Spread prediction model of continuous steel tube based on BP neural network

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Abstract. According to the geometric pass of roll and technological parameters of three-roller continuous mandrel rolling mill in a factory, a finite element model is established to simulate the continuous rolling process of seamless steel tube, and the reliability of finite element model is verified by comparing with the simulation results and actual results of rolling force, wall thickness and outer diameter of the tube. The effect of roller reduction, roller rotation speed and blooming temperature on the spread rule is studied. Based on BP (Back Propagation) neural network technology, a spread prediction model of continuous rolling tube is established for training wall thickness coefficient and spread coefficient of the continuous rolling tube, and the rapid and accurate prediction of continuous rolling tube size is realized.

1. Introduction

As a high efficiency continuous rolling-tube unit of hot-rolled seamless steel tube production, three-roller continuous mandrel rolling mill has been widely employed in the domestic and foreign seamless steel tube manufacturers [1-3]. In the continuous rolling process of seamless steel tube, the steel tube is extruded by roller and mandrel, which makes the metal produce complex three-dimensional deformation flow. The bottom and side walls of pass have the largest amount of reduction, which makes the metal flow towards the roll gap. However, the metal in the roll gap is in free condition without contact with the mandrel and the roller and forms spread in the roll gap. Spread decides whether pass would have overfill or underfill in the rolling process. The overfill of pass will lead to rolling fold on the steel tube outer surface and the underfill of pass will lead to hollows on the steel tube inner surface [4]. At the same time, the accurate calculation of the spread determines the accuracy of each stand’s outlet area, and it is important for making roller rotation speed. The rolling process of eight-stand full floating mandrel seamless steel tube was simulated by ZHAO Zhi-yi [5], and the simulated wall thickness, outer diameter and rolling force were a good agreement with the actual results. The effect of rolling parameters on spread was studied by SHUAI Mei-rong [6] using finite element method, and she concluded that the diameter of inscribed circle of pass has an upmost effective on spread, roller diameter ranks secondly, and the rolling velocity, the temperature, and the friction coefficient have little effect on spread. The application of artificial neural network with its unique advantages on spread study of strip rolling has achieved good results [7-11], but artificial neural network is less employed in the spread of continuous tube. In this paper, a finite element model is established based on the geometric pass of roll and technological parameters in a factory to simulate the continuous rolling process of steel tube. And the effect of roller reduction, roller rotation speed and blooming temperature on the spread rule is studied. At the same time, based on BP neural network technology and according to the finite element numerical simulation results on the wall thickness
coefficient and spread coefficient, a spread prediction model of continuous tube is established to predict the size of continuous tube quickly and accurately by learning and training.

2. Spread parameters of continuous tube

In the process of steel tube continuous rolling, spread variation will affect the section size of shell. The wall thickness and outer diameter at the roll gap are important parameters in researching the spread of continuous tube. The wall thickness variation can be expressed as the wall thickness coefficient: $\alpha$. The outer diameter variation can be expressed as the spread coefficient: $\beta$. The formulas of $\alpha$ and $\beta$ are as follow:

$$\alpha = \frac{S_{bi} - S_{gi}}{S_{bi}} \quad (1)$$

$$\beta = \frac{R_{gi} - R_{bi}}{R_{bi}} \quad (2)$$

Where, $S_{gi}$ is the wall thickness of steel tube at the roll gap of the pass, $S_{bi}$ is the wall thickness of steel tube at the pass bottom of the upper pass. $R_{gi}$ is the outer diameter of steel tube at the roll gap of the pass. $R_{bi}$ is the outer diameter of steel tube at the pass bottom of the upper pass.

3. Establishment and verification of finite element model

3.1. Establishment of finite element model

A five stands three-roller continuous mandrel rolling mill is adopted as the research object in this paper. The basic dimension of the tubular billet is $\Phi222 \times 18.45$mm while the dimension of shell is $\Phi193.28 \times 10.24$mm. The outlet dimension of extracting mill is $\Phi182 \times 10.55$mm. The blooming temperature is 1150℃. The material of tubular billet is adopted 45#. The inlet velocity and outlet velocity of tubular billet is 1500mm/s and 2969.9mm/s respectively.

![Image](image.png)

Figure 1. The simulation area of three-roller mandrel pipe mill and finite element model.

