

Stiffness analysis method of rolling mill based on process data

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Abstract. Mill stiffness is an important parameter for strip rolling mill, but it is difficult to online detect. When the wide of strip are changed, or the rollers are changed, the mill stiffness will change slightly. This change can affect the thickness precision and flatness precision significantly. Making full use of the massive process data, the mill stiffness hidden in the data was found out by data mining. Firstly, according to the structure and principle of the rolling mill, the vertical thickness error equation and transverse thick error equation were established. According the error tracing theory, the stiffness tracing formulas were established. With the experiment data of 300 experimental four roll rolling mill, the stiffness analysis of rolling mill stiffness data were reliable. Experiment results showed that the plate thickness and shape control effect were good, using the rolling stiffness values from analysis.

Introduction

Mill stiffness is an important parameter for strip mill, including vertical mill stiffness, transverse mill stiffness, and roller bending stiffness. The vertical mill stiffness is the pressing down force for unit rolling mill spring, the transverse mill stiffness is the pressing down force for unit roll gap deflection, and roller bending stiffness is the bending force for unit roll gap deflection, the plate flatness can be controlled by roll bending force in rolling process^[1].

The traditional two main methods to test rolling mill vertical stiffness are the rolling experiment method and the forced-Contract method^[2]. Used the first method, many strips in different thickness are rolled with the fixed original roll gap, and the press force and thickness are measured. This method can't be used online in actual rolling process. Used the second method, there isn't strip in the mill. The upper and lower work rollers are press together, and the press force and press displacement are measured. Because the touching length of roller is different from actual rolling situation, the measured vertical mill stiffness value will be deviated from the actual value^[3].

In the cold strip steel rolling process, a large number of real-time data are stored in the database file. Except for a few are submitted to the user as a finished product data, the vast majority of process data are used inadequate. In fact a lot of important information is hidden behind these massive data^[4,5]. If a suitable data mining method is fund up, we can find the mill stiffness from the process data online.

Error tracing can be regard as inverse problem of system error analysis theory. According to system-wide dynamic accuracy theory, the total error of the system is composed of errors of the composite, and the characteristics of each error signal in time domain and frequency domain will be reflected in the overall error signal^[6]. Conversely, by decomposing the overall error in time domain and frequency domain, we can trace to error signal of each composite.

Vertical thickness equation

Such as a four-roll mill, the working principle of press down system is shown in figure 1. The work parts of the rolling mill include the two support rolls and two work rolls. Working rolls complete steel strip rolling directly, its position is completely determined by the support rollers. The bearing seat of lower support roll is fixed in rolling mill frame. The bearing seat of upper support roll is connected to hydraulic cylinder body through spherical pads, and the cylinder piston rod fixed in rolling mill frame. In the rolling process, signals from AGC system drive the electro-hydraulic servo valve to control the piston displacement, pushing the upper support roll and the upper work roll up and down, eventually control the export thickness of strip^[1].

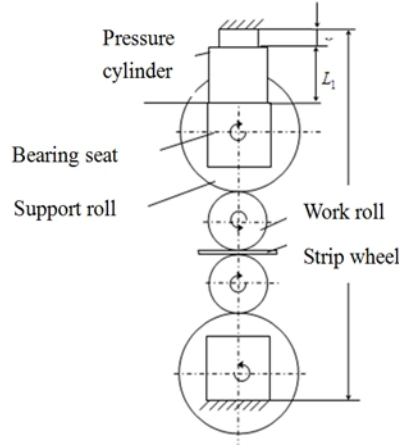


Fig.1. The strip cold rolling system

For the rolling mill with certain stiffness, the spring equation can be expressed as follows model^[7]:

$$h(t) = S_0 + \frac{P}{M} \quad (1)$$

Where P is the rolling force, M is mill vertical stiffness, and S_0 is no-load roll gap, it can be expressed as:

$$S_0 = c + x_p - x_t - x_e + x_m \quad (2)$$

Where C is a constant determined by the structure of rolling mill, x_p is the displacement of press down cylinder piston, x_t is rolls radial expansion, x_e and x_m are the eccentricity and wear of rollers. Based on the above two equations, next equation is got:

$$h = (c + x_p - x_t - x_e + x_m) + \frac{P}{M} \quad (3)$$

Transverse thickness difference equation

The transverse thickness difference related to the flatness of the strip. The Common control methods include roller bending, roller shifting and roller crossing, and so on^[8,9].

