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ANALYSIS OF WORK ROLL THERMAL BEHAVIOR FOR 1450MM HOT STRIP MILL WITH GENETIC ALGORITHM

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ABSTRACT

Work roll thermal contour is one of the important factors for roll contour design and configuration in hot strip rolling, for which the temperature field calculation is a critical factor. To realize the work roll thermal behavior for 1450mm hot strip mill, the temperature field and thermal contour calculation model was built with finite different methods, and the genetic algorithm was introduced to the model parameter optimization in order to improve the simulation precision. It was proved that the model can match the engineering precision requirement by the comparison between several calculated values and measured values of the work roll temperature. With the model, the work roll thermal contour variations in a rolling process, as well as the effect of rolling rhythm and shifting strategy on the work roll thermal contour were calculated. The results show that the work roll thermal crown varies relatively fast at the beginning of a rolling unit, and then tends to be stable. In the rolling process, the rolling rhythm shows great influence on the work roll thermal contour, while the shifting strategy shows little influence.

Keywords: *Hot rolling, Work roll, Thermal behavior, Genetic Algorithm*

1. INTRODUCTION

A 1450mm hot strip rolling production line has produced thin strips with considerable good quality soon after its operation in 2008. To further improve the stability of the strip production and the profile quality of the strips, it is essential to analyze and optimize the configuration of the roll contour. Since the temperature field calculation is the critical factor in work roll thermal contour, which is one of the most important factors for work roll design. Domestic and foreign scholars have paid a lot attention to the building of a rational work roll temperature field and thermal contour forecast model with high calculation accuracy. Most models are based on the basic law of heat transfer and calculate with modern numerical method such as the analytic method [1-2], the finite element method [3-4] and the finite difference method [5-9]. Among them, the finite difference method gains a wide range of application in engineering, because of its simple and quick calculation and high calculation accuracy.

For calculating the temperature field with finite difference method, the most critical problem is the building of different calculating model and the treatment of boundary conditions, especially the latter, which aims to truly reflect the heat exchange of the work roll in the rolling process. It is very difficult to give an accurate expression of the work roll heat exchanging in the whole rolling process, so certain assumptions are necessary[5-9]. In addition, it is difficult to accurately determine the heat transfer coefficients in the simulated calculation, such as the heat transfer coefficients between the work roll and the strip, the cooling water, and the air. This is mainly because of the complexity of the rolling process. Therefore, the work roll temperature field is still difficult to calculate accurately. So it is advisable to search for each heat transfer coefficient suitable for a certain rolling mill based on the actual production data to further improve the calculation accuracy of the work roll temperature field. Applying genetic algorithm to the parameter optimization of the work roll temperature field contributes to improving the calculation accuracy of the temperature field and laying a good foundation for mastering the work roll thermal behavior accurately.

2. THE TEMPERATURE FIELD AND THERMAL CONTOUR CALCULATION MODEL OF 1450MM HOT STRIP MILL

Heat conduction equation & difference equation. The work roll is geometry symmetrical and the variation of its thermal boundary is strictly cyclical. In the study of thermal contour caused by temperature, the circumferential temperature fluctuation that occurs in the roll surface can be simplified and the variation along the circumference can be neglected, thus the temperature field can be converted to a two-dimensional problem. For this reason, the heat conduction equation in cylindrical coordinate system can be express as:

$$\frac{\partial T}{\partial t}=\frac{\lambda}{\rho c}\left(\frac{\partial^2 T}{\partial r^2}+\frac{1}{r}\frac{\partial T}{\partial r}+\frac{\partial^2 T}{\partial x^2}\right) \qquad (1)$$

Where, T is temperature; t is time; λ is thermal conductivity of the material; ρ is the density of the roll material; c is the mass heat capacity; r is the radius coordinate; x is the axial coordinate.

First a meshing model should be built, the axial space step noted as Δx and the radius space step noted as Δr . Via the method of controlling volume balance, the relevant differential equations were established based on the characteristics of the boundary conditions. And then based on the energy conservation law, noted $\frac{\lambda \Delta t}{\rho c(\Delta x)^2}$ as fx and $\frac{\lambda \Delta t}{\rho c(\Delta r)^2}$ as fr , the internal grid point's differential equation turned to be:

$$\begin{aligned}T_{i,j}^{n+1} &= T_{i,j}^{n}+frT_{i-1,j}^{n}+fxT_{i,j-1}^{n}+fxT_{i,j+1}^{n}\\ &+fr\left(1+\frac{\Delta r}{r}\right)T_{i+1,j}^{n}-\left(2\,fr+fr\frac{\Delta r}{r}+2\,fx\right)T_{i,j}^{n}\end{aligned} \qquad (2)$$

Similarly, the differential equations of the surface boundary, the side element, the end region element, the corner element, the core element and the core element of the end region can be established.

