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REPETITIVE CONTROL FOR AGC SYSTEM BY USING ROLLING DATA

Hwan–Seong KIM * **Jin–Seon PARK** **
Sam–Sang YOU ***

* *Dept. of Logistics Eng., Korea Maritime Univ. #1, Dongsam, Yeongdo, Pusan 606-791, KOREA.*
E–mail:kimhs@kmaritime.ac.kr
** *Electrical Control Team, DongKuk Steel Co, #1867, Janghung, Nam, PoHang, KyongBuk, KOREA*
*** *School of Mechanical and Information Eng., Korea Maritime Univ. #1, Dongsam, Yeongdo, Pusan 606-791, KOREA*

Abstract: This paper deals with a modified repetitive control method for compensating automatic gauge control (AGC) to reduce the effect of skid mark which directly influence the quality of products in plate mill process. Since the skid mark on the plate have thermal difference, it makes a different stretching rate and deflection of thickness. Firstly, the AGC system and the plate mill process are described by considering function in each control levels. The skid mark of the plate in practical control fields is shown. Also, its frequency variation is given by on-line FFT analysis method. Secondly, a key idea of the modified repetitive control method with time varying periodic disturbance is presented, and it is also compared with standard repetitive control method. Lastly, we show that the variation of thickness is attenuated about 35% in comparison with standard repetitive control method.

Keywords: AGC, Compensation, Pass data, Time varying period, Repetitive control

1. INTRODUCTION

In plate roll products, it is known that flatness, metallurgy, and surface finish etc. is one of the most essential parts. To satisfy the customer requirements, highly automated and high-speed processing lines are very critical on off-gauge master (Dongkuk, 2000).
One of numerous control methods, the dynamic control of the strip thickness, called automatic gauge control (AGC), is required to meet the tolerances demanded by today's customer requirements.
Since the mill stand is an elastic structure, the changes in the rolling load cause the roll gap to open or close. Also, the rolling load is affected by numerous disturbances. In general, these disturbances start at the very beginning of the rolling process in the plate mill line as temperature due, for example, to furnace skid chills or temperature run-down leading to variations in hardness which in turn would lead to variations in thickness (Dongkuk 2000, Kim et.al. 2001).
These disturbances, an unpredictable metal-in point, and a skid mark in mill process govern mainly the variation of thickness. At the metal-in point (approximately 500 – 800[mm] from the beginning of products) in mill process, the thickness of plate can not be controlled for unpredictable impulse forces. A look-up table method or a model prediction method is generally used to compensate this.
The skid mark, caused by thermal difference in furnace, is one of the serious problems. Under the assumption of constant period of skid mark, a repetitive control method for constant periodic disturbances is applied to offset this skid mark by Kim et. al. (2001). However, the period of skid mark would be changed by the roll speed and the stretching rate of material.

In this study, we deal with a modified repetitive control method for compensating AGC to reduce the effect of skid mark which directly influence the quality of products in plate mill process. This paper is organized as follows. In section 2, the AGC system and the plate mill process are described by considering function in each control levels. The skid mark of the plate in practical control fields is presented, and its effect is also provided. The variation of frequency, effected by skid mark, is described using on-line FFT analysis. In section 3, a modified repetitive control method with time varying periodic disturbance is presented. The modified repetitive control method is compared with standard one. Simulation results are presented in section 4. It is shown that the maximum peak value is attenuated about 35% as compared with standard repetitive control case. Thus, we verify that the modified repetitive control method for AGC can attenuate the variation of thickness.

2. AGC SYSTEM

2.1 *Mill Stand*

Generally, the plate mill process is constructed by one or two mill stands. In the former case, a whole mill process is performed by only one mill stand. In the latter case, two mill stands are concerned with roughing mill (RM) which performs the mill process for making adequate the width and length of a slab, and finishing mill (FM) which makes the specified thickness of the slab by milling on the direction of length side of the slab. In this paper, only finishing mill stand is dealt with for controlling thickness.

In each mill stand, backup roll and work roll which can be reversed in the upper and down sides are constructed. The maximum press force is 8000[ton] in RM and FM, respectively, and it is used to mill the plate repeatedly. By adjusting the press force, the products can be produced within 6 – 250 [mm].