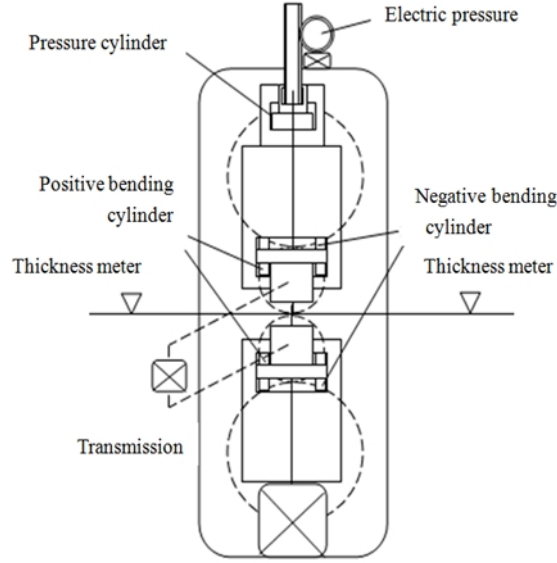


Fig. 2. The principle of work roll bending

The principle of work roll bending is shown in fig. 2. Both sides of the press down cylinder pistons are fixed on the rolling mill frame, the cylinders are fixed on the upper roll bearing seat. The cylinders drive support roller, and change the initial roll gap. Work roll bearing seats are embedded in the supporting roller bearing seats. They can fluctuate along the guide. The position in the vertical direction is determined by the positive bend and negative bend cylinder. This structure can guarantee that the work roll bending force can only affect the transverse distribution of the load on strip, without any effect on the total rolling force. There are eight positive bending cylinders and eight negative bending cylinders in both sides.

For the four-roll mill with the bending work roll control, the up rollers and low rollers are arranged symmetrically. The upper rolls, for example, are consisted of the upper support roller and the upper work roller. In the rolling process, press force is load on the bearing seats of support rolls, bending force is load on the bearing seats of work rolls, pressure load q from low work roll acts on the up rollers through strip steel as shown in fig. 3. Work roll occurs bending deformation under load, adding the original roll shape, form the shape of the roll gap, which determines the plate shape. In order to analyze conveniently, ignoring the higher order flatness, the transverse thickness difference can be represented by Strip thickness difference between center and edge.

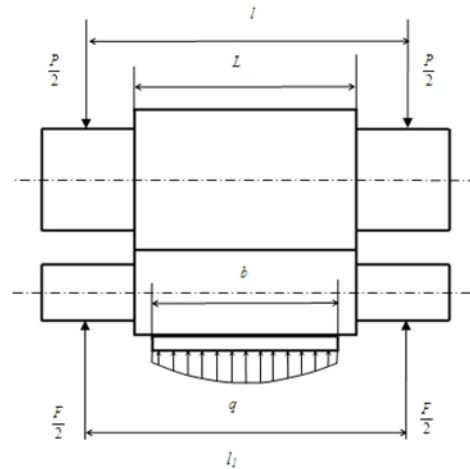


Fig. 3. Force analysis of work roll bending system

$$\Delta h_d = h_b - h_m \quad (4)$$

In this equation, h_e is the strip thickness in edge, and h_m is the strip thickness in center. Ignoring some secondary factors, the transverse thickness difference will be:

$$\Delta h_d = \frac{P}{k_p} - \frac{F}{k_f} - \frac{\Delta D_1}{k_1} + \frac{\Delta D_2}{k_2} + \frac{\Delta H_b}{k_0} - \frac{\Delta \sigma_{b1}}{k_{\sigma 1}} - \frac{\Delta \sigma_{b2}}{k_{\sigma 2}} \quad (5)$$

