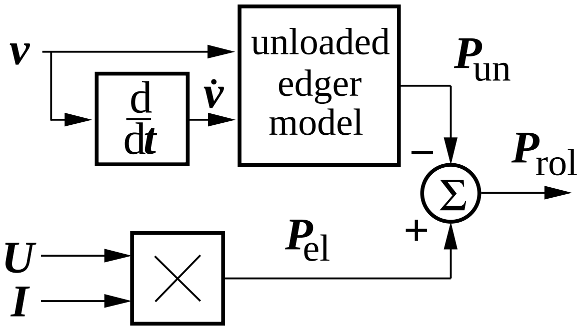

Fig. 1 Scheme for determining the power consumed for slab-width rolling. The measure of the edger velocity *v(t)* / m/s is used as a model input. The product of the voltage *U(t)* / V and the current *I(t)* / A of the edger motor is a measure of the electrical power. Subtraction of the model's estimated power for the unloaded edger $P_{un}(t)$ from the measured electrical power yields the power consumed only for the slab rolling $P_{rol}(t)$.

All three input variables, *v*, *U* and *I*, in Fig. 1 are measured values. First, we develop a dynamic model of the unloaded edger, where the model input is the edger velocity and the output is $P_{un}(t)$, the power consumption of the unloaded edger. The product of the other two measured variables, *U(t)* and *I(t)*, which are DC values, is the electrical power $P_{el}(t)$ consumption. If we subtract the calculated power of the unloaded edger $P_{un}(t)$ from the measured value of the electrical power being consumed by the edger motor ($P_{el}(t)$), the result is the power being consumed for the side rolling of the slab, $P_{rol}(t)$. Integration of $P_{rol}(t)$ over the time for a slab pass through the edger roller yields the energy consumption for the slab-side rolling of a particular pass, i.e., the deformation energy. First, let us present the mathematical background of the unloaded edger model.

2.1 Mathematical model of the unloaded edger

The unloaded edger can be viewed as a stiff rotating body [2] that is driven by an electrical motor. This approximation does not generate an important systematic error. The electrical power is transformed into mechanical power

$$P_{el}(t) = P_{meh}(t)\,. \tag{1}$$

Considering the definition of power for a rigid rotating body [2] and using the definition of electrical power $P_{el}(t)=U(t)\cdot I(t)$ results in the following equation

$$U(t)I(t) = M(t)\omega(t)\,. \tag{2}$$

The momentum M is defined [2] as $M = \dfrac{\mathrm{d}(J\omega)}{\mathrm{d}t}$, ω is defined as $\omega = v/r$ and the associated differential $\dfrac{\mathrm{d}\omega}{\mathrm{d}t} = \dfrac{1}{r}\dfrac{\mathrm{d}v}{\mathrm{d}t}$. Substituting the above relations into Eq. 2 and changing the velocity derivative notation $\frac{dv}{dt} = \dot{v}$ yields

$$U(t)I(t) = \frac{J}{r^2}\dot{v}(t)v(t)\,. \qquad (3)$$

In Eq. 3, J and r^2 are unknown model parameters. Both are constant and therefore the ratio $\frac{J}{r^2} = const. = k$ is constant. The second input signal of the model is $\dot{v}$, which can only be numerically derived from v. The derivation of signals increases the signal noise; therefore, we use the following numerical derivation. The left and right differences are calculated as $\dot{v}_{\mathrm{L,k}} = \frac{v_k - v_{k-1}}{\Delta t}$ and $\dot{v}_{\mathrm{R,k}} = \frac{v_{k+1} - v_k}{\Delta t}$, respectively. The average of these is used as the derivative value $\dot{v}$ at time k $\dot{v}_{t=k} = \frac{v_{\mathrm{L,k}} + v_{\mathrm{R,k}}}{2}$. The numerical derivation and the short sampling time are the weakest points of the modeling.

Eq. 3 has a single unknown parameter, k, which can be found using the least-squares method[1]. For a determination of k with the least-squares method the U, I as well as $\dot{v}$ and v need to be available and must originate for the period of time when the edger was unloaded. Other details on data requirements for a determination of the parameters with the least-squares method are described in the literature [1].

