

# A Strategy to Monitor AGC in Consideration of Rolling Force Distribution

WEI-YI CHIEN\*, HENG-HSING CHENG\*, CHING-SHUN YI\*\*  
and MING-CHANG CHANG\*\*

*\*Steel and Iron Research & Development Department*

*\*\*Rolling Mill Department-II  
China Steel Corporation*

In this paper, an improved strategy for the monitor automatic gauge control (MAGC) with consideration of the rolling force distribution in hot strip rolling mills is proposed. The strip delivery thickness deviation is corrected by keeping the same setup rolling force distribution ratio for the last 3 downstream stands in a 7 tandem-stand mill. The advantage of this strategy is that the strip thickness deviation is not corrected dominantly by the final stand so that the strip flatness disturbance during the correction of thickness errors can be minimized. In order to evaluate the effectiveness of this new strategy, the flatness conditions of two thin gauge rolling cycles in the same rolling campaign are examined based on the original MAGC and on the improved MAGC. The results show that the calculated strip flatness variations in downstream stands before and after the MAGC taking effect are smaller using the improved MAGC compared to those using the original MAGC. Furthermore, the measurements of the flatness meter show that the strip flatness achieves a stable condition more quickly using the improved MAGC.

**Keywords:** Thickness control, rolling, flatness, MAGC

## 1. INTRODUCTION

Thickness precision is one of the most important indices of the strip quality. However, since the mill stand is an elastic structure, the strip thickness accuracy is influenced by disturbances such as the hardness and the temperature fluctuation of the strip. In hot strip mills, the monitor automatic gauge control (MAGC) is a gauge control system to eliminate the strip delivery thickness deviation by adjusting roll gaps based on the actual thickness measurement from the gauge meter. However, the gauge meter is located some distance behind the final stand. Therefore, a time delay of thickness correction exists in the MAGC system. The delay time deteriorates the accuracy and efficiency of the thickness corrections. In order to minimize the effect of the time delay, the correction of strip delivery thickness deviation is usually dominated by the final stand. However, when the strip delivery thickness deviation is significant, an instability in strip flatness can be expected due to the incompatibility of roll gap adjustments between the final stand and the upstream stands.

In this paper, the original MAGC is first explained. Then, an improved strategy for MAGC based on the

setup rolling force distribution ratio in the last 3 downstream stands is proposed. In order to evaluate the effectiveness of the new strategy, two thin gauge rolling cycles in the same rolling campaign are tested based on the original MAGC and on the improved MAGC, respectively. Finally, the rolling force variations, the calculated flatness variations, and the flatness measured by a flatness meter, are compared between the original MAGC and the improved MAGC, respectively.

## 2. MONITOR AGC

The function of the MAGC is to eliminate strip delivery thickness deviations based on the strip thickness measured by the gauge meter. The delivery strip thickness error is obtained by comparing the reference thickness with the actual thickness feedback from the gauge meter. The error and the rate of change of error are inputted into the controller, and then a dynamic roll gap adjustment is obtained to eliminate the delivery thickness error. In the following sections the original MAGC and the improved MAGC are described.

### 2.1 Original MAGC

The mathematical model for the correction of the reference thickness at each stand in the original MAGC

can be described as follows:

$$\Delta h_i = \frac{1}{3T_{xi}} \times K_{m\_Total} \times \frac{K_i}{S} \times \Delta h_{err} \dots\dots\dots(1)$$

Where:  $\Delta h_i$  is the thickness correction at the  $i^{th}$  stand;  $T_{xi}$  is the transport time from  $i^{th}$  stand to the gauge meter;  $K_{m\_Total}$  is the compensation gain;  $K_i$  is the integral control gain; and  $\Delta h_{err}$  is the thickness error measured by the gauge meter.

It is clear that the transport time  $T_{xi}$  at the final stand is significantly less than that at other upstream stands due to the higher roll speed and shorter distance to the gauge meter. Therefore, in order to increase the efficiency of the MAGC, the thickness deviation is corrected dominantly by the final stand, as can be seen in Eq.(1). However, the strip flatness is affected by adjustments of the roll gaps in the rolling process. Based on Shohet and Townsend<sup>(1)</sup>, the flatness index unit (IU) is defined as the change of the strip crown ratio through the roll gap:

$$I = \left( \frac{C_{out}}{h_{out}} - \frac{C_{in}}{h_{in}} \right) \times 10^5 \dots\dots\dots(2)$$

Where C is the strip crown, h is the strip thickness, and indices "out" and "in" refer to the output and input strip to the stand. An empirical equation can be employed as the flatness criterion<sup>(1)</sup>:

$$-80 \times \left( \frac{h}{w} \right)^a < I < 40 \times \left( \frac{h}{w} \right)^b \dots\dots\dots(3)$$

Where  $w$  is the strip width, and  $a$  and  $b$  are constants. For low carbon steel,  $a$  and  $b$  are both equal to 1.86. If the flatness index unit  $I$  satisfies Eq.(3), then the strip flatness can be preserved. In Eq.(2) and (3), it can be seen that in the condition where the strip thickness is high enough, the adjustment of the roll gap can be higher without causing any flatness problem. However, at the final stand, the flatness limitation is tightest. For this reason, a flatness problem can easily occur if the thickness deviation is corrected predominantly by the final stand.

