Research of on-line prediction method of plate temperature during hot rolling

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Abstract. Aiming at the demand of on-line calculation of temperature in the process of hot rolling production, the method of on-line forecasting of plate temperature based on PLC is studied. The rolling micro-tracing queue is established, and one-dimensional differential temperature iterative calculation formula is developed to realize the whole process of plate production. The temperature distribution in the plate thickness direction can be obtained in real time, and the forecasting results can meet the engineering requirements.

Introduction

With the advanced computer and control technology in the rolling of the wide range of applications, the product size, quality and performance requirements have become increasingly stringent. For the plate rolling, the rolling temperature control is very important. The temperature determines the metal deformation resistance. Temperature is the sensitive factor of mechanical parameters such as rolling force, torque and power, and affects the thickness precision of the product and the surface quality. The temperature is also an important condition for the recrystallization, transformation and precipitation of the hot rolling [1-4]. The control precision of the rolling temperature determines the structure and properties of the product after rolling.

During the rolling process, the development of process rules is closely related to the temperature system. The change of the temperature of each plate in the production line is an important basis for the control of the rolling rhythm and the accurate calculation of the force and energy model. The method for the treatment and calculation of the temperature in the current production environment has the following drawbacks.

(1) The temperature measuring instrument can only measure the temperature of certain location in the plate surface. Moreover, the measured values of the plate temperature near the rolling mill cannot represent the actual plate temperature because of the iron oxide skin and the residual cooling water on the surface of the rolling plate, and the accurate temperature data cannot be provided for the model calculation.

(2) At present, the non-real-time operating system often used in computer, the calculation cycle of temperature model is long, cannot achieve high-speed calculation, and the calculation accuracy cannot be guaranteed. In addition, the computer temperature model requires data from the production site, the communication between computer and control PLC also takes up a lot of system resources.

Using PLC for plate queue tracking and temperature calculations, the on-line prediction of the temperature change and the temperature distribution in the thickness direction can be obtained,, to avoid the above disadvantages, and computational speed and accuracy can meet the production requirements.

One-dimensional temperature difference model setup

In the case of the hot rolling plate, since the amount of heat dissipation in the length and width directions is much smaller than the thickness, the heat transfer in the length and width directions can be neglected, and the heat transfer process is regarded as a one-dimensional heat transfer process, thermal conductivity equation with internal heat source can be expressed using the Eq. (1).

$$\frac{\partial^2 T}{\partial y^2} + \frac{\dot{q}}{k} = \frac{1}{a}\frac{\partial T}{\partial t} \tag{1}$$

in it, $a = k/(r c)$ is a combination of physical parameters; r is the material density; c is the specific heat capacity; k is the thermal conductivity.

The third type of temperature boundary condition for a given surface heat transfer coefficient and the temperature of the surrounding medium is given by the Eq. (2).

$$k\frac{\partial T}{\partial y} + h(T - T_w) = 0 \tag{2}$$

where, h is the heat transfer coefficient between the plate surface and the outside; T_W is the ambient temperature.

For the Eq. (1) and Eq. (2), the iterative form of the temperature differential equation can be deduced by the finite difference quotient method. Since the temperature distribution of the plate in the thickness direction is symmetrical, in order to reduce the calculation amount, it is only necessary to calculate the half thickness. Before the temperature calculation, the finite difference method needs to divide the plate in the thickness direction [5, 6]. Fig. 1 shows the nodal division of the plate in half thickness direction.

