Study of Short Stroke Control Model on Hot Rolling Mill

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Abstract—Head and tail width defects have a negative effect on hot strip quality. This paper developed a short stroke control (SSC) model to improve the width accuracy of head and tail. The model established a database to store the data of feature points, according to the steel grade and the working condition. This paper fitted the polynomial control curves with the feature points by the least square method, and executed the control curves on the vertical rolling. The results indicate that the model is useful for strip ends width control.

Keywords—hot mill; vertical rolling; short stroke control; least square

I. INTRODUCTION

Width is one of the important standards to evaluate the quality of hot rolling strip. Vertical rolling is the main method of width control. In the process of width reduction, head and tail width defects occur because of the different metal fluidity between the end and the body of strip. In order to prevent the problem, an on-line hydraulic press system is set up to change the opening of the vertical roll when the head and the tail pass the mill. This process is called short stroke control (SSC).

Many researchers have devoted much effort to analyze short stroke control model. Nikaido [1] built the width model of unsteady deformation in edge rolling by rigid-plastic finite element method. Li [2] built the FEA model for edging and horizontal rolling, which has been used to investigate the control model for head and tail shape on the roughing. Wu [3] established the slick curve model which has been applied to online controlling. Jiang [4] created the Gauss Bell-shaped model to simulation analysis of short stroke control and the strip width control optimization.

In this work, the short stroke control model was studied based on the production control system in Qiangang 2250mm hot strip rolling. The data of the feature points were designed and stored in the database, according to the steel grade and the working condition. The polynomial control curve was fitted with the feature points by the least square method. The method provides new ways to increase width accuracy.

II. THE PRINCIPLE OF SHORT STROKE CONTROL

In the roughing mill, strips should be rolled alternately by vertical roller and horizontal roll, and the width of the strip can be controlled by the side pressure of the vertical roller. Because of the different metal fluidity between the end and the body of the strip, the longitudinal metal flow is more likely to occur on the two end of the strip [5]. This seriously affects the end sharp

of the strip and the quality of width. Short stroke control is an advanced technology used to solve the end sharp defects. According to the contour curve of the head and tail, the vertical roll gap is changed continuously during the rolling process. If the roll gap variation curve is symmetrical and opposite to the contour curve, the width exception could be compensated. The control schematic is expressed in Figure I.

FIGURE I. SHORT STROKE CONTROL SCHEMATIC

In practical applications, the vertical roller short stroke control curve is usually made up of two parts. In the head control area, the gap opening of the terminal is the largest. As the rolling proceeds, the opening degree gradually shrinks to steady state (the opening of the strip body). In the tail control area, the strip contour curve is more complex, usually like the fishtail. The tail control curve is more complex than the head.

III. THE POLYNOMIAL CURVE MODEL OF SHORT STROKE CONTROL

The core of the model is the control curve. This paper selects polynomial curve as the control curve. The polynomial curves have the following advantages: First, it is smoother than a broken line and more adaptable to the complex contour curve; Secondly, it is easy to adjust by the operator.

The data of the points which describe the characteristics of the curve was stored in a database. According to the steel grade and the working condition, the data could be queried when the strip is going to enter the rolling mill. The least square method is used to fit the control curve, with the data of the points. After the curve fitting, the polynomial equation is sent to the PLC for the strip head and tail sharp control. The flow chart of the control model is shown as Figure II.

FIGURE II. FLOW CHART OF THE CONTROL MODEL

A. The Database of the Feature Points

The feature points data are the basis of the control curve. The database was built to store the feature points data. The basic functions of the database are the data storage and query. With different rolling conditions, the model uses different control curve. The feature points data should be classified according to rolling conditions. The rolling conditions associated with the defects of the strip include the yield strength, the entry width, the width reduction and the entry thickness. On the basis of yield strength, the strips are divided into 20 categories. The width of the main product is between 700mm to 1800mm. The thickness of the main product is between 30mm to 400mm in rough rolling. The limit of the reduction of vertical roller is 60mm. The data classification rules are shown in Table I.

TABLE I. THE DATA CLASSIFICATION RULES OF DATABASE

project	range	classification rules
steel grade	(0-20)	yield strength
entry width	(700mm-1800mm)	per 100mm
width reduction	(0-60mm)	per 10mm
thickness	(0-400mm)	per 100mm

In accordance with the classification rules, the database has about 8000 groups of data, covering all rolling conditions. And the head data and the tail data are stored separately. Each group of data contains the coordinates of the 6 points, the length of the control area and the highest degree of the polynomial. The 6 feature points are used to describe the shape of the control curve. The point coordinate is shown as $P_i(x_i, y_i)$, x_i represents the distance between the control start point and the point P_i in the direction of length. y_i represents the distance between the strip body and the point P_i in the direction of width. The length of the control area is usually less than 300mm.