The unknown parameter k was determined in the following way. The edger measurements for several rolled slabs were available in separate ASCII formatted files. From all the different long-slab steel grades a total of 20 random slab-rolling files were used, and on each a parameter-fitting process was performed and the resulting model-parameter k was stored. This was done for two reasons: to verify the repeatability of the obtained parameters and also to check the extent to which the model could be extrapolated. Each of these parameter-fitting tasks was visualized and verified to exclude possible unsuitable data files, e.g., errors in the data files, unsuitable dynamics, etc. The average of these 20 model parameters was used as a model parameter in the subsequent analyses. The model-parameter value varied from $39 \cdot 10^3$ to $47 \cdot 10^3$, and the average value was found to be $k = 47 \cdot 10^3$. The agreement between the model estimation and the measured value can be seen in Fig. 2, on the upper graph from timestamp 110s to 140s, where the edger is unloaded. The signal P_{el} in a particular time interval is a measured value and can be seen as a true value of the model's output. The agreement between the model's power prediction, P_{un}, and the measured value of the power, P_{el}, is satisfactory, taking into account the long sampling period of 0.5s. The second diagram in Fig. 1 presents the power of rolling, P_{rol}, which is the base signal for additional analyses.

2.2 The edger model as a source of additional information and the obtained results

As described in the previous section, the mathematical model presents a basis for the extraction of additional information from the edger measurements. For a determination of the rolled/not-rolled slab width the following empirically obtained integral criterion is used

$$R = \frac{\int_{t_{\mathrm{pass}}} |UI| \mathrm{d}t}{\int_{t_{\mathrm{pass}}} \left(UI \frac{1}{2\dot{v} + 0.08} \right)^2 \mathrm{d}t} 10^6\,. \qquad (4)$$

R is always positive and R values between $0 \leq R \leq 1$ determine that edger has rolled slab sides. Values $R>1$ determine, that edger did not roll slab sides. The criterion is calculated for every slab pass through the edger. The part $\frac{1}{2\dot{v} + 0.08}$ in the lower integral in Eq. 4 accents the power contributions where the velocity is not changing rapidly and vice-verse, the power contribution of the samples with rapid velocity changes are descended. The ratio of both integrals is also independent of the slab length and the number of samples. Note that for the calculation of the R characteristics, the measured value of the power P_{el} is used rather than P_{rol}. The choice of P_{el} as the base signal and the incorporation of the acceleration signal $\dot{v}$ for the R characteristics are due to the sequence of the research work. The first question we were trying to answer was: Did the edger roll the slab-width or not? This question was answered with the R characteristics, which do not require P_{rol}.

The next calculated characteristic for each pass through the edger is the energy consumed during the rolling in a particular pass, E_{rol}. This value can be obtained simply by an integration of P_{rol} over the whole pass of the slab through the edger. The following integration is performed

$$E_{\mathrm{rol}} = \int_{t_{\mathrm{pass}}} P_{\mathrm{rol}} \mathrm{d}t\,. \qquad (5)$$

The integration is performed over the particular pass time t_{pass}, where additional conditions $P_{\mathrm{rol}} > 0.02\, P_{\mathrm{max}}$ and $|\,P_{\mathrm{rol}}| > 3\, P_{\mathrm{un}}$ are satisfied. The power is summed for those samples where P_{rol} is at least 2 percent of the maximum edger power P_{max}, and where the absolute value of P_{rol} is more than three times higher than the power of the unloaded edger P_{un}. Where both conditions are fulfilled, the integration is performed. The sum of the time when these two