2.2 *Plate Mill Process*

In plate mill process, the control tasks are normally divided into three main levels. Fig. 1 shows a block diagram of how these levels are split up for a rolling mill automation system.

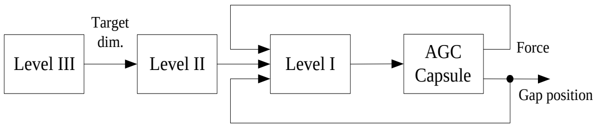

Fig. 1. Block diagram for control commends

First of all, the level III is concerned with looking at the overall plant and evaluating the processing route for a given set of slabs. From the customer requirements, adequate slab should be selected by considering material characteristics, size, and hardness of slab. Also, the level III decides the process sequence for each slabs and order to the level II.

The level II is concerned with controlling the mill as a whole and is usually termed supervisory control. The basic role is to provide a suitable actuator setpoints and target values from the estimated roll force and tension set points for satisfying the closed loop's aim. In each pass, the roll gap, calculated by estimated roll force, is obtained, and target roll force is ordered to level I.

The level I is concerned with controlling the inner closed loops of the system. These loops control the quality of the strip with a single coil. In this level, two control systems are generally included: automatic position control (APC) system which control the screw position for tracking the commanded roll gap, and AGC system which control the precise thickness of plate for tracking the reference roll force. In this case, the measurements are fed into the controllers and the control error is calculated by comparison with the desired target value for the particular parameter. Also, some modifications are made to the chosen actuators for the control error within 2[mm].

2.3 *Thickness Control of AGC System*

A gauge meter, compensating the roll force error between reference and fed signals, is operated to control the thickness, where the reference roll force is given by level II system. In this case, a time delay between measurement of roll force and cylinder actuator is generated, and it affects to the error of thickness. Since the thickness control is difficult to eliminate the disturbances during delay time period, a thickness offset occurs always.

2.4 *Time Varying Disturbance*

Before the mill process, the slab is heated in furnace. In processing heat, there is a temperature distribution around the two supporting arm's location, and this distribution leads to the variations of thickness on the mill process. Generally, it is called as a "skid mark".

On the characteristics of mill process, the thickness of strip mill is related to the gap position. So, we can evaluate the variation of thickness by using that of gap position on driving side (DS) in FM. Figure 2 shows a driving side gap position on the first pass of FM, and it gives two skid mark points on 1600 and 3300 [mm] position, respectively. From the figure, we verify that the skid mark affects to the thickness of a plate.

In mill process, however, the velocity of metal-in point and difference characteristic of material have different effect on the position and magnitude of skid mark in whole length. So, the period of skid mark differs on the each pass in mill process.

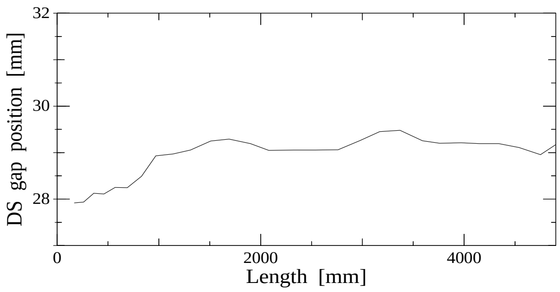

Fig. 2. Skidmark on the first pass data in FM

Fig. 3 shows the full pass rolling data on DS. And the on-line FFT analysis data is given in Fig. 4.

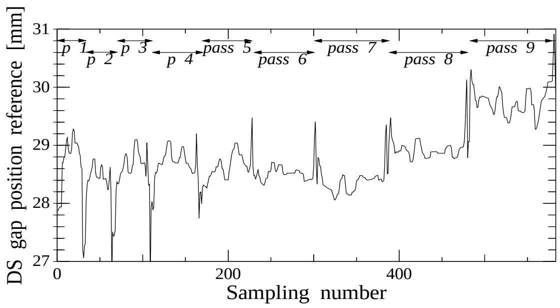

Fig. 3. Gap position reference on DS

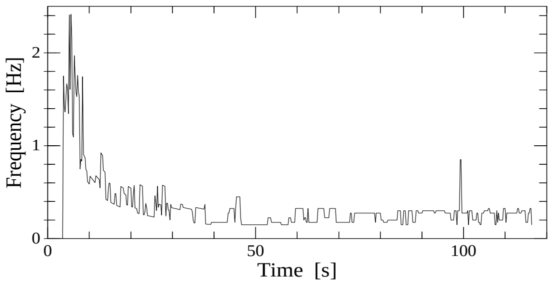

Fig. 4. Frequency variation of gap position(2nd mode)

On the results of FFT analysis, the variation of gap position includes lots of frequency modes, and just the 2nd mode of frequency is shown in Fig. 4. In the figure, due to lack of data at beginning the FFT analysis, the frequency mode can not obtained, and it is given as a zeros at beginning section in Fig. 4.

