DECOUPLED MODEL FOR FLATNESS CONTROL IN 4-H CVC COLD ROLLING MILLS[①]

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ABSTRACT The decoupling of complex interactions between work roll shifting and work roll bending is very important in achieving optimum strip flatness control of CVC mills. An analytically decoupled model that can explicitly describe the functions of work roll shifting and bending has been developed through analysis of the roll gap profile. The model can be used for flatness on-line control of 4-h CVC cold rolling mills.

Key words decoupled model gage and shape control cold rolling

1 INTRODUCTION

The precise control of roll gap in 4-h CVC mills is particularly difficult due to the complex interactions between work roll shifting and bending. The shifting is coupled with bending to provide a wider control range of the strip flatness but cause the control of strip flatness to be more difficult.

For many years, flatness has been modeled by a quartic polynomial with two most significant 2nd-order and 4th-order coefficients being assigned to the x^2-term and x^4-term respectively. CVC work roll bending influences 2nd-order (wavy edges and center buckles) and 4th-order (quarter buckles or a combination of wavy edges and center buckles) flatness errors. CVC shifting basically changes only 2nd-order flatness errors. The coupled roll gap interactions arising from shifting and bending create some flatness control difficulties, which requires special care if precise control of roll gap is to be achieved.

A number of articles[1-10] have been published that deal with the flatness control in 4-h CVC mills. Usually, discrete or regressive strip profile models combined with some control strategies have been used in the flatness control. In this paper, we shall make use of an analytical roll gap model to develop a decoupled model for on-line flatness control in 4-h CVC cold rolling mills.

2 STRIP SHAPE MODEL

The strip transverse profile can be modeled by the contour of roll gap within the strip width. Referring to Fig. 1, we can find the following two differential equations[11]:

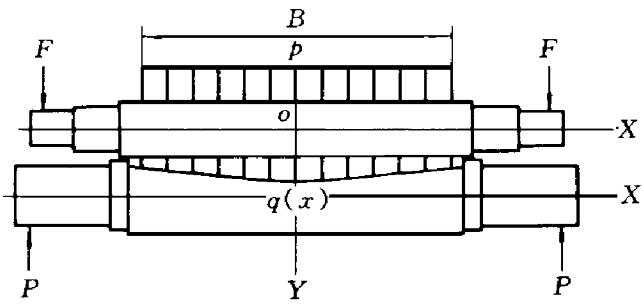

Fig. 1 Roll loading mode
(only lower part is shown)

$$\frac{d^4 y_w(x)}{dx^4} = \frac{p - q(x)}{EI_w} + \frac{\alpha}{GA_w} \cdot \frac{d^2 q(x)}{dx^2} \quad (1)$$

$$\frac{d^4 y_B(x)}{dx^4} = \frac{q(x)}{EI_B} - \frac{\alpha}{GA_B} \frac{d^2 q(x)}{dx^2} \quad (2)$$

in which the specific roll force distribution

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$$p = (P - F)/B \quad (3)$$

and a compatibility condition equation

$$y_w(x) - y_B(x) = K_1 q(x) \quad (4)$$

where $y_w(x)$, $y_B(x)$ —deflections of work roll and backup rolls;
$q(x)$ —inter-roll pressure distribution;
E —Young's modules of elasticity;
G —shear modules;
α —shear correction factor;
I_w, I_B —moments of inertia of work roll and backup roll bodies;
A_w, A_B —cross-section areas of work roll and backup roll;
P —separating force;
F —work roll bending force;
B —strip width;
K_1 —inter-roll flattening constant.

Hence, the roll gap profile or the strip shape can be expressed as

$$g(x) = y_w(x) + y_B(x) + G(x) + K_2 p \quad (5)$$

in which, the equivalent profile of the work roll gap[12]

$$G(x) = f_1(S) + x^2 f_2(S) \quad (6)$$

and work roll/strip flattening constant[13]

$$K_2 = \frac{4(1-\mu^2)}{\pi E} \quad (7)$$

where $f_1(S)$ and $f_2(S)$ are functions of CVC shifting distance S, μ is the Poisson's ratio.

3 FLATNESS ERRORS

The 2nd-order and 4th-order flatness errors can be described as 2nd-order and 4th-order crowns respectively[12]. The 2nd-order crown

$$C_2 = g(0) - g(0.5B) \quad (8)$$

and the 4th-order crown

$$C_4 = g(0.25B) - 0.75g(0) - 0.25g(0.5B) \quad (9)$$

From Eqns. (1) ~ (9), we can finally find that

$$C_2 = a_0 + a_1 S + a_2 F + a_3 P \quad (10)$$

$$C_4 = b_0 + b_1 S + b_2 F + b_3 P \quad (11)$$

where $a_{0\sim3}$ and $b_{0\sim3}$ are constants. The analytical relations explicitly shown in these two equations are consistent with what have been revealed from experiments and theoretical regressive results[14-16].

4 DECOUPLED CONTROL MODEL

Now, the decoupled model for flatness control can be easily obtained from simultaneous Eqns. (3), (10) and (11) as follows:

$$F = \frac{a_0 b_1 - a_1 b_0}{D} - \frac{b_1}{D}C_2 + \frac{a_1}{D}C_4 - \frac{a_1 b_3 - a_3 b_1}{D}Bp \quad (12)$$

$$P = \frac{a_0 b_1 - a_1 b_0}{D} - \frac{b_1}{D}C_2 + \frac{a_1}{D}C_4 + \frac{a_1 b_2 - a_2 b_1}{D}Bp \quad (13)$$

$$S = \frac{a_1 b_0 (a_1 + a_2)}{a_1 D} - \frac{a_0[a_1(b_2 + b_3) + b_1(a_1 - a_3)]}{a_1 D} + \frac{a_1(b_2 + b_3) + b_1(a_1 - a_3)}{a_1 D}C_2 - \frac{a_1 + a_2}{D}C_4 + \frac{a_1 b_3 (a_1 + a_2)}{a_1 D}Bp - \frac{a_3[a_1(b_2 + b_3) + b_1(a_1 - a_3)]}{a_1 D}Bp \quad (14)$$

where

$$D = a_1(b_2 + b_3) - b_1(a_2 + a_3)$$

Therefore, if we have known the required values of 2nd-order crown C_2, 4th-order crown C_4 and specific roll force distribution p (or strip thickness), we can make use of this analytically decoupled model to determine the settings of the roll force P, CVC shifting distance S and bending force F.

5 SUMMARY

A general method has been introduced to establish an analytical roll gap model. With this model, an analytically decoupled model for roll gap control is developed. The model can be used for flatness on-line control in 4-h CVC cold rolling mills. The analysis method introduced in this paper can be used to develop roll gap profile models and control models for other kinds of mills.

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