Research on finite element simulation and control method of plate head bending

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Abstract. During the plate rolling process, due to the influence of the asymmetry conditions, the head of the rolled piece often shows bending. When the head of the rolled piece is bent to a certain extent, the damage to the on-site production equipment is extremely great. It is important to study how to control the head bending phenomenon in the production process to the actual production process. This paper chooses the range of parameters in which the plate is prone to head bending, and establishes the thermo-mechanical coupling model of finite element. Based on the inlet thickness, reduction ratio and roller speed difference as the initial conditions, the head bending was simulated to analyse the law affecting the plate head bending. At the same time, artificial neural network is used to train the simulation result data, and the nonlinear mapping relationship between each influencing factor and the head bending value is obtained, and then the control method of the plate head bending is established. The research in this paper has practical guiding significance for the development of plate technology.

1. Introduction

The plate head bending is a phenomenon that often occurs during the rolling process. The head bending of the rolled piece is due to the asymmetry of the thickness direction during the biting, which makes the metal flow on the upper and lower surfaces of the rolled piece inconsistent [1-3]. Due to the numerous factors affecting the head bending of the rolling piece, when the head is bent, if the adjustment is not suitable, it may cause serious equipment damage accidents.

It is a common method to control the head bending by controlling the speed difference of the rolling. Since the influence of the influencing factors on the head bending is nonlinear, it is difficult to make an accurate adjustment when the head is bent. In this paper, the head bending phenomenon occurred during the plate rolling process is taken as the research object. Based on the finite element modelling, the head bending under different influencing factors is simulated, and the head bending data under different rolling conditions is obtained [4]. Using artificial neural network algorithm to train, establish the mapping relationship between the head bending and various influencing factors, and give corresponding solutions and control methods for the head bending problem.

2. Finite Element Modelling of Head Bending

There are many factors affecting the head bendin and many factors are coupled with each other. If the rolling process is to be accurately and reasonably simulated, the rolling model must be simplified to make the model fit the actual requirements correctly. In the process of establishing the finite element model, the following assumptions are made: ① uniformity of material. ② plate is defined as deformation body, roller is defined as rigid body. ③ metal in plastic deformation zone obeys flow
criterion and hardening law. \( \textcircled{4} \) ignores widening, only consider the deformation of the sheet thickness direction.

In the process of high-speed wire rolling, the factors affecting the properties of the rolled piece after rolling include the following aspects.

Based on ABAQUS finite element software, the two-dimensional modelling of the thermo-mechanical coupling process of plate rolling was carried out according to the production conditions by explicit dynamic method. For the condition that the head bending is easy to occur in the plate rolling process, different initial parameters are set for simulation calculation. The length of the plate rolled out one meter is taken as the comparison position of the head bending value, and the influence law of different factors on the head bending is analysed. The initial parameters of the simulation calculation are shown in Table 1.

| Parameters            | Initial values |
|-----------------------|----------------|
| steel grade           | Q345           |
| work roll diameter(m) | 1.0            |
| rolling speed(m/s)    | 1.5            |
| friction coefficient  | 0.3            |
| initial temperature(℃)| 1000.0         |
| entry thickness(mm)   | 20, 30, 40, 50, 60, 70, 80, 90, 100 |
| reduction rate(%)     | 10, 15, 20, 25, 30 |
| roller speed ratio    | 1.0, 1.03, 1.06, 1.09, 1.12 |

The material stress-strain relationship during rolling is described by the Johnson-cook constitutive equation, which includes the stress state, work hardening effect and temperature softening effect \([5]\), and its form is shown in equation (1).

\[
\sigma = (A + B \varepsilon_p^m) [1 + C \ln (\dot{\varepsilon} / \dot{\varepsilon}_0)] (1 - T^*)
\]  

in the formula, \( \sigma \) is the material plastic stress, \( \varepsilon_p \) is the equivalent plastic strain, \( \dot{\varepsilon} / \dot{\varepsilon}_0 \) is the relative strain rate, \( T^* \) is a temperature-related parameter. In this paper, Q345 is selected for simulation, and the stress-strain curve is fitted to obtain the formula parameters, as shown in Table 2.

| A          | B          | n  | m  | C  |
|------------|------------|----|----|----|
| 374.1MPa   | 320.7MPa   | 0.064 | 1.06 | 0.28 |

Based on ABAQUS finite element software, the simulation calculations were carried out according to different combinations of entry thickness, reduction ratio and roller speed ratio, and the corresponding head bending values were obtained and compared. The schematic diagram of the modelling and calculation results of the finite element software is shown in Figure 1.