3. REPETITIVE CONTROL WITH TIME VARYING PERIOD

3.1 *Standard Repetitive Control System*

For a servo system which have a function to track a periodic reference time signal or to reject a periodic disturbance, a repetitive control was developed several years ago (Hara et.al. 1988). This control system deals with a special kind of internal model principles (Francis and Wanham, 1975) which generate a periodic disturbance or reference signal internally. And it has proved to be very effective in practical applications. Figure 5 shows the block diagram of a typical repetitive control system in which $P(s)$ is the transfer function of the plant to be controlled, and $C(s)$ is the controller designed to stabilize the closed loop system.

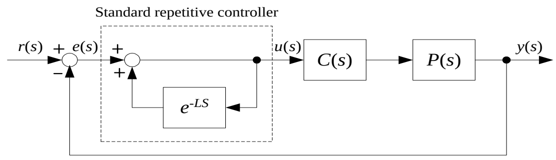

Fig. 5. A typical repetitive control system

A sufficient condition for this system is to find $C(s)$ such that $\| I - C(s)P(s) \|_\infty < 1$. The key idea in the repetitive control is the introduction of the positive feedback loop which involved the time delay element e^{-Ls}, where L denotes the period of the reference signal $r(s)$.
In the AGC system, the gap position reference for each pass includes the influence of skid mark, regarded as a time invariant periodic disturbances. The block diagram of repetitive control systems for the AGC system is given in Fig. 6.

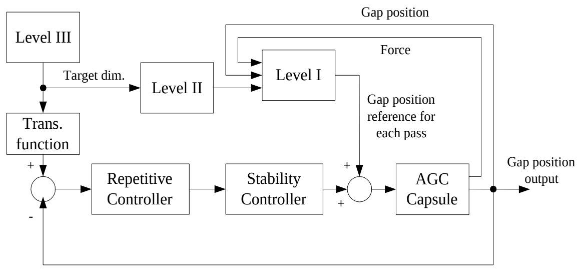

Fig. 6. A block diagram of AGC repetitive control system

By applying a filter and/or a compensation design technique, the repetitive controller can improve the performance and the tracking/rejection for the given references/disturbances. However, practically the period of reference signals or disturbances can be time varying, and thus the above repetitive controller is not directly applicable to this case.

3.2 *Repetitive Control System with Time Varying Period*

Recently, Mahawan and Luo (2000) has proposed a repetitive control method for time varying periodic reference systems. The key idea is that the reference signal can be regarded as one of periodic signal functions, even if the reference is a time varying signal function. For example, we consider any reference signal as

$$r(t) = \sin(\theta(t))$$

Here we known that $r(t)$ is not a periodic as a function of time t, but a periodic function of

θ. These kinds of reference and/or disturbance signals can be considered in the practical control systems (Kobayashi et.al. 1990, Nakano et.al. 1996).

Consider a function $\omega(t)$ given by $\frac{d\theta}{dt}$, then the relation between $\omega(t)$ and θ is represented as

$$\theta = \int_0^t \omega(t)dt = f(t)$$

Let us consider a plant $P(s)$ as in Fig. 5 for time invariant systems as

$$P(s) : \begin{cases} \dot{x}(t) = Ax(t) + Bu(t) \\ y(t) = Cx(t) + v(t) \end{cases} \quad (1)$$

where $v(t)$ denotes a disturbance.

In θ domain, eq. (1) is transformed by transfer function $f(t)$ into

$$\begin{cases} \bar{\omega}(\theta)\dot{\bar{x}}(\theta) = A\bar{x}(\theta) + B\bar{u}(\theta) \\ \bar{y}(\theta) = C\bar{x}(\theta) + \bar{v}(\theta) \end{cases} \quad (2)$$

where $\bar{x}(\theta)$ is given as

$$\bar{x}(\theta) = x(f^{-1}(\theta)) = x(t)$$

with other signals defined similarly.

