Application and Research of New Monitor AGC in Hot Strip Mill

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Abstract. A Monitor AGC control system is applied to a hot strip mill in a steel plant, due to some irrationality gain factors and the hysteresis of the Monitor AGC control output, the strip thickness deviation is large. This paper designs a new type Monitor AGC that includes two control methods:Integral type Monitor AGC and Smith's method Monitor AGC, they are able to select alternately. The experimental results show that the effect of Integral type Monitor AGC and Smith's method Monitor AGC is obvious, and the accuracy of thickness control is obviously improved.

Keywords: Monitor AGC, Integral type, Smith's method, hot strip mill, thickness deviation.

1. Introduction

The Monitor AGC (M-AGC) refers to precise measurement of the finish mill delivery thickness of the strip by means of X-ray thickness gauge and the result is applied as a gap correction to the Gap Control for each stand [1]. X-ray Monitor defaults to Absolute and will produce gap corrections to make the strip thickness equal the X-ray gage target thickness (zero deviation).

The indirect thickness control system based on the bounce equation considers various compensation factors (roll bending deformation compensation, roller roll crown compensation, oil film compensation, roll thermal expansion compensation, etc.), but its thickness measurement accuracy is much lower than X-ray thickness gauge, therefore, M-AGC is indispensable for modern strip hot rolling.

2. Integral Type Monitor AGC

The X-ray Monitor regulator uses integral control to eliminate steady state errors. The regulator provides independent control of the correction to each stand to allow fast response for the head of the strip with a means to control overshoot and a scheme to balance monitor corrections among stands. Figure Fig.1 is an overview of the X-ray Monitor Function.

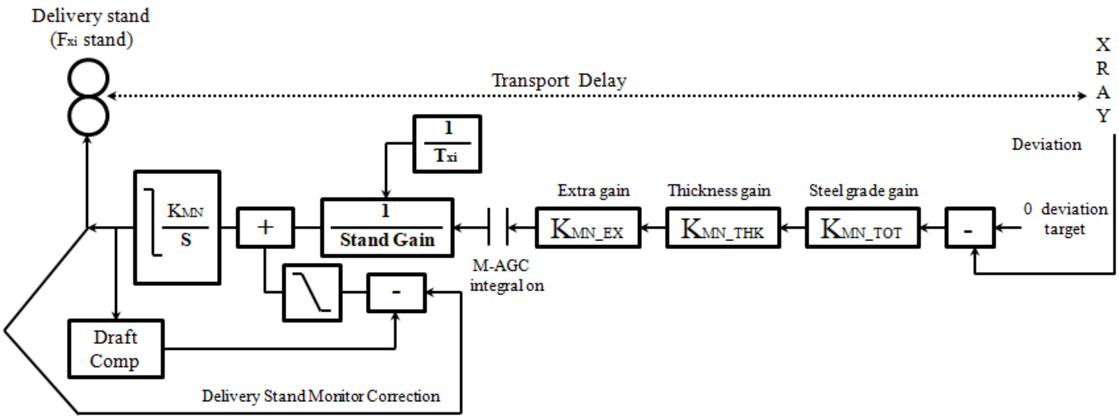

Fig. 1 X-ray Monitor Block Diagram

The regulator for the delivery stand can act the quickest because the delivery stand is closest to the X-ray gage. However, all correction cannot be applied by the delivery stand because of power, load distribution and shape considerations [2-4]. Therefore, the X-ray Monitor control will make a correction at the delivery stand quickly and gradually add correction upstream to distribute the load to other stands.

2.1 Calculation of Gain.

Experience has proven that stability of the X-ray Monitor control varies with strip thickness. A higher gain can be tolerated when rolling heavier gage. Therefore, the gain (K_{MN_TOT}) for all stands is modified based on the X-ray gage target thickness. This gain (K_{MN_TOT}) is also modified based on the steel grade classify.

$$K_{MN\_TOT} = K_H \times K_G \times K_C \tag{1}$$

where, K_{MN_TOT} is the F_{xi} M-AGC total gain (-). K_H is the HI-B steel grade correction (-), and different steel grade family, different values. K_G is the steel grade gain (-). K_C is the M-AGC stand (F_{xk}, F_{xk-1} or F_{xk-2}) change gain.

The gain (K_{THK}) modifier related to product thickness is created by linear interpolation between gains for target thickness.

$$K_{THK} = \left(h_{ext} - X_{n-1}\right)\frac{Y_n - Y_{n-1}}{X_n - X_{n-1}} + Y_{n-1} \tag{2}$$

where, K_{THK} is F_k M-AGC thickness gain, hext is last stand delivery thickness (mm), F_k M-AGC thickness gain table X(-) and Y(-) are shown as below.