**2.2 Improved MAGC**

The philosophy of the delivery thickness deviation correction for each stand in the improved MAGC is based on the setup rolling force distribution. In this strategy, upstream roll gaps are correspondingly adjusted to keep the stability of the rolling process in upstream spans. The derivation of the adjustment of roll gap for the downstream stands is described as follows:

The relationship between strip thickness and the rolling force can be expressed as Eq.(4):

$$h = S + \frac{P}{M} \dots\dots\dots(4)$$

Where  $h$  is the strip thickness,  $S$  is the roll gap,  $P$  is the rolling force, and  $M$  is the mill modulus. The incremental form of the rolling force can be expressed as:

$$\delta P = Q\delta H - Q\delta h \dots\dots\dots(5)$$

Where  $Q$  is the strip plastic deformation modulus,  $H$  is the strip thickness at the entry side of the stand, and  $h$  is the strip thickness at the exit side of the stand. Substituting Eq.(5) into Eq.(4), and arranging it, we can obtain Eq.(6).

$$\delta h = \frac{M}{M+Q} \delta S + \frac{Q}{M+Q} \delta H \dots\dots\dots(6)$$

Let  $\delta H=0$ , then from Eq.(4) and (6), we obtain:

$$\delta S = - \left( \frac{M+Q}{MQ} \right) \delta P \dots\dots\dots(7)$$

Based on the improved MAGC strategy, it is assumed that the change in the rolling force due to the adjustment of roll gap is proportional to the setup rolling force at each stand. Therefore, Eq.(7) can be rewritten as:

$$\delta S_i = - \left( \frac{M_i+Q_i}{M_iQ_i} \right) \beta P_i \dots\dots\dots(8)$$

Where  $\beta$  is a constant. Substituting Eq.(8) into Eq.(6), the change of the reference thickness at each stand can be expressed as follows:

$$\delta h_i = \left( \frac{M}{M+Q} \right)_i \delta S_i + \left( \frac{Q}{M+Q} \right)_{i-1} \delta h_{i-1} \dots\dots\dots(9)$$

Finally, the constant  $\beta$  can be solved by letting  $\delta h_7$  be equal to the delivery thickness deviation. Then, the incremental change of thickness at stands F5 and F6 can be derived as shown in Eq.(10) and (11), respectively.

$$\delta h_5 = - \left( \frac{1}{Q} \right)_5 \beta P_5 \dots\dots\dots(10)$$

$$\delta h_6 = - \left( \frac{1}{Q} \right)_6 \beta P_6 - \left( \frac{Q}{M+Q} \right)_6 \left( \frac{1}{Q} \right)_5 \beta P_5 \dots\dots\dots(11)$$

**3. RESULTS**

The improved MAGC is implemented in stands F5~F7. In order to evaluate the performance of the improved MAGC, two cycles (5 pieces per cycle) of 1.4 mm gauge strips were tested with the original

MAGC and with the improved MAGC. Since the strip flatness is most sensitive during the strip threading period, it is of great importance to examine the rolling force variation at each stand when the strip head portion exits the final stand. Average rolling forces at stands F5~F7 are calculated at the time interval where the strip head exits the final stand for 0~0.5s (t1) and 4~4.5s (t2). The two time intervals represent the periods where it can be determined whether the function of the MAGC is taking effect or not. Table 1 summarizes the result of each coil based on the original MAGC and the improved MAGC.

Figure 1 shows the average of rolling force differences at stands F5~F7 based on the original MAGC and the improved MAGC, respectively. As shown in Fig.1, the rolling force difference at F7 in the original MAGC is significantly larger than that at F5 and F6. On the other hand, the rolling force difference at F7 decreases from 698 kN in the original MAGC to 154 kN in the improved MAGC, while the rolling force differences at F5 and F6 show slight increases in the improved MAGC over those in the original MAGC.

Based on the actual rolling forces measured at t1 and t2, the flatness index unit at the inter-stands of F5, F6 and F7 are also calculated and compared for the original MAGC and the improved MAGC, as shown in Fig.2. The results indicate that the strip flatness conditions at F5 and F6 are nearly identical using the two different MAGC systems, while the flatness condition at F7 based on the improved MAGC shows less

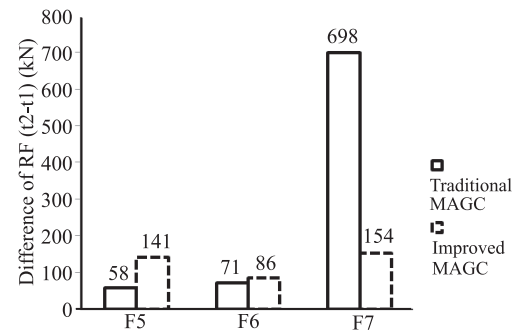


Fig.1. Comparison of rolling force differences between t1 and t2.