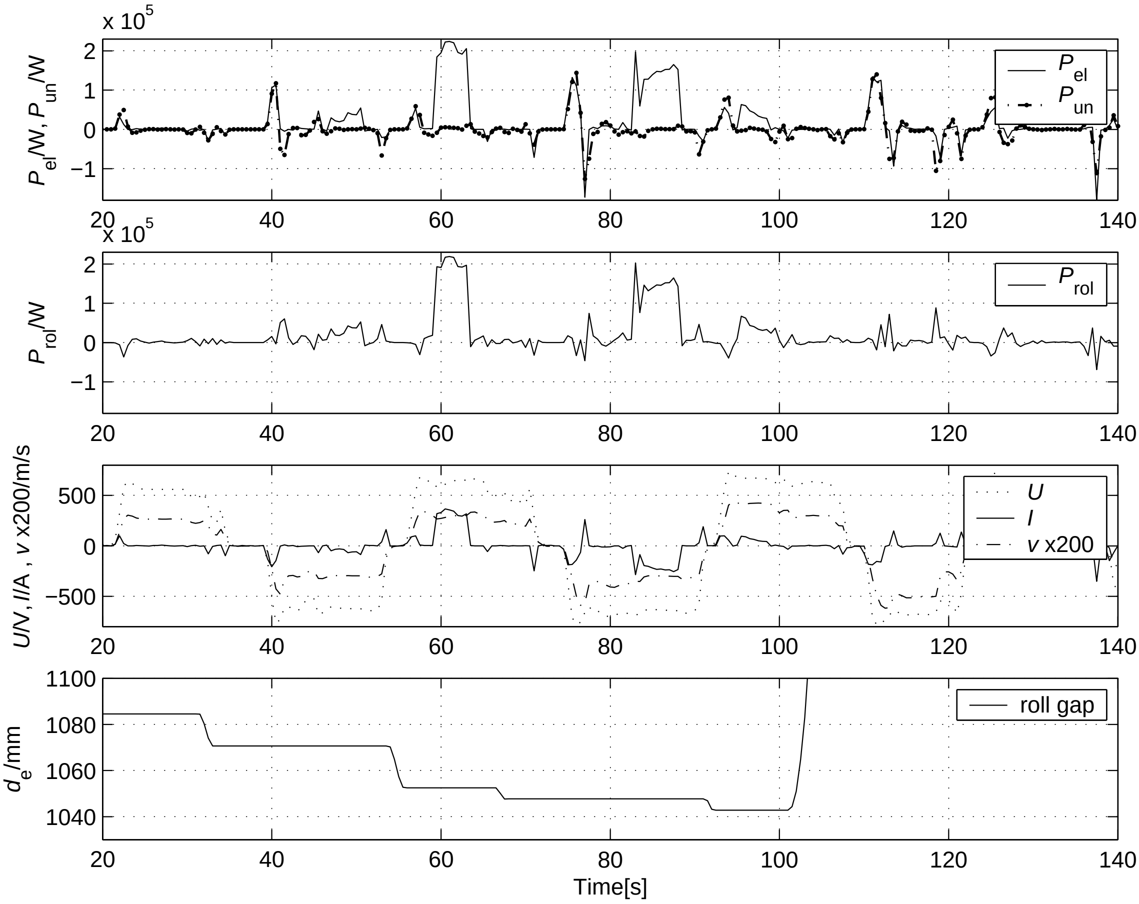

Fig. 2 Example signals. In the first diagram the power estimation of the unloaded edger rotations P_{un} calculated using this model is presented next to the measured value of the power P_{el}. The signals fit where no slab-width rolling is present. The second diagram presents $P_{\mathrm{rol}}=P_{\mathrm{el}}-P_{\mathrm{un}}$, the power consumed for slab-width rolling. On the third and fourth diagrams the edger source measurements are presented: *v*, *U*, *I* in diagram 3 and the roll gap in diagram 4.

Tab. 1 Calculated integral criteria for the signals shown in Fig. 2. The *R* characteristic is calculated using Eq. 4 and determines whether the edger has rolled the slab width or not. The energy of rolling, E_{rol}, is calculated using Eq. 5. The average power of rolling for a particular slab pass is calculated using Eq. 6.