In equation, P is pressing force, F is bending force, k_p is transverse stiffness corresponds to pressing force P , k_f is transverse stiffness corresponds to bending force F , ΔD_{ab} is the initial roll gap difference between the center and edge, including the original crown and thermal crown, k_1 is influence coefficient of work roll crown ΔD_1 , k_2 is influence coefficient of support roll crown ΔD_2 , k_0 is influence coefficient of incoming materials crown ΔH_b , $k_{\sigma 1}$ is influence coefficient of transverse pre tension difference $\Delta \sigma_{b1}$, $k_{\sigma 2}$ is influence coefficient of transverse post tension difference $\Delta \sigma_{b2}$.

300 experimental mill and rolling experiment

Table 1 The main parameters of 300 rolling mill

Project	Quantity	Unit
The maximum rolling force	50	T
Maximum tension	5000	N
The maximum bending force	2	T
Maximum rolling torque	700	Nm
Roll surface width	300	mm
Maximum principal rolling speed	2	m/s
Hydraulic system pressure	20	MPa
Main drive motor power	45	kw
Winding motor power	22	kw
Work roll diameter	90	mm
Support roller diameter	270	mm

The rolling experiment was carried out with 300 reversible four-roller experimental rolling mill. The experiment strip was selected as low-carbon steel strip material F1006 in cold-rolled annealed condition. Experimental process was divided into continuous rolling experiments and auxiliary experiments. Continuous rolling began at room temperature, and continuous rolled forth and back three times in order to obtain a complete roll thermal transition process. In order to study the transverse thickness difference and work roll thermal crown, two thickness meters are arranged at the exit side of the mill for measuring the center thickness and edge thickness of the strip respectively, as shown in Fig.4. The main parameters of 300 mill was shown in Table 1.



Fig. 4. Ttransverse thick difference measurement scheme

Since the amount of rolling experiments data is limited, some auxiliary experiments were necessary for error tracing, including the transverse stiffness of the rolling force experiments, and the transverse stiffness of the bending force experiments.

Stiffness analysis of 300 experiment mill

Analysis of vertical stiffness Rollers will reached the thermal equilibrium state when the rolling continuous. Because Roll wear is the result of long-rolling, in a short period, the wear effect can be ignored. After removing the wear and thermal expansion and eccentricity of rollers, thickness difference equation can be expressed as:

$$h = c + x_p + \frac{P}{M} \quad (6)$$

$$P = (h - x_p)M + cM \quad (7)$$

In the above formula, the mill stiffness M and C are constant, the others is time-varying. The difference between roll gap value and the press down distance $(h - x_p)$ is the amount of bounce mill.

$$S = h - x_p \quad (8)$$

So,

$$\Delta P = M\Delta S \quad (9)$$

After preprocessing, the data are still distribute in different density, it will affect the accuracy of the regression analysis, so a partial condensation method was used, and the converted data were shown as line 1 in the Fig.5. Finally, Fitting with MATLAB "cftool" linear fit toolbox, the linear curve fitting of elastic deformation was shown as line 2, and its expression was:

$$\Delta P = 55.8\Delta S \quad (10)$$

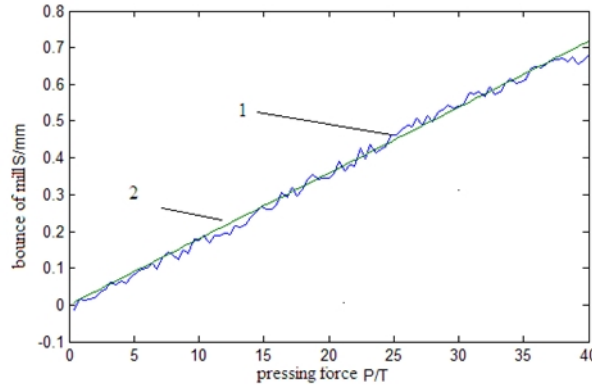


Fig. 5. Linear regression of vertical stiffness

According to the traditional roll touching stiffness testing method, the stiffness value was 58.9T / mm. So the data analysis result was slightly smaller than the results of roll touching stiffness testing method. The reason is that the data for analysis are from actual rolling, the strip width $B = 210$ mm, less than the full length of rollers 300 mm in the roll touching testing. The data analysis result is more close to the actual rolling process.