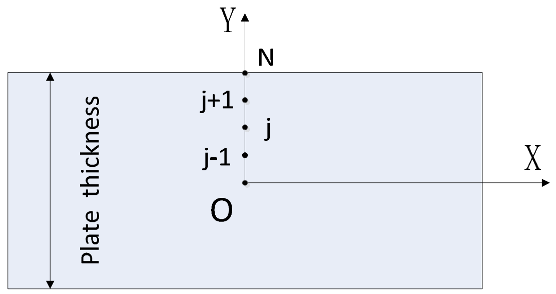

Fig.1 The finite difference calculation node division of plate temperature

Ignoring the internal heat source, the explicit finite difference iterative formula for the internal node is given by Eq. (3).

$$T_j^{k+1} = (1-2f)T_j^k + fT_{j+1}^k + fT_{j-1}^k \tag{3}$$

where, $f = a\Delta t/(\Delta y)^2$; T_j^k denotes the temperature of node j at time k; T_{j-1}^k denotes the temperature of node j at time k-1; T_{j+1}^k denotes the temperature of node j+1 at time k; T_j^{k+1} denotes the temperature of node j at time k+1.

The explicit finite difference form of the boundary condition is given by Eq. (4).

$$T_N^{k+1} = (1-2f-2B_i f)T_N^k + 2fT_{N-1}^k + 2fB_i \tag{4}$$

in it, $B_i = h\Delta y/k$; T_N^k denotes the temperature of the boundary node N at time k; T_{N-1}^k denotes the temperature of the node N-1 at time k; T_N^{k+1} denotes the temperature of the node N at time k+1.

Knowing the initial plate temperature at time k, according to the Eq. (3) and Eq. (4) constant iterative calculation can obtain temperature changes at any time.

Establishment of Rolling Tracking Queue

In the rolling process, the production line is often the existence of multiple rolled pieces, the size, location and temperature boundary conditions of each rolled piece are inconsistent. In order to be able to simultaneously predict the temperature values of multiple rolled pieces, it is necessary to establish a queue to manage. The temperature model continually traverses the rolled piece and solves the temperature according to the boundary conditions. Specific methods are as follows:

① the tracking program is called by the PLC timer interrupt OB, and the tracking queue is added when the rolled piece is released. After the whole rolling phase is finished, it is deleted from the queue;

② the position of the head is calculated according to the roller speed, the direction and the trigger time period in the PLC;

③ the rising and falling edge signals of the metal detector, and the bite and throw signal of the mill are used to modify the position of the rolled piece in the queue;

④ Rolling process with the steel plate thinning, longer, according to the rolling process to update the rolled piece size.

The one-dimensional explicit difference model of plate temperature calculation is developed in PLC. The use of structured control language (SCL) to write code for all the rolled piece of the queue in accordance with a certain trigger cycle on-line calculation of temperature changes, the result data is stored in a data block created in the PLC. The calculation of plate temperature mainly includes three kinds of boundary conditions: air cooling, water cooling and rolling process. The calculation results are transmitted to the HMI and process control system through communication interface for real-time display and temperature data for force model calculations. The plate temperature on-line computation structure design is shown in Fig. 2.

