Algorithm design and application of novel GM-AGC based on mill stretch characteristic curve

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Abstract: As the spring equation is limited to the accuracy of mill stiffness and the linearity of the mill spring curve, the traditional gaugemeter automatic gauge control (GM-AGC) system based on spring equation cannot meet the requirements of practical production. In allusion to this problem, a kind of novel GM-AGC system based on mill stretch characteristic curve was proposed. The error existing in calculating strip thickness by spring equation were analyzed first. And then the mill stretch characteristic curve which could effectively eliminate the influence of mill stiffness was described. The novel GM-AGC system has been applied successfully in a hot strip mill, the application results show that the thickness control precision is improved significantly, with the novel GM-AGC system, over 98.6% of the strip thickness deviation of 3.0 mm class can be controlled within the target tolerances of ±20 μm.

Key words: hot strip mill; gauge meter automatic gauge control; mill stretch characteristic curve; mill stiffness

1 Introduction

The thickness accuracy is the important quality index in hot tandem rolling process. In order to improve the thickness accuracy, the automatic gauge control (AGC) system which is usually composed of feed forward AGC, gaugemeter automatic gauge control (GM-AGC), smith-predict monitor AGC system and other compensations is widely used in modern hot strip mills of the world [1−2]. Feed forward AGC system measures the hardness pattern (furnace skid marks) at the entry stand and adjusts the gap of downstream stands to correct for hardness changes. This entry hardness profile is recorded in a list and tracked as the strip moves through the mill [3]. The GM-AGC system is developed from the BISRA-AGC system which only takes the mill stiffness into account. Compared with BISRA-AGC, the dynamic response characteristics of GM-AGC system are desirable with the consideration of mill reduction efficiency compensation [4−5]. The smith-predict monitor AGC system further improves control of the hot strip mill’s exit thickness using strip thickness deviation feedback measured by an X-ray gauge meter. It compensates for long-term changes in strip properties. Although the strip thickness of each stand is controlled using GM-AGC. The smith-predict monitor AGC system augments these subordinate controls to produce optimum control of exit strip thickness [6−8]. The combined application of GM-AGC system and smith-predict monitor AGC system obtains good control precision and becomes the common form applied in hot strip mill.

Due to the direct measurement of the loaded roll gap with metal in stand is still a problem to be resolved, the spring equation is used to calculate the loaded roll gap during rolling process, and strip exit thickness results directly from the loaded roll gap. The GM-AGC system which calculates strip thickness by spring equation as the feedback to regulate exit strip thickness from each stand has become the critical AGC function. But the control precision of GM-AGC system is not satisfied as it is impossible to obtain accurate strip thickness reference by spring equation. Many scholars have made unremitting efforts to improve the control precision of GM-AGC system for many years, however, the studies all focused on the accuracy of the mill stiffness, the problem of strip thickness reference radically was not solved because of the nature of spring equation has not been revealed [9−13]. Thus, the traditional GM-AGC cannot meet the severe requirements of practical production.
In this work, the error causes in calculating strip thickness by spring equation were analyzed. The foundation, drawbacks, and limitations of GM-AGC system based on spring equation were revealed. To overcome the deficiency of the traditional GM-AGC system, a new model which developed from the mill stretch characteristic curve was brought forward to calculate strip thickness reference for GM-AGC system. Therefore, the GM-AGC system based on mill characteristic curve has theoretical basis and it improves control precision significantly.

2 Basic principles of GM-AGC system

The GM-AGC system modifies gap position to maintain strip thickness constant. Under the steady-state rolling conditions, a linear relationship between the exit strip thickness, roll gap, and rolling force was expressed by spring equation:

$$h = S + \frac{P - P_0}{K_m}$$  \hspace{1cm} (1)

where $S$ is unloaded roll gap; $P$ is rolling force; $P_0$ is the calibration rolling force; $K_m$ is the mill stiffness. The spring equation provides theoretical basis for GM-AGC system to estimate stand exit strip thickness.

For the GM-AGC system, the strip thickness reference has first to be created during logon phase by calculating the average valves over the actual roll gap and the actual rolling force. According to spring equation, the strip thickness reference is shown in Eq. (2):

$$h_L = S_L + \frac{P_L - P_0}{K_m}$$  \hspace{1cm} (2)

where $S_L$ is locked roll gap; $P_L$ is locked rolling force.

Substituting Eq. (2) into Eq. (1), the thickness deviation $\Delta h$ can be obtained as

$$\Delta h = h - h_L = S - S_L + \frac{P - P_L}{K_m}$$  \hspace{1cm} (3)

Considering the reduction efficiency of screw down system, the adjustment of GM-AGC system $\Delta S_{GM}$ to eliminate the thickness deviation is obtained as

$$\Delta S_{GM} = -(1 + \frac{Q}{K_m})\Delta h = -(1 + \frac{Q}{K_m})(S - S_L + \frac{P - P_L}{K_m})$$  \hspace{1cm} (4)

where $Q$ is plastic coefficient.

3 Analysis of calculation error of spring equation

For calculation of the strip thickness by spring equation, it is necessary to ensure the premise conditions as follows: 1) the spring curve is linear; 2) the mill stiffness $K_m$ is accurate. Limited to the clearance in mechanical structure and the contact deformation, the ideal conditions do not exist, which lead to the accurate strip thickness for traditional GM-AGC system is impossible to be obtained by spring equation. This not only causes the strip thickness deviation cannot be eliminated completely, but also under some special conditions, the control effect will be deteriorated because of the inverse of roll gap regulate direction.

3.1 Error analysis caused by stiffness deviation

The spring equation is graphically shown in Fig. 1, where the slope of mill spring curve represents the mill stiffness which is defined as the rolling force on roll gap generates unit change.

![Fig. 1 Mill spring curve](image)

It is well known that the establishment condition of spring equation is that the mill spring curve is linear, which means that the mill stiffness is constant. Mill spring curve can be approximately considered as linear on high rolling force phase. The spring equation shows that the mill stiffness plays a key role in calculation of strip thickness. But the mill stiffness has deviation from the actual mill stiffness during rolling with the change of the rolling force.

Assume that the mill stiffness deviation $\Delta K_m$ exists between calculated mill stiffness $K_m^*$ and actual mill stiffness $K_m$. According to spring equation, the relationship between actual strip thickness deviation, mill stiffness and the mill stiffness deviation is expressed by [14]

$$\Delta h = \frac{P_L - P}{K_m^*} + \frac{P - P_L}{K_m} = (P - P_L)(\frac{1}{K_m} - \frac{1}{K_m + \Delta K_m}) = (P - P_L)(\frac{\Delta K_m}{K_m^2 + K_m \cdot \Delta K_m})$$  \hspace{1cm} (5)

According to Eq. (5), if $P - P_L \neq 0$, the actual strip thickness deviation is impossible to be eliminated.