Roll pass No.	1	2	3	4	5	6	7
R	21.25	0.64	0.20	0.11	0.76	8.51	42.74
E_{rol}/kWh	0	0.068	0.448	0.443	0.086	0	0
$\overline{P_{\mathrm{rol}}}$ /kW	0	34.9	201.9	145.1	44.3	0	0
Start time / s	22	39.5	56.5	75	93	110.5	124
End time / s	35	54	71.5	91.5	108.5	122.5	138.5

conditions are satisfied is referred to as t_{rol}. All the above integrals are calculated numerically and therefore the discretely equivalent criteria are used.

The third calculated characteristics for each pass through the edger roller is the average value of the edger power during the detected rolling, $\overline{P_{\mathrm{rol}}}$. This is calculated simply by dividing the rolling energy by the time for which the rolling was performed, t_{rol}.

$$\overline{P_{\mathrm{rol}}} = \frac{E_{\mathrm{rol}}}{t_{\mathrm{rol}}}. \qquad (6)$$

This characteristic provides information about the edger loading, which is useful for determining the suitability of the edger settings during the rolling.

2.3 Discussion of the obtained results

Let us first comment on the example data shown in Fig. 2, diagrams 3 and 4. Seven passes through the edger roller are detected for the sample data. The presented integral characteristic *R* for the example data yields the presented values in Tab. 1. The *R* being greater than 1 means that the slab-width rolling in the particular pass was not detected.

From Tab. 1, looking at the *R* values one can conclude that in 2nd, 3rd, 4th and 5th passes the edger has rolled the slab sides. This is also visible from Fig. 2, signal P_{rol}. The $\overline{P_{\mathrm{rol}}}$ is calculated using Eq. 6, and for the sample data presented in Fig. 2, yields the values presented in Tab. 1. Note that $\overline{P_{\mathrm{rol}}}$ is the average value of the signal P_{rol} over the actual rolling time, t_{rol}.

3 Charge-width report

The most important information, which was the reason for beginning the estimation of the edger's influence on the strip width, is the traction of the relative influence of the edger's operation through the whole charge. To assemble data from all the slabs/strips belonging to a particular charge and visualize them a charge-width report is automatically generated for each charge.

The charge-width report is in pdf format, which is independent of operating system and is a sufficiently compact file format.

3.1 Structure of the charge-width report

A sample of a charge-width report is presented in Fig.3. The charge-width report consists of a document head with a charge number, a quality code and a quality name. The body of the report consists of five diagrams, successively presenting the following process variables (Fig. 3)

1. Reference (dash-dot-dot), measured (dots) and tolerance border value (solid) of the hot-rolled strip width
2. Reference (dash-dot-dot), measured (dots) and tolerance border value (solid) of the hot-rolled strip thickness
3. Edger roll gap d_{i} (line)
4. Energy consumed for rolling for first six edger passes E_{rol} of each slab (bar). The sum of all the edger passes is presented in the graph as a line. $E_{\mathrm{rol}}=0$ indicates that the slab side was not rolled in the particular pass.
5. The average power of the edger during the rolling for the first six edger passes $\overline{P_{\mathrm{rol}}}$ of each slab, represented with bars. The average value of the power through all the edger passes for a particular slab is plotted with a line.

Some more details on the presented diagrams.

On diagram 1 the strip width is presented along its length, and the strip thickness is presented in diagram 2. The measured values (width or thickness) along strip length are presented in the space between the particular and the following slab number (x-axis) independent of the strip length. Both data are measured on the finishing mill.

Diagrams 3, 4 and 5 show how the observed process variables are changing through the 1st to the 6th pass on the edger. If more than six passes appear during rolling, the 7th and higher passes are not presented on the diagram. This happens rarely.

