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Information

An adaptive algorithm for pass adaptation in plate rolling

Zhichun Mu, Weiming Li, and Ke Liu

Information Engineering School, University of Science and Technology Beijing, Beijing 100083, China
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Abstract: A new algorithm for pass adaptation in plate rolling is developed to improve thickness accuracy of plate products. The feature of the algorithm is that it uses the measured data rather than the schedule calculated data in adaptation, which leads to notable improvement in prediction accuracy of the rolling parameters and thickness accuracy of products can be improved accordingly. Results show that this adaptive algorithm is effective in practice.

Keywords: adaptive algorithm; plate rolling; measured data

Thickness accuracy and its performance along the plate length are very important quality indexes of plate products. Rolling practice has shown that the accurate prediction of rolling parameters can not rely on static rolling models only. The reasons are (1) the accuracy of models is limited; (2) the rolling conditions are kept changing during the rolling process.

Generally speaking, the mathematical models for the rolling parameters prediction are assumed consistent with a certain rolling condition. If rolling condition changes, the accuracy of the model-based prediction can not be guaranteed. Therefore, adaptation of the model-based prediction, in accordance with the rolling condition, is necessary. However, conventional adaptation algorithms use the schedule calculated data as reference to modify the predicted rolling force. These are clearly wrong practice. It is the measured data, which contains real time information of rolling process, should be used for adaptation purpose. A new adaptation algorithm using the measured data needs to be developed.

1 Model of rolling force

In plate rolling, the rolling parameters (*i.e.* setup values) of each pass are calculated by rolling schedule model running on the process control computer. The typical parameters include rolling force, rolling torque, rolling speed and exit gauge. During rolling, if there is a difference between actual rolling force and anticipated rolling force, an error between actual exit gauge and scheduled exit gauge would be expected. Without effective pass adaptation, the gauge error will be in turn introduced to next pass, causing accumulated error.

However, for plate production, the mill configuration normally adopts the single-stand or two-stands reversing mill. There is a time space between passes while changing rolling direction, which can be used for pass adaptation to improve rolling performance.

The rolling force prediction model is one of the most important models to the adaptation. It is defined in the following adaptive form:

$$P = 10^{-3} B L Q_\sigma \sigma \cdot \mathrm{SZM} \tag{1}$$

Where B is average width of rolled plate (mm); L contact arc length, $L=\sqrt{R\Delta h}$, R deformed roller radius, Δh draft; Q_σ stress factor; σ deformation resistance; SZM adaptive factor.

The calculation of stress factor Q_σ is based on Sims equation. In this computer control system, the following simplified equation is used:

$$Q_\sigma = 0.75 + 0.25\frac{L}{h_m} \tag{2}$$

Where $\frac{L}{h_m}$ is geometry factor of deformation area; L contact arc length; h_m average thickness of rolled plate in deformation area.

The method to obtain the deformation resistance can be easily found in open literature, *e.g.* reference [2].

2 Deficiency of pass adaptation based on schedule calculated data

At present, the most of pass adaptation practice are based on schedule calculated data, which uses the equation (1) to calculate the anticipated rolling force.

The adaptive factor SZM is defined as:

Corresponding author: Zhichun Mu **E-mail:** zcmu@public.fhnet.cn net

$$\mathrm{SZM} = \mathrm{SZM}_1 + \alpha(\mathrm{SZA} - \mathrm{SZM}_1) \tag{3}$$

Where SZM_1 is the SZM value used in last pass (initial value of SZM is 1); α correction factor; SZA the ratio of the actual rolling force and the schedule calculated rolling force, *i.e.* $\mathrm{SZA} = \frac{P^*}{P}$.

With the equation (3), it is expected to bring the anticipated rolling force closer to actual rolling force after several pass adaptations. However, the problem is that the algorithm based on the schedule calculated data does not conform with the current rolling conditions. In fact, the schedule calculated rolling force and the actual rolling force are incomparable because they are obtained based on different rolling conditions. For example, if the actual rolling force is greater (less) than the schedule calculated force in last pass, as a result of mill stretch, the exit gauge of last pass will be thicker (thinner) than schedule calculated gauge. The rolling condition of current pass, therefore, is changed with thicker (thinner) entry gauge. As the consequence of its deficiency, the schedule calculated data-based adaptation is often ineffective. To improve accuracy of the prediction, the measured data, which reflect the current rolling condition, should be used as the adaptation basis.

3 Measured data-based pass adaptation algorithm

Instead of using the schedule calculated data, the measured data is introduced as the basis of adaptation in this new algorithm.