The determination of influencing factors. The main factors of the boundary heat transfer are the contact heat transfer between the work roll and the strip, as well as the convective heat transfer between the work roll and the cooling water accompany with the air. In order to simplify the engineering calculation, the equivalent heat transfer coefficient method is used in the model. With the equivalent contact heat transfer coefficients between the work roll and the strip, the work roll and the cooling wate, as well as the work roll and the air noted as h_s, h_w, h_a, the relationship of the hot-flow density and the equivalent heat transfer coefficients can be acquired via the third type of boundary conditions.

The parameters of the temperature field model can be classified into two categories: the first category is the known parameters which can be acquired directly or via certain formulas , such as ambient temperature, the temperature of cooling water, the physical parameters of the work roll, the strip width and the rolling rhythm, they are all noted as parameter E; the second category is the undetermined parameters, namely the equivalent contact heat transfer coefficients h_s, h_w, h_a .Then the temperature field $T(t)$ at moment t can be defined as $f(E,h_s,h_w,h_a,t)$.

The optimization of the model parameters with genetic algorithm. The initial value of h_s, h_w, h_a can be acquired by the traditional theory formula and experience. In order to make the simulation model match the actual condition and meet the need of engineering simulation analysis, the genetic algorithm was introduced into the optimization of the three parameters. Noted the design variables to be optimized as vector $H=(h_s,\ h_w,\ h_a)$, then the $T(t)$ turned to be $f(E,H,t)$

With the 1450mm hot strip mill F5 stand as the study object and the measured values of work roll temperature as the calculation foundation, the temperature field model parameters were optimized.

With the Genetic Algorithm and Direct Search Toolbox in MATLAB, the objective function is defined as:

$$F=\sum_{1}^{N_m}\sum_{i=0}^{N_t}(T_c(1,i,t_n)-T_m(1,i,t_n))^2 \qquad (3)$$

Where, N_m is the number of the rolls used in the optimization; N_t is the number of the points measured in the temperature field; T_c is the actually measured value of the work roll surface temperature field; T_m is the value acquired from the model.

The calculation model of the thermal contour. The thermal contour of the work roll can be solved by using the analytic method after the temperature distribution is acquired. The work roll could be assumed as a cylinder with infinite length because its axial length was long enough. The displacement was irrelevant to the direction of the axis and the temperature field was symmetric about the center section of the roller. Based on the simultaneous basic stress and strain equations of the thermo elasticity theory, the diameter expansion $u(x,t)$ of the roll at moment t was described as follows [9]:

$$u(x)=\frac{1+\nu\beta}{1-\nu r}\int_0^r T(r)rdr+c_1r+\frac{c_2}{r} \qquad (4)$$

Where, ν and β are Poisson's ratio and the coefficient of the linear expansion respectively, r is the radius.

Then the thermal contour $D(x,t)$ can be calculated via the following formula:

$$\begin{aligned} D(x,t) &= u(x,t) \\ &-\left[u(x_w,t)+u(x_d,t)\right]/2 \end{aligned} \qquad (5)$$

The validation of the simulation model. The parameter vector H gained in the genetic algorithm optimization was validated by the 5 series of data. The comparison between the model results and the actual results was shown in Figure1. It reflected that the calculation value generally coincided with the actual value but there was also relatively large deviation at some points, especially the calculation value of the 5th series. There may be some reasons such as:

The rolling rhythm used in the model calculation is not the actual rolling rhythm, in other words, the input is not the actual rolling time and intermittence time, but the average value of the rolling rhythm.

After a rolling unit and before unloading the work roll, there were still cooling water works on the rolls about 1~2 minutes, which is difficult to measure accurately.

After work roll unloading, the cooling water remains on the surface of the work roll which influences the test results.

It is difficult to make every series of data to be the optimal parameters. All the factors mentioned lead to the difficulty in the consistence between the off-line simulated calculation and the actual condition. So it is feasible to use a model that can just meet the need of engineering calculation.