4 References

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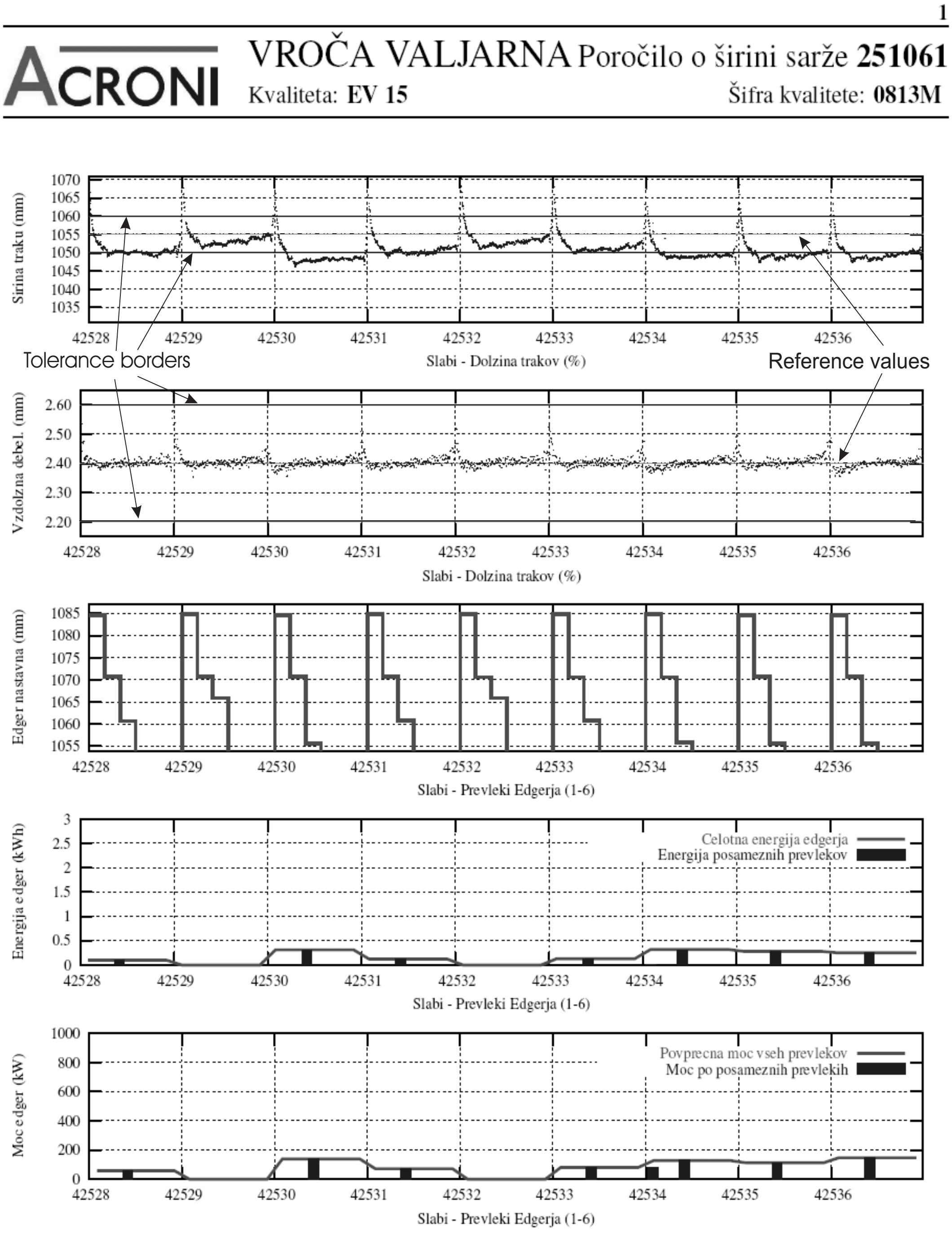

Fig. 3 An example of automatically created charge-width report. All the diagrams have the same x axis, which is the slab number sequence, belonging to a particular charge. Diagram 1 presents the strip width measured on the finishing mill together with the reference value and the tolerance borders. Diagram 2 similarly presents the strip thickness measured on the finishing mill. The reference thickness and the tolerance limits of the thickness are presented as well. Diagrams 3, 4 and 5 accompany the process of rolling on the edger for the first six passes and some characteristics through all the passes for a particular slab. Diagram 3 presents the roll gap of the edger for the first six passes. Diagram 4 presents the energy consumed for rolling (Eq. 5) with bars and the sum of the energy through all the passes (line). Diagram 5 presents the average rolling power (Eq. 6) with bars of the average value of power