Table 1.Fk M-AGC Thickness Gain Table

F_k M-AGC THICKNESS GAIN TABLE X(-)		F_k M-AGC THICKNESS GAIN TABLE Y(-)	
if	$X_0 = 1.2$	*then*	$Y_0 = 0.60$
if	$X_1 = 1.6$	*then*	$Y_1 = 0.65$
if	$X_2 = 2.0$	*then*	$Y_2 = 0.68$
if	$X_3 = 2.5$	*then*	$Y_3 = 0.70$
if	$X_4 = 3.0$	*then*	$Y_4 = 0.75$
if	$X_5 = 4.0$	*then*	$Y_5 = 0.80$
if	$X_6 = 5.0$	*then*	$Y_6 = 0.80$
if	$X_7 = 6.5$	*then*	$Y_7 = 0.80$
if	$X_8 = 11.0$	*then*	$Y_8 = 0.80$
if	$X_9 = 14.0$	*then*	$Y_9 = 0.80$

The X-ray Monitor Gain for all stands is increased when the error is excessively large. When the error is large the gain can be increased to try to bring the strip on gage more quickly and then returned to a level that will not cause excessive overshoot. The level at which the extra gain is applied and the amount of extra gain are adjustable to allow coordination with the limits of the Loopers ability to maintain mass flow.

$$K_{MN\_XGAIN} = \begin{cases} 1.55 & 7 \le h < +\infty \\ 1.45 & 3 \le h < 7 \\ 1.35 & 2 \le h < 3 \\ 1.35 & 0 \le h < 2 \end{cases} \qquad K_{MN\_EX} = \begin{cases} 1.0 & \Delta h < l_j \\ K_{MN\_XGAIN} & \Delta h \ge l_j - l_d \\ 1.0 & \Delta h < l_j - l_d \end{cases} \tag{3}$$

Where, K_{MN_XGAIN} is monitor extra gain (-), K_{MN_EX} is M-AGC selected extra gain (pu), △h is M-AGC error from deviation reference (mm), l_j (j=1, 2) is monitor extra gain error level (mm), $l_1 = 0.02$ in 5s after opening, $l_2 = 0.04$ after opening 5s, l_d ($l_d = 0.01$) is monitor extra gain error level dead band (mm).

2.2 Effects of Transport Delay.

The regulator gain for each stand determines the rate at which that regulator can correct. The gain is limited by the transport time from the correction of the strip at the stand until the effect of that correction is measured by the X-ray gage. The gain must be reduced as transport time increases.

$$T_{Xi} = \sum_{i=j}^{k-1} \frac{L_i}{\left(1+f_i\right)\cdot V_{Ri}} + \frac{L_{Xk}}{\left(1+f_k\right)\cdot V_{Rk}} \qquad 1 \le \mathrm{i} \le k \quad \text{k is final control stand} \tag{4}$$

where, T_{Xi} is No. i stand ~ X-ray transport time (sec), $1 \le i \le k$, k is final control stand; L_i is No. i to No. i+1 stands distance (m); f_i is No. i stand forward slip ratio (-); V_{Ri} is No. i stand roll peripheral speed (m/s); L_{Xk} is final control stand ~ X-ray distance (m); f_k is final control stand forward slip ratio (-); V_{Rk} is final control stand roll peripheral speed (m/s).

M-AGC control output ΔS_{MN_AGC} is within limit. If ΔS_{MN_AGC} is over limit, M-AGC control output is held.

$$-\Delta S_{LM\_MN\_AGC} \le \Delta S_{MN\_AGC} \le \Delta S_{LM\_MN\_AGC} \tag{5}$$

$\Delta S_{LM\_MN\_AGC}$ = 0.5 mm.

3. Smith's Method Monitor AGC

Smith's method Monitor AGC get rid of offset error between final stand's gage-meter thickness and Finishing mill delivery side X-Ray strip thickness. Smith's method Monitor AGC works with ABS-GM-AGC, and works as gage-meter thickness correction for ABS-GM-AGC. Smith's method Monitor AGC and Integral type Monitor AGC are able to select alternately. Smith's method Monitor AGC block diagram is shown as below.