In the new algorithm, the form of the equation for rolling force prediction is the same as the equation (1), but the equation for adaptive factor is modified as:

$$\mathrm{SZM} = \mathrm{SZM}_1 + \alpha(\mathrm{SZA}' - \mathrm{SZM}_1) \tag{4}$$

Where SZM_1 and α have the same meanings as in equation (3), while the definition of the SZA is changed to: $\mathrm{SZA}' = \frac{P^*}{P^*_c}$, *i.e.* the ratio of the actual rolling force and the measured data-based calculated rolling force.

In practice, α can be set to different values for different exit gauge ranges to achieve better adaptive performance. In this case, the settings for α are: 0.8 for exit gauge over 40 mm; 0.6 for 40 mm to 20 mm; 0.5 for under 20 mm.

The flow chart of the new algorithm is given in **figure 1**. The prediction or calculation of the rolling force is implemented in two stages. In first stage, the first predictions of rolling force (P_{G1}) and rolling torque (M_{G1}) are obtained presuming that the rolling is at the rated rolling speed (N_e); the entry gauge (h^*_{i-1}) is the gauge calculated with the gaugemeter principle on the basis of measured data in last pass; and the exit gauge (h_i) is set to the schedule calculated exit gauge for the pass. Then the maximal rolling speed (N_{max}) is determined on the basis of P_{G1}, M_{G1}. With the N_{max}, h_i, h^*_{i-1}, in second stage, the second predictions of rolling force (P_{G2}) and rolling torque (M_{G2}) are calculated again to modify the predictions in the first stage. The second prediction values are then downloaded to the actuators as the anticipated rolling force and rolling torque for the pass. On completion of current pass, the actual rolling speed (N^*), calculated exit gauge (h^*_i) and h^*_{i-1} are taken as the measured data to calculate the so-called the measured data-ba sed calculated rolling force (P^*_c) which plays the key role in this new algorithm for following pass adaptation.

The convergence of the new algorithm can be explained in **figure 2**. Refering to figure 2, if $P^*_{i-1} > P_{i-1}$ and $\mathrm{SZA}'_{i-1} > \mathrm{SZM}_{i-1}$ then have $\mathrm{SZM}_i > \mathrm{SZM}_{i-1}$, $P_i > P_{i0}$, $P^*_c > P^*_{c0}$, $\mathrm{SZA}'_i < \mathrm{SZA}'_{i-1}$, where i is the count of the current pass; P_{i0} the schedule calculated rolling force without being corrected; P^*_{c0} the measured data-based calculated rolling force without being corrected.

From equation (4), conclude that $|\Delta\mathrm{SZM}_i| < |\Delta\mathrm{SZM}_{i-1}|$

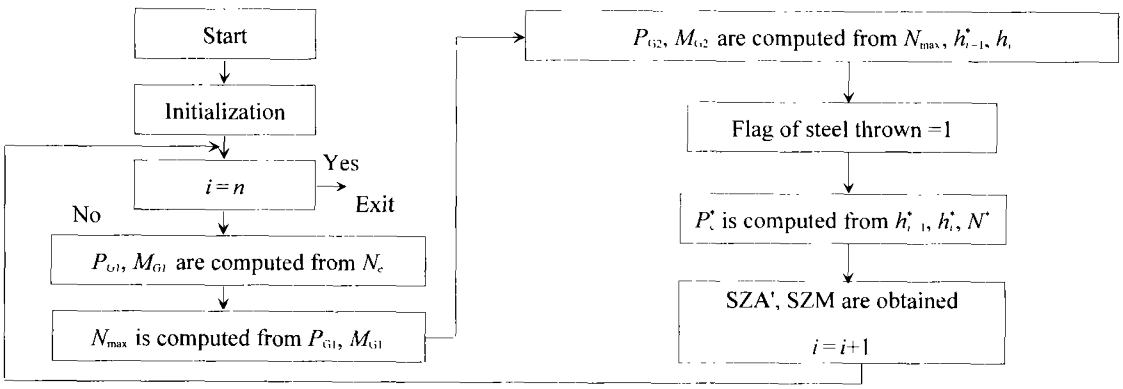

Figure 1 Flow Chart of Algorithm based on adaptation.