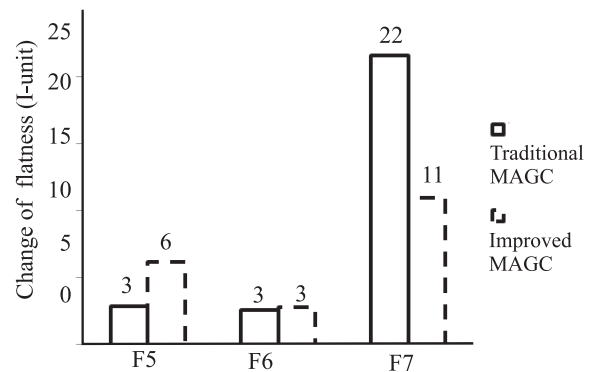


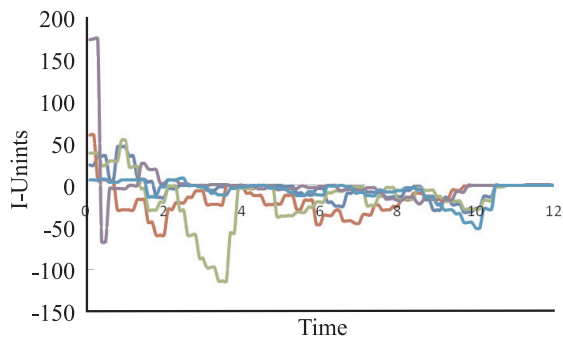
Fig.2. Comparison of the indices of flatness at the inter stand of F5, F6 and F7.

Table 1 Test results of the original MAGC and the improved MAGC

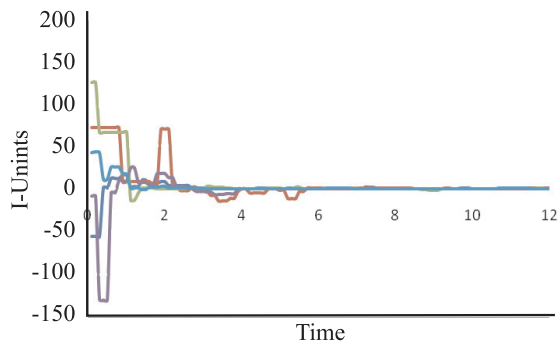
	Coll ID	Average RF at (kN)			Average RF at t2 (kN)			Difference of RF (t2-t1)(kN)			Percentage of RF Variation		
		F5	F6	F7	F5	F6	F7	F5	F6	F7	F5	F6	F7
Traditional MAGC	1	17373	15491	14261	17391	15618	15309	18	127	1048	0.10%	0.82%	7.35%
	2	17631	15737	14322	17511	15874	14548	-119	137	226	-0.68%	0.87%	1.58%
	3	17592	15823	14544	17640	15822	14270	48	-1	-274	0.27%	-0.01%	-1.88%
	4	17188	15327	14122	17151	15389	15930	-36	62	1808	-0.21%	0.40%	12.80%
	5	17477	15629	14271	17407	15601	14406	-70	-28	135	-0.40%	-0.18%	0.95%
Improved MAGC	6	17088	14805	14588	16928	14843	14975	-160	38	387	-0.94%	0.26%	2.66%
	7	16928	14729	14644	16771	14569	14616	-157	-161	-28	-0.93%	-1.09%	0.19%
	8	16752	14122	14441	16714	14030	14205	-39	-92	-236	-0.23%	-0.65%	1.63%
	9	16786	13800	14157	16684	13802	14251	-102	2	94	-0.61%	0.01%	0.67%
	10	16798	13966	14251	16549	13827	14274	-249	-139	23	-1.48%	-1.00%	0.16%

variation than that based on the original MAGC. The result is not surprising since the difference of the rolling force at F7 is smaller in the improved MAGC than that in the original MAGC.

The flatness index units measured by the flatness meter at the strip head portion for each coil are shown in Figs.3 and 4 for the original MAGC and the improved MAC, respectively. In the figures, each line represents the flatness index units of a coil. In Fig.3, the flatness index units approach to 0 around 10s in which the tension between the final stand and down-coiler is established. In contrast, in Fig.4, the flatness index units approach to 0 within 6s, indicating that the improved MAGC provides more stable rolling performance.



**Fig.3.** Measurements of the flatness in the original MAGC.



**Fig.4.** Measurements of the flatness in the improved MAGC.

## 4. CONCLUSIONS

In this work, an improved MAGC strategy for tandem hot rolling mills is proposed with consideration of the setup rolling force distribution ratio in the downstream stands. In order to evaluate the effectiveness of the strategy, the flatness conditions of the two thin gauge rolling cycles in the same rolling campaign are compared based on the original MAGC and the improved MAGC, respectively. The new MAGC strategy results in a lower rolling force variation at the final stand and consequently improves the strip flatness condition. Therefore, the proposed strategy for MAGC could be effectively used to eliminate the strip delivery thickness deviation and to improve the stability of the rolling process.

## REFERENCE

1. K. N. Shohet and N. A. Townsend, Flatness control in plate rolling, *J. Iron Steel Inst.* 1971, pp. 769-775.