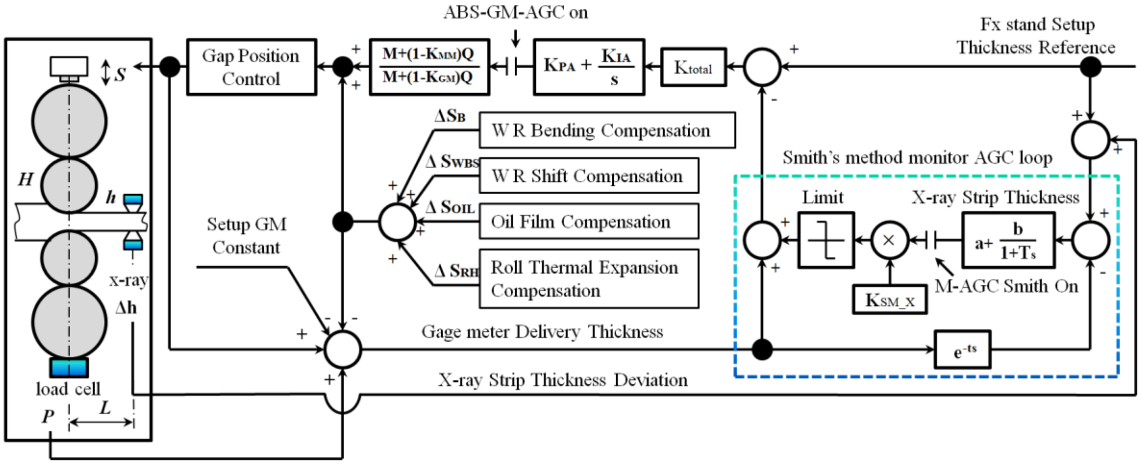

Fig. 2 Smith's method Monitor AGC block diagram

3.1 Calculation of Gain.

In Smith's method Monitor AGC loop block, the K_{SM_i} is upstream stand distribution gain (-); T_S is main scan time (sec); a and b is constant; e^{-ts} is the lagging link [5].

$$K_{SM\_i} = \frac{P_{SET\_Fi}}{P_{SET\_Fx}} \times K_{SMADJ\_i} \tag{6}$$

where P_{SET_Fi} is F_i stand predict force (kN); P_{SET_Fx} is last stand predict force (kN); K_{SMADJ_i} is adjust gain (-).

The K_{total} is compensation gain (-); K_{PA} is proportional gain (-); K_{IA} is integral gain (-) ; M is mill modulus (kN/mm), (calculated by Level based on mill modulus curve equation and actual force); Q is plasticity coefficient(strip hardness) (kN/mm) (set by FSUC); K_{GM_LK} is gage meter gain for LKON-GM-AGC (-) (constant gain × strip hardness gain); K_{MM} is MMC gain (-), when ABS-GM-AGC on: K_{GM} = 1.0, when LKON-GM-AGC on: $K_{GM} = K_{GM\_LK}$ when MMC off: K_{MM} = 0.0.

3.2 Application of Smith's Method Monitor AGC.

Smith's method Monitor AGC correction is distributed to upstream stand AGC to prevent the load unbalance [6]. Smith's method Monitor AGC block diagram for each stand is shown as below.