Transverse stiffness and bending stiffness analysis

Bending stiffness analysis data were obtained through the auxiliary rolling experiments, in the course of the experiment, the AGC was working in the position inner-loop model, setting the rolling force p as 36T, the rolling velocity v as 0.2m / s, and other parameters were set as the table 1. Dynamic changing bending force, and record test data. Ignoring other minor factors, the strip thickness difference between the center and edge of strip could be expressed as:

$$\Delta h_{df} = \frac{\Delta F}{k_f} \quad (11)$$

After re-queuing, condensation and other data processing, the preprocessed data in warehouse for roll bending force transverse stiffness analysis were shown as line1 in Fig.6. fitted with a least squares method, the stiffness curve was shown as line 2 in Fig.6, the transverse stiffness equation of bending force in incremental form was:

$$\Delta h_{df} = -0.00391\Delta F \quad (12)$$

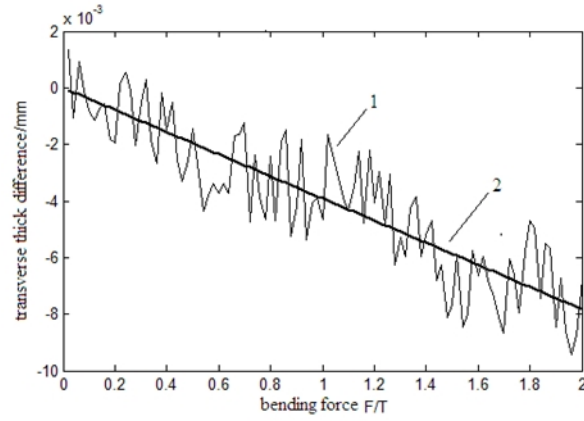


Fig. 6. T Transverse thickness difference measurement scheme

In the data analysis process for press down force transverse stiffness, all the data were preprocessed as in the process for roll bending force transverse stiffness analysis. The preprocessed data were shown as line1 in Fig. 7.

Because all the rolls used were flat rolls, $\Delta l_1 = \Delta l_2 = 0$. Keeping tension stable in the rolling process, and ignoring other minor factors, the strip thickness difference between the center and edge of strip could be expressed as:

$$\Delta h_{dp} = \Delta h_d + \frac{\Delta F}{k_f} = \frac{\Delta P}{k_p} \quad (13)$$

After fitting, the curve of stiffness curve was shown as line2 in Figure7. And the incremental deflection equation was:

$$\Delta h_{dp} = 0.000664 \Delta P \quad (14)$$

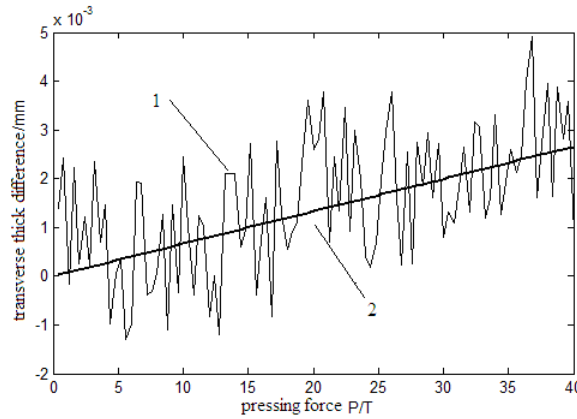


Fig. 7. Linear regression of press down transverse stiffness

Conclusion

Take advantage of a lot of rolling process data, each of stiffness of mill can be obtained using data mining and thickness error tracing method. Experimental results show that the rolling process is stable and flatness is fine using the stiffness data from data analysis. This stiffness analysis method can be extended to other mills.

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