B. Least Square Fitting

The least square method is a commonly used mathematical optimization technique. It searches for the best function matching of data by minimizing the sum of errors squares. The control curve was fitted with the feature points by the least

square method. Based the feature points P_1 to P_6 , the curve function was established as follows:

$$p(x) = a_0 + a_1x + \dots + a_mx^m \quad (2 < m < 5) \quad (1)$$

The optimal conditions can be expressed as follows:

$$\sum_{i=1}^n (p(x_i) - y_i)^2 = \text{MIN} \quad (2)$$

Replace $p(x)$ in (2) with (1):

$$Q(a_0, a_1, \dots, a_m) = \sum_{i=1}^n (a_0 + a_1x + \dots + a_mx^m - y_i)^2 = \text{MIN} \quad (3)$$

Solve the above equation, transform (3) as follows:

$$\begin{cases} na_0 + (\sum_{i=1}^n x_i)a_1 + \dots + (\sum_{i=1}^n x_i^m)a_m = \sum_{i=1}^n y_i \\ (\sum_{i=1}^n x_i)a_0 + (\sum_{i=1}^n x_i^2)a_1 + \dots + (\sum_{i=1}^n x_i^{m+1})a_m = \sum_{i=1}^n x_i y_i \\ \dots \\ (\sum_{i=1}^n x_i^m)a_0 + (\sum_{i=1}^n x_i^{m+1})a_1 + \dots + (\sum_{i=1}^n x_i^{2m})a_m = \sum_{i=1}^n x_i^m y_i \end{cases} \quad (4)$$

The solution (a_0 - a_m) of the (4) is the coefficient of the control curve. After the fitting of the control curve, the coefficient of the control curve will be sent to the PLC. When the strip pass passes through the vertical roll, The opening of the head and tail will change with the curve.

IV. APPLICATION OF THE SHORT STROKE CONTROL

The polynomial curve model and the database have been established on the production control system in Qiangang 2250mm hot strip rolling. Tail short stroke experiments have been conducted to verify the accuracy of the model. Every experimental strip rolling five times in the rough mill. Only in the forward pass, vertical roller is enabled. The basis rolling information is shown in Table II.

TABLE II. ROLLING INFORMATION OF FORWARD PASSES

pass	steel grade	width(mm)		thickness(mm)	
		entry	reduction	entry	reduction
1	M3A33	1155	30	220	40
3	M3A33	1167	24	156	37
5	M3A33	1171	9	87	24

According to the rolling information, the data of the feature points are queried from the database. In the pass 1, the curve function is quadratic equation, and the length of the control area is 1.0m; In the pass 3, the curve function is cubic equation, and the length of the control area is 1.2m; In the pass 5, the

curve function is quintic equation, and the length of the control area is 1.6m. The data of the feature points coordinates is shown in Table III.

TABLE III. THE DATA OF TAIL FEATURE POINTS

pass	the feature points coordinates(mm)					
	P1	P2	P3	P4	P5	P6
1	(0,1)	(0.2,1)	(0.4,3)	(0.6,2)	(0.8,1)	(1,0)
3	(0,2)	(0.48,3)	(0.72,1.5)	(0.96,0.5)	(1.08,-1)	(1.2,0)
5	(0,3)	(0.64,4)	(0.96,2)	(1.28,-2)	(1.44,-3)	(1.6,-1)

The tail control curve of the three passes was fitted by the least square method, with the date of the feature points coordinates. The tail control curves are shown in Figure III. The opening of the vertical roll was adjusted on the basis of the tail control curves.

FIGURE III. THE TAIL CONTROL CURVES

A comparable experiment was conducted to test the validity of the control model. Two strips produced in the same batch, which had the same steel grade and the same dimensions as above mentioned. The former one used the short stroke control, the latter did not use the short stroke control. Tail width measurement results are shown in Figure IV. The results show that short stroke control not only reduces the deviation, but also shortens the length of the tail defect area.

FIGURE IV. TAIL WIDTH MEASUREMENT RESULTS

The short stroked control model has been used in the Qiangang 2250mm hot strip rolling for all kinds of strips. The width accuracy is increased from 98.15% to 98.50%, and the disqualification caused by the width defects of head and tail reduced by 70%.

V. CONCLUSIONS

The strip head and tail defects can be resolved by the short stroke control model. The model was established on the polynomial control curve, which was fitted with the feature points by the least square method. The experiments show that the new model not only reduces the deviation, but also shortens the length of the tail defect area. The application of the model improves the precision of width control and reduced disqualification caused by the width defects of strip head and tail.

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