The simulation area of three-roller continuous mandrel rolling mill and the finite element model are shown in figure 1. The tubular billet was defined as elastic-plastic deformation body while the mandrel and the roller were defined as rigid bodies. The penalty friction model was taken. The friction coefficient between tube and roller was set to 0.3 and the friction coefficient between mandrel and tube was set to 0.07. The plastic work heat transfer coefficient is 0.9. The contact heat transfer coefficient between mandrel and tube is 8KW/(m²·k) and the contact heat transfer coefficient between tube and roller is 20KW/(m²·k). Radiative heat transfer coefficient and convective heat transfer coefficient are considered as comprehensive effect: 0.17KW/(m²·k).

3.2. Verification of finite element model

After simulation, the average rolling force of each stand was obtained. By comparing simulation values with the measured rolling force as shown in figure 2 (a), the maximum error of rolling force is 7.88%. Figure 2 (b) is the radar chart of comparison between simulated and measured wall thickness values of outlet shell of extracting mill. And it is shown that the maximum absolute error of the wall
thickness is 0.13mm and the relative error is 0.22%. Figure 2 (c) is the radar chart of comparison between simulated and measured outer diameter values of outlet shell of extracting mill. And it is shown that the maximum absolute error value of outer diameter is 0.15mm and the relative error is 0.16%. The simulation results are in good agreement with the measured results, so the established finite element model of three-roller continuous rolling tube is reliable.

![Graph](image_url)

(a) Comparison of rolling force

(b) Comparison of wall thickness

(c) Comparison of outer diameter

Figure 2. Comparison of measured and simulated results.

4. Spread rule analysis

4.1. The influence of reduction on spread
The size of the roller reduction of three-roller continuous mandrel rolling mill is decided by the eccentricity of the roller pass. The original eccentricity of the first mill is 3mm in this paper. Keeping the blossoming temperature and the velocity schedule unchanged and the eccentricity between 2.4~3.6mm, the influence of reduction on spread coefficient of the pass is studied. The spread coefficient with the variation of eccentricity is shown in figure 3. It is concluded from figure 3 that the spread coefficient of continuous tube decreases gradually with the increase of eccentricity. This is because with the increase of eccentricity the roll gap value and the volume of metal accommodated in the roll gap decrease. Therefore, the outer diameter value of continuous tube decreases. According to the law of the lowest resistance, the metal has more axial extension.

4.2. The influence of blossoming temperature on spread
Keeping the roller reduction and the velocity schedule of continuous tube unchanged, the blossoming temperature increases by 25℃ between 950~1150℃. Then simulate the continuous rolling process of steel tube at different blossoming temperature and study the influence of blossoming temperature on spread. Figure 4 shows the effect of different blossoming temperature on spread coefficient of continuous tube. As can be seen from figure 4, the spread coefficient of continuous tube shows an increasing trend with the increase of blossoming temperature. The reason is that with the increase of the blossoming temperature the surface metal of continuous tube is oxidized and the friction coefficient increases. Therefore, the longitudinal resistance of metal flow increases and more metal flow to the roll gap which will lead to the increase of spread coefficient.
4.3. The influence of velocity schedule on spread

4.3.1. The influence of retaining speed of mandrel on spread. Keeping the roller rotation speed, the blooming temperature and the roller reduction unchanged, the retaining speed of mandrel changes every 0.3m/s. The influence of retaining speed of mandrel on spread coefficient of continuous tube is obtained as shown in figure 5. Figure 5 shows that with the increase of retaining speed of mandrel the spread coefficient of continuous tube basically unchanged, which illustrates that the retaining speed of mandrel has little effect on the spread of continuous tube.

4.3.2. The influence of roller rotation speed difference on spread of continuous tube. When setting the initial process of three-roller continuous tube, the tension force between stands is firstly required to be zero and then the tension force between stands is produced by the increase or decrease of roller rotation speed. The rotation speed difference between two adjacent stands is reduced by increasing the rotation speed of the upper pass’ rollers. The rotation speed difference between two adjacent stands is increased by increasing the rotation speed of the next pass’ rollers.

(1) The influence of roller rotation speed difference decreases between two adjacent stands on spread of continuous tube.