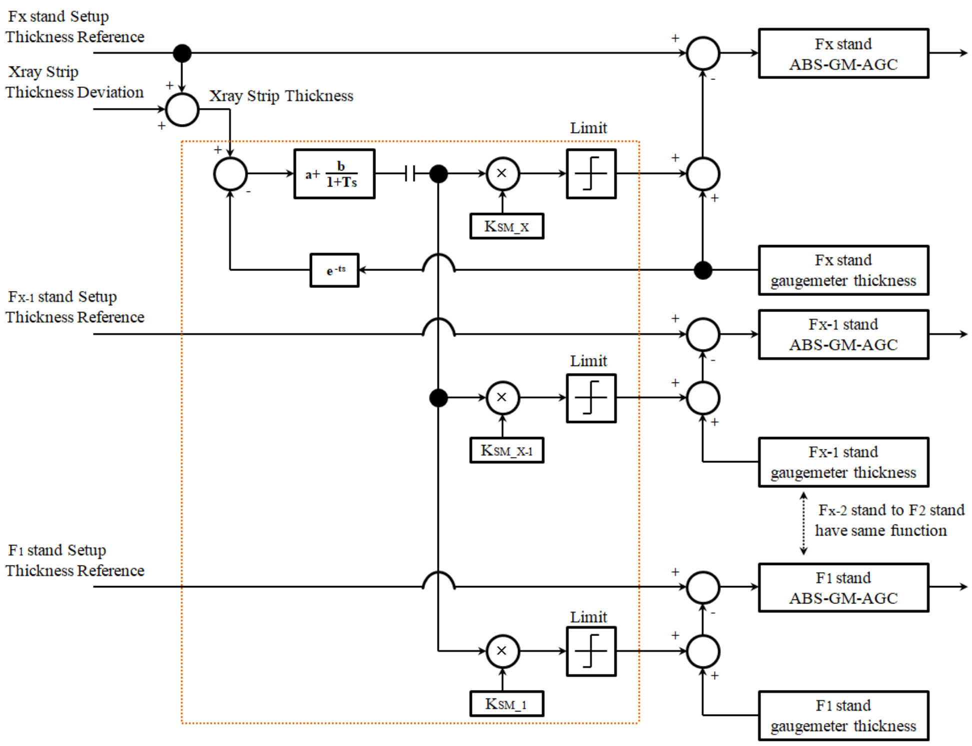

Fig. 3 Smith's method Monitor AGC block diagram for each stand

Switching between Smith's method Monitor AGC and Integral-type M-AGC.

If $V_P \leq V_{limit(L)}$ is realized during Integral-type M-AGC is executing, Integral-type M-AGC stops, Smith's method starts, where V_P is F_k delivery speed, $V_{limit(L)}$ is M-AGC changing speed lower limit.

If $V_P \geq V_{limit(U)}$ is realized during Smith's method is executing, Smith's method stops and Integral type M-AGC starts, where $V_{limit(U)}$ is M-AGC changing speed upper limit.

Smith's method Monitor AGC control output ΔS_{SM_AGC} is within limit. If ΔS_{SM_AGC} is over limit, Smith's method Monitor AGC control output is held.

$$-\Delta S_{LI\_SM\_AGC} \leq \Delta S_{SM\_AGC} \leq \Delta S_{UP\_SM\_AGC} \tag{7}$$

For F_K, F_{K-1}, F_{K-2} stands $\Delta S_{LM\_MN\_AGC}$ = 0.5 mm, $\Delta S_{UP\_MN\_AGC}$ = 0.6 mm. For upstream $\Delta S_{LM\_MN\_AGC} = \Delta S_{UP\_MN\_AGC}$ = 0.5 mm.

The new Monitor AGC was tested on the machine. Without removing the head and tail of the strip, the thickness difference of each 100-volume strip before and after using the new Monitor AGC was calculated. Taking silicon steel S30-Y as an example, the specification of the 200-volume strip is 2.6mm × 1222mm. The statistical results are shown as below.

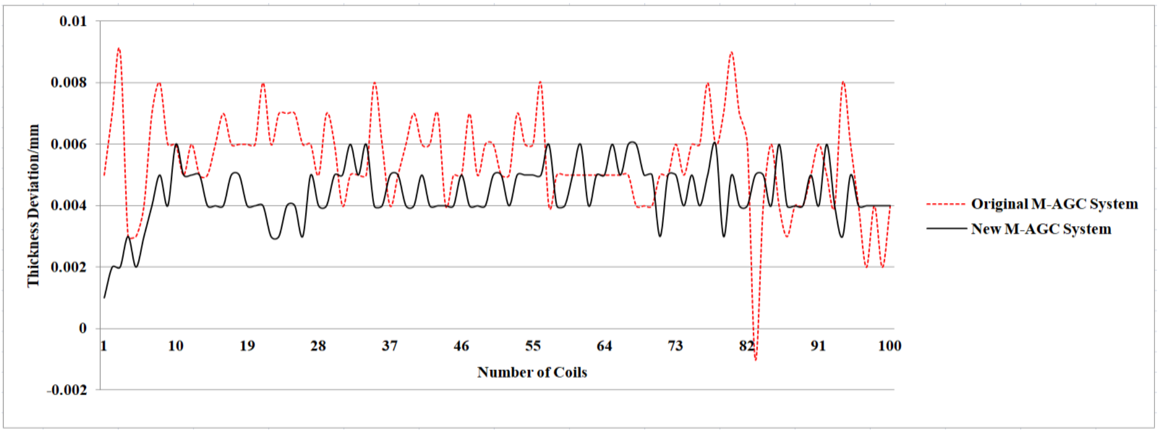

Fig. 4 Statistical results of thickness difference

4. Conclusion

Monitor AGC has a strong function, if the model error is larger; Monitor AGC plays a decisive role in the control effect of thickness precision. Two kinds of control methods for Monitor AGC are designed: Integral type Monitor AGC and Smith's method Monitor AGC, they are able to select alternately according to needs. The practical application shows that the new Monitor AGC system has good stability and control precision. The delivery actual thickness deviation can be controlled within or below ± 0.006mm.

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