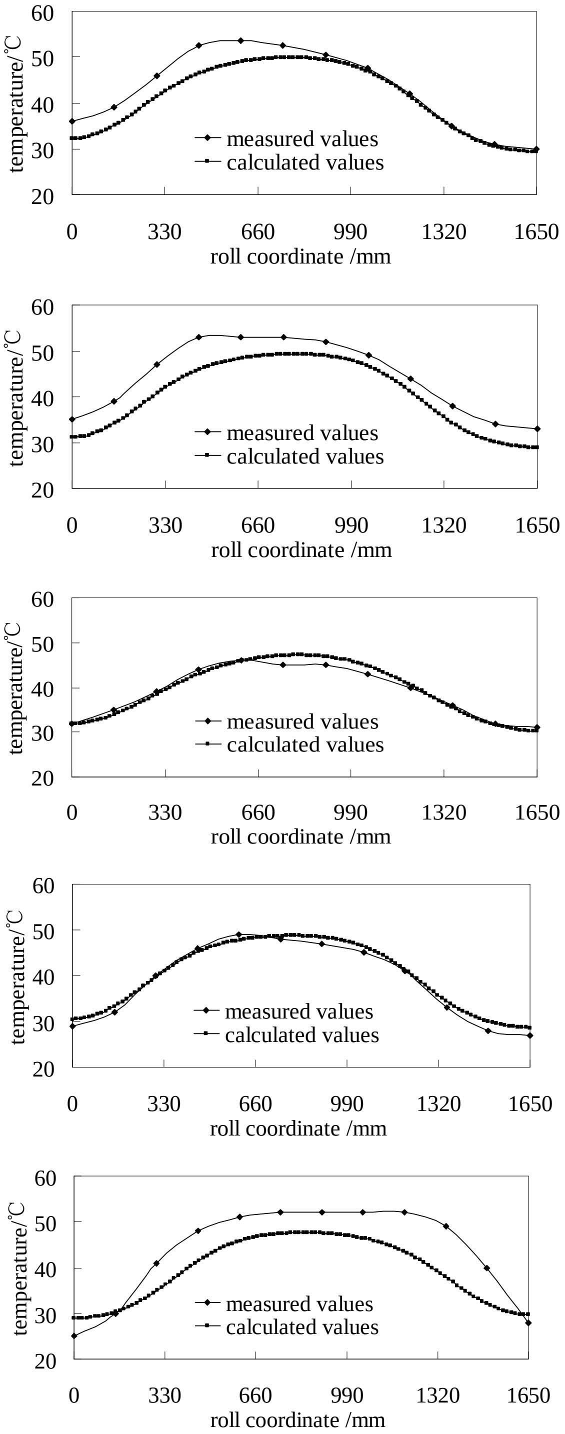

Figure 1 The measured values and the calculated values of the work roll temperature

3. ANALYSIS OF THE WORK ROLL THERMAL BEHAVIOR FOR 1450MM HOT STRIP MILL

After the validation, the simulation model can be used to analyze the work roll thermal behavior for 1450mm hot strip mill, in order to improve the strip profile control technologies.

The variation of the thermal contour in the rolling process. In a service period of a work roll, if there is no work roll shifting, the rolling rhythm is 80s (rolling time)/45s (intermittence time) and the strip width is 1020mm, the variation of the thermal contour is shown in Figure2. It can be seen that the thermal contour is increasing gradually with the proceeding of rolling. The variation of the thermal crown is shown in Figure3. In the rolling process of the first 20 strips, the thermal crown increases rapidly, and then the increasing rate of the thermal crown decreases gradually and tends to be stable.

The effect of the rolling rhythm on the thermal contour. While the rolling time remains 80s, and the intermittence time is 45s, 65s and 85s, the corresponding thermal contours are shown in Figure4 (the shifting step is 5mm and the shifting stroke is 80mm) after 100 pieces of strips have been rolled.

It can be seen that the thermal contour varies obviously with the change of the rolling rhythm. The variance of the thermal crown of the work roll is about 20μm when the intermittence time changes from 45s to 65s; and it is about 10μm when the intermittence time changes from 65s to 85s. The thermal contour doesn't vary linearly with the change of the intermittence time, and the faster rolling rhythm has greater influence on the thermal contour.

The effect of the shifting strategy on the thermal contour. The shifting strategy mainly has two factors: the shifting stroke and the shifting step. The effects of the two factors on the thermal contour are analyzed as follows.

Change the shifting step and keep the shifting stroke constant

Using the same rolling parameters just mentioned, the variation of the thermal contour is analyzed when the shifting stroke was ±80mm and the shifting step was 5mm and 10mm respectively. In order to make the work rolls ultimate axial position unanimous, 97 pieces of strips are rolled and the strip width is 1020mm. After the work roll service period, the thermal contours are shown in Figure5.