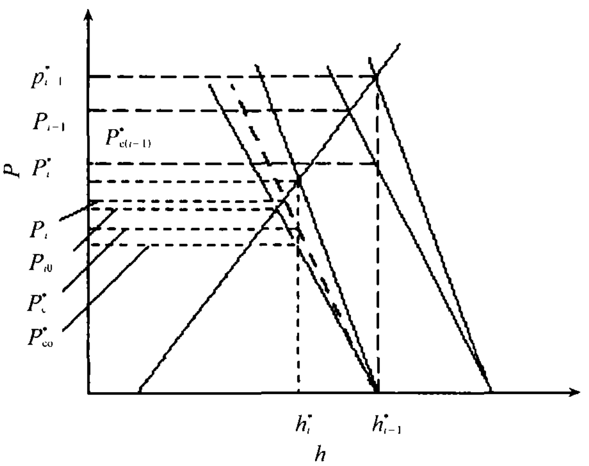

Figure 2 Convergence of algorithm.

(note that the value of ΔSZM_i is positive in this case).

For the case of $P^{*}_{i-1}<P_{i-1}$ and $SZA'_{i-1}<SZM_{i-1}$ then $SZM_i<SZM_{i-1}$, $P_i<P_{i0}$, $P^{*}_c<P^{*}_{c0}$, $SZA'_i>SZA'_{i-1}$.

From equation (4), conclude that $|\Delta SZM_i|<|\Delta SZM_{i-1}|$ (note that the value of ΔSZM_i is negative in this case).

In summary, the algorithm is convergent, which will bring the predicted rolling force closer to the actual rolling force in adaptation process.

4 Result of application

Applying the measured data-based pass adaptation algorithm in plate rolling, more than 300 slabs with different types were rolled in the rolling site. Results show that there is less deviation between the actual rolling force and the prediction rolling force than adopting the algorithm based on schedule calculated data. **Figure 3, table1** and **figure 4, table2** are comparison of two algorithms for two steel types as example, the null pass of the sixth and the end pass. From effect comparison of two algorithms, the measured data-based pass adaptation algorithm has higher prediction accuracy.

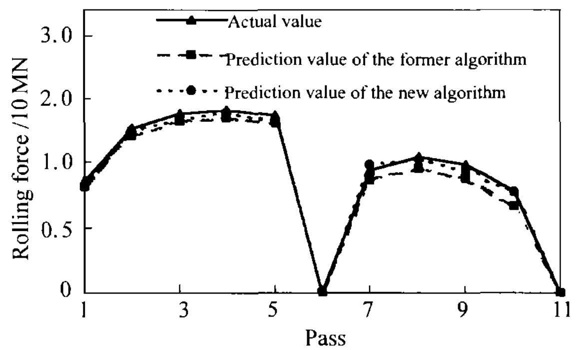

Figure 3 Comparison of effect. type: ordinary steel; slab: 3 800 mm×1 650 mm×230 mm; production: 6 900 mm× 2 100 mm×100 mm.

Table 1 Comparison of the two algorithms on predicted rolling force for ordinary steel

Pass (n=11)	Measured rolling force /MN	Prediction rolling force(former) /MN	Prediction rolling force (new) /MN
$n-3$	20.90	19.18	20.62
$n-2$	19.93	17.84	19.07
$n-1$	15.87	13.38	15.62

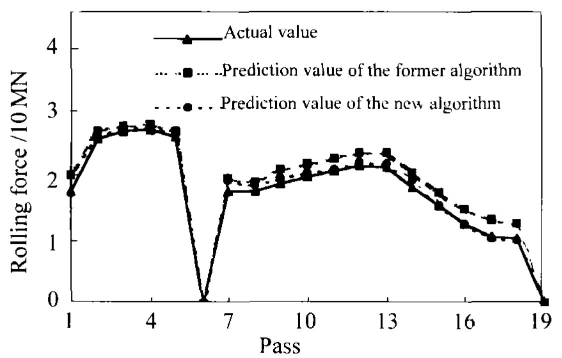

Figure 4 Comparison of effect. type: high quality structural steel; slab: 3 700 mm×1 650 mm×230 mm; production: 26 900 mm×2 200 mm×25 mm.

5 Conclusion

In view of the deficiency of the algorithm based on schedule calculated data, a new algorithm of pass adaptation is developed to modify the rolling parameters by using the information contained in measured data. Results show that this adaptive algorithm is effective in practice.

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Table 2 Comparison of the two algorithms on predicted rolling force for high quality structural steel

Pass (n=19)	Measured rolling force /MN	Prediction rolling force(former) /MN	Prediction rolling force (new) /MN
$n-3$	12.38	14.76	12.46
$n-2$	10.59	12.94	10.15
$n-1$	10.17	12.32	9.81

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