A schematic diagram of the effect of different rolling conditions on the bending of the steel plate head is shown in Figure 2. It can be seen from the figure that under the same reduction ratio, different rotation speed differences have different effects on the head bending of different entry thickness plates. As the roller speed difference increases, the head bending tendency of different thickness plates increases first, and then gradually stabilizes. The effect of the reduction ratio on the head bending is also a nonlinear relationship. When the reduction ratio is small, the deformation only occurs on the surface of the plate. At this time, if the upper roller linear velocity is greater than the lower roller, the plate head generally has a downward bending tendency. As the reduction ratio increases, the
deformation gradually penetrates into the plate interior, the head shape of original plate gradually became the trend of upturning.

Figure 1. Finite element modelling and calculation results.

![Figure 1: Finite element modelling and calculation results.](image1)

Figure 2. Effect of different rolling conditions on plate head bending.

![Figure 2: Effect of different rolling conditions on plate head bending.](image2)

3. Intelligent prediction method for head bending value
The simulation of the head bending of the plate by finite element software shows that the influence of different factors on the head bending value is complicated and cannot be fitted by a simple mathematical formula. In this paper, the artificial neural network is used to train the simulated data to realize the nonlinear mapping between the head bending and other factors, to obtain the influence law of the head bending, and to realize the rapid prediction of the head bending [6,7].

![Figure 3: BP neural network training structure.](image3)

The simulation data of head bending is trained by BP neural network, which consists of input layer, hidden layer and output layer. When the actual output does not match the expected output, it enters the backpropagation phase of the error. The error is gradually corrected by the output layer in accordance with the error gradient. The information forward propagation and error back propagation process is a learning and training process in which the weights of each layer are continuously adjusted until the training results meet the set accuracy.
4. Head bending control method
There are many factors affecting the plate head bending, including the rolling line elevation, the roller diameter difference, the friction coefficient, the temperature difference between the upper and lower surfaces of the rolled piece, and the roller speed difference. In the actual production process, it is often controlled by the roller speed difference. The training of numerical simulation results by BP neural network has obtained the influence of entry thickness, reduction rate and roller speed difference on head bending. If other factors do not change or change very little during the rolling process, the control of the head bending can be achieved by adjusting the influence factor of the roller speed difference.

Before implementing the speed difference control, it is necessary to obtain the influence of other influencing factors on the head bending value under a certain rolling condition. The feedback of the head bending value can be set by the head bending measuring device or the operator according to the observation. According to the feedback of the bending value of each rolling pass head, the trained neural network is used to solve the roller speed difference setting that satisfies the head bending setting, and the reverse adjustment is performed to limit the head bending value, thereby achieving the purpose of adjusting the head bending. The head bending control method is shown in Figure 4.

5. Conclusion
(1) The factors affecting the plate head bending are complicated. The finite element software is used to numerically simulate the plate rolling process under different initial conditions, and the actual engineering model is transformed into a numerical model, and the influence of various factors on the head bending can be analysed to calculate the head bending value under different rolling conditions.

(2) Based on a large number of simulation data obtained by numerical simulation, BP neural network was used to establish the prediction method of plate head bending. Taking the reduction ratio, entry thickness and roll speed ratio as input, and using the head bending value as the output, after the network training of the input data, the mapping relationship between each influencing factor and the head bending value is obtained, which provides data support for the control.

(3) In order to control the head bending value, the control method is designed for the feedback of the head bending. According to the rolling schedule, the adjustment of the speed difference under different rolling passes is calculated to meet the requirements of the automatic control of the head bending in the production process, which provides a reference and theoretical basis for the development of the head bending control process.

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