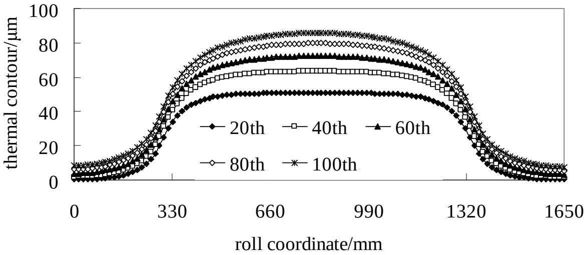

Figure 2 Work roll thermal contour variation in a rolling process

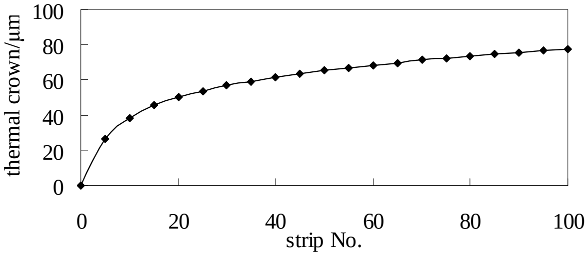

Figure 3 Work roll thermal crown variation in a rolling process

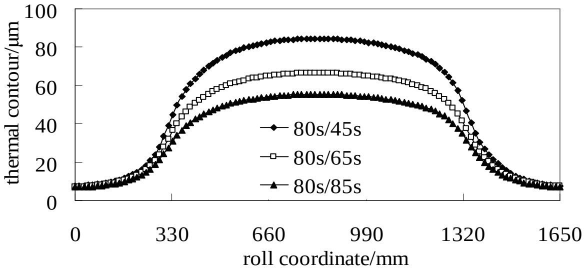

Figure 4 Work roll thermal contours with different rolling rhythm

It can be acquired that when the shifting stroke remains unchanged, the change of the shifting step has little influence on the temperature field and the thermal crown, and only causes the translation along the axial direction of the roll. It is mainly influenced by the strip distribution probability along the axial direction which is caused by the change of the shifting strategy.

Change the shifting stroke and keep the shifting step constant

The shifting step remained 5mm and the shifting stroke was changed from ±80mm to ±100mm. The influence on the thermal contour is shown in Figure6.

It can be acquired that the change of the shifting stroke also has little influence on the thermal contour when the shifting step remains unchanged.

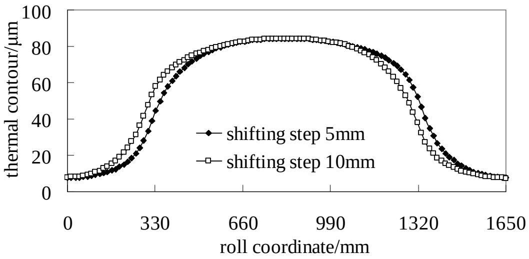

Figure 5 Work roll thermal contours with different shifting step

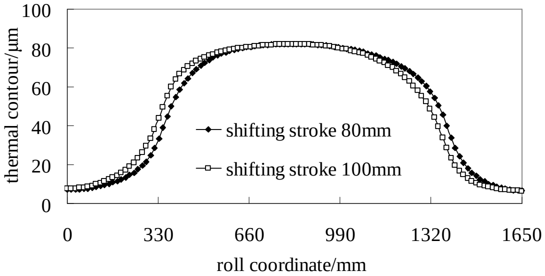

Figure 6 Work roll thermal contours with different shifting stroke

4. SUMMARY

(1) With the equivalent contact heat transfer coefficients between the work roll and strip, the work roll and the cooling water, as well as the work roll and the air as the optimization objects, the genetic algorithm was used in the parameter optimization of the temperature field calculation model, making the temperature field and thermal contour model meet the demand of engineering calculation precision.

(2) With this model, the work roll thermal contour variation in a rolling process of 1450mm hot strip mill is calculated. In the earlier stage of the rolling process, the thermal crown of work roll increases rapidly, and then the increasing rate decreases gradually and tends to be stable gradually.

(3) The effect of the rolling rhythm on the work roll thermal contour is calculated. The results show that the thermal contour doesn't vary uniformly with the change of the intermittence time. It can be concluded that the faster rolling rhythm has greater influence on the thermal contour.

(4) The effect of the shifting strategy on the work roll thermal contour is calculated. The results show that the shifting strategy had little influence on the thermal contour.

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