Keeping the retaining speed of mandrel, the blooming temperature, the reduction and the roller rotation speed of other four stands unchanged, the roller rotation speed of the upper pass between two adjacent stands is only changed. The influence of the roller rotation speed difference decrease on spread coefficient is obtained as shown in figure 6. It seems from figure 6 that with the decrease of roller rotation speed difference between two adjacent stands the spread coefficient of continuous tube increases. It is because the compressive stress increases between the two adjacent stands on the basis of original roller rotation speed with the decrease of roller rotation speed difference. Meanwhile, the longitudinal flow velocity of metal in the deformation zone becomes slow in the upper pass and more metal is forced to flow towards the roll gap. Therefore, the tendency of piling-up of steel increases and the spread coefficient of continuous tube increases.
(2) The influence of roller rotation speed difference increases between two adjacent stands on spread of continuous tube.

Keeping the retaining speed of mandrel, the blooming temperature, the reduction and the roller rotation speed of other four stands unchanged, the roller rotation speed of next pass between two adjacent stands is only changed. The influence of the roller rotation speed difference increases on spread coefficient is obtained as shown in Figure 7. Figure 7 illustrates that with the increase of roller rotation speed difference between two adjacent stands the spread coefficient of continuous tube decreases. The reason is that the tensile stress increases between the two adjacent stands on the basis of original roller rotation speed with the increase of roller rotation speed difference. In addition, the metal flows along the longitudinal direction more easily and the tendency of pulling steel increases. Therefore, the spread coefficient of continuous tube decreases.

![Figure 7](image.png)

**Figure 7.** The effect of roller rotation speed difference increase on spread of continuous tube.

**Figure 8.** Neural network structure for spread prediction.

5. Establishment of BP neural network model

BP network is a multilayer feedforward artificial neural network. It employs the back-propagation algorithm to train the network model. And the steepest descend algorithm is adopted to keep adjusting the weights and thresholds of network to reduce the error to the minimum.

Design of input layer: The material and size of tubular billet in finite element model are the same. During the simulation process, the influencing factors of spread are studied including the roller eccentricity $E$, the blooming temperature $T$, the retaining speed of mandrel $V_m$, the roller rotation speed $V_1$ of the first stand and the roller rotation speed $V_2$ of the second stand. Considering the little influence of retaining speed of mandrel on spread of continuous tube, there are four input units of BP neural network: $X = \{E, T, V_1, V_2\}$.

Design of hidden layer: In this paper a single hidden layer is adopted. The trial and error method is adopted to determine the number of hidden layer units. Therefore, six units of hidden layer are obtained by testing and training.

Design of output layer: The output units are wall thickness coefficient $\alpha$ and spread coefficient $\beta$. Therefore, the output vector is: $Y = \{\alpha, \beta\}$. Considering the large difference in magnitude, the input date and the output date should be normalized before training. The fundamental structure of spread prediction model of continuous mandrel rolling mill based on BP neural network can be determined as shown in Figure 8.

![Figure 8](image.png)

**Figure 8.** Neural network structure for spread prediction.

Design of transfer function: In this neural network model, the transfer function of hidden layer is type S logarithmic function $\logsig$, and the transfer function of output layer is type S tangent function $\tansig$.

6. The implementation of spread prediction model

The date of wall thickness coefficient and spread coefficient adopted in establishing the neural network model in this paper arises from the finite element numerical simulation. After learning and training, the error curve is obtained as shown in Figure 9. Figure 9 shows when the number of training steps reaches 8 steps it has been convergence and achieved a certain accuracy requirement. Another 15 groups of date were input into the model for prediction. The predicted date obtained were normalized
and compared with the value of finite element simulation, as shown in figure 10. Figure 10 shows that the spread coefficient and the wall thickness coefficient obtained by learning and training fit well with simulation value and BP neural network can predict well for nonlinear spread of continuous tube. In production, if these variables are arbitrarily changed, the spread of continuous tube can be predicted accurately by this neural network model.

![Figure 9. The deviation curve of BP network.](image)

**Figure 9.** The deviation curve of BP network.

![Figure 10. The comparison between simulation value and predictive value.](image)

**Figure 10.** The comparison between simulation value and predictive value.

7. Conclusion

The spread of continuous tube decreases with the increase of roller reduction and increases with the increase of blooming temperature. The influence of retaining speed of mandrel on spread is little in the process of steel tube rolling. The spread coefficient increases with the decrease of roller rotation speed difference and decreases with the increase of roller rotation speed difference of the two adjacent stands.

Based on the BP neural network, the prediction model of continuous tube spread is established. The predicted values of spread coefficient and wall thickness coefficient by learning and training fit well with simulation values which illustrates that it is feasible to predict continuous tube spread by the established neural network model.

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