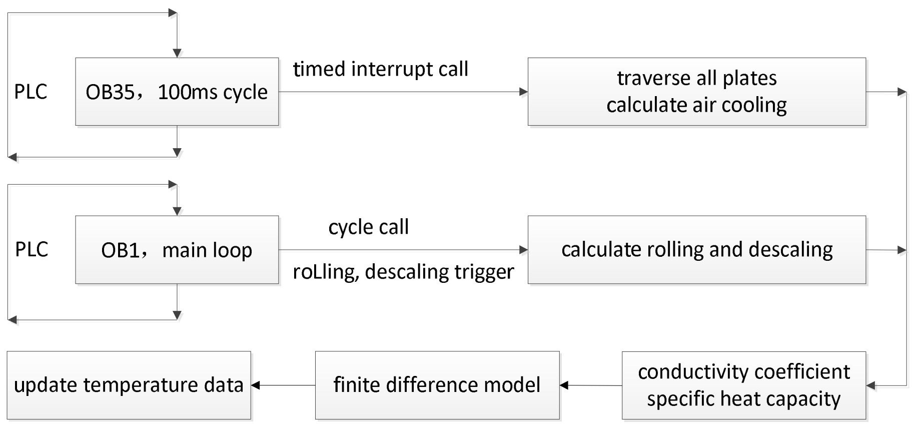

Fig.2 The plate temperature on-line computation structure

On-line prediction of plate temperature

During the plate rolling process, the temperature calculation of the rolled pieces in the queue is divided into two calling modes according to different heat transfer modes. One way for the timer interrupt call, calculate the air-cooled temperature drop, each time interval is calculated once, the temperature of the rolled piece in the queue is updated; Another way to conditional calls for the rolling process and descaling process [7, 8]. Rolled piece is rolled one time to produce a rolling call event trigger, calculating the rolling temperature change according to the current rolled piece state, and modifying the thickness. Similarly, the descaling of high-pressure water trigger generated descaling call, according to the current descaling state to calculate temperature changes.

The conductivity coefficient, specific heat and other thermal properties are affected by the composition and plate temperature. In the data block of the PLC, the composition tables of conductivity coefficient, specific heat are established in advance, the temperature is calculated according to the need to look-up table interpolation to obtain accurate initial parameters. Based on the finite difference method to calculate the plate temperature flow is shown in Fig. 3.

According to the actual rolling process, the plate temperature variation curve during the air cooling, descaling and rolling process predicted by PLC on-line is shown in Fig. 4. The prediction results show that the temperature variation of the hot rolling plate is well simulated. Compared with the measured value, the temperature prediction deviation is less than 15℃, which can meet the engineering application.

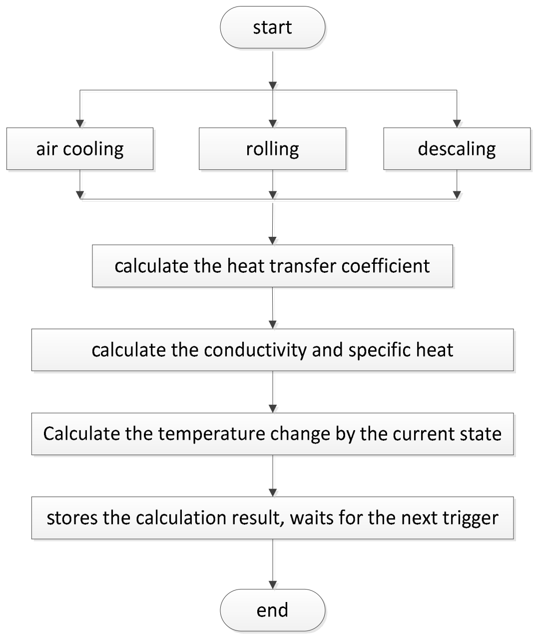

Fig.3 Temperature model calculation flow chart

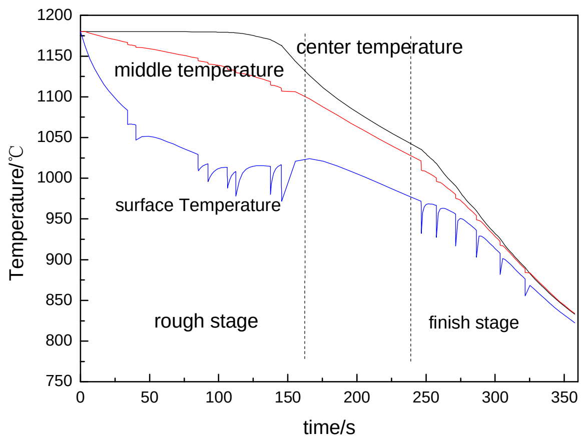

Fig.4 Rolling process temperature curve

Conclusion

By means of the discretization of temperature partial differential equations, one-dimensional explicit differential temperature iteration equation is deduced. Based on the PLC system, the plate temperature triggering calculation structure was designed, and the embedding of temperature on - line prediction model was realized.

Through the management of the rolled piece queue, the rapid temperature prediction is realized for the whole process of plate production. The temperature prediction method based on PLC has the advantages of fast calculation speed, high precision and fast response, and realizes the temperature distribution in the plate thickness direction in real time, which has important practical significance for guiding the rolling process and the calculation of the process control model.

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