To design a repetitive controller based on time invariant control theory, we consider the approximated model of eq. (2) around $\bar{\omega}(\theta) = \omega_0$ by Nakano et al [6].

Let us assume that P_θ is the class of reference signals. If the compensator $C(s)$ is designed for a system to track a reference signal belonging to the class P_θ, then only the repetitive controller has to be redesigned.

A modified repetitive controller with a compensator for time-varying periodic system is given in Fig. 7.

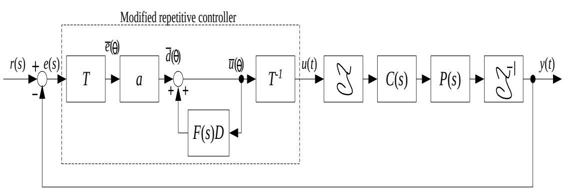

Fig. 7. Repetitive control for time varying system

In above figure, a denotes repetitive control gain, and T denotes a transform operator $u(t) \in L^2_\omega(0, t_f)$ into a function $\bar{u}(\theta) \in L^2(0, \theta_f)$, where $\theta_f = f(t_f)$. The delay operator D is defined as

$$D\bar{d}(\theta) = \bar{u}(\theta) = \bar{d}(\theta - L) \quad (3)$$

and $\Im$ denotes the slightly modified Laplace transform defined by

$$\Im(g(t)) = G(s) = \frac{1}{\sqrt{2\pi}} \int_0^\infty e^{-st}\sqrt{\omega(t)}g(t)dt \quad (4)$$

Also, stable filter $F(s)$ has to be designed for stabilizing the repetitive controller, and it is given by

$$F(s) : \begin{cases} \dot{x}_f(t) = A_f x_f(t) + B_f u_f(t) \\ u(t) = C_f x_f(t) + D_f u_f(t) \end{cases} \quad (5)$$

The stability of the modified repetitive controller have been proved in the following lemma and theorem.

Lemma 1 :(Mahawan and Luo, 2000) If the L^2 gain $\| u \|_{L^2_\omega} / \| e \|_{L^2_\omega}$ is less than or equal to 1 and the induced operator norm of $L^{-1}F(s)W(s)L$ is strictly less than 1, then the closed-loop system with the modified repetitive controller in Fig. 7 is stable in the sense that any bounded input yields bounded output, where $W(s) = I - aC(s)P(s)$.

Theorem 1 :(Mahawan and Luo, 2000) The closed-loop system with the modified repetitive controller is asymptotically stable if

$$\| L^{-1}F(s)W(s)L \| < 1 \quad (6)$$

4. SIMULATION AND CONSIDERATIONS

On the simulation, AGC model and its parameters are refereed by Kim et. al. (2001). Also the design method for compensator $C(s)$ and stable filter $F(s)$ are refereed in reference (Kim et. al., 2001). The control reference set to 29 [mm], and repetitive control gain is designed as $a = 1$. The sampling time is given as 200 [ms].

The comparison between the conventional repetitive control for constant period disturbance and the modified repetitive control for time varying periodic disturbance is given in Fig. 8, where the 2nd frequency mode is used.

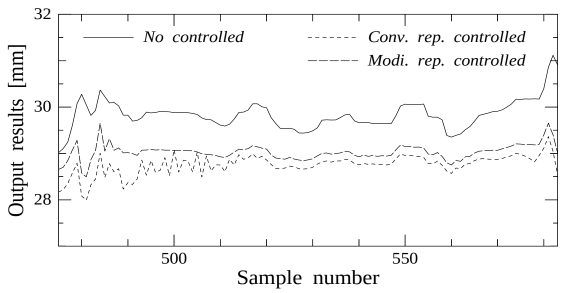

Fig. 8. Comparison with repetitive control methods (2nd mode, $a = 1$)

In Fig. 8, since the 2nd frequency mode (refer Fig. 4) is used for the numerical simulation, the specified 2nd frequency mode(about 3 [Hz]) is mainly attenuated. However, the low frequency mode still remains in the results. This means that the results of FFT analysis does not include the low frequency domain, because of the lack of number of data.

Table 1 shows the absolute value of maximum peak and the integrated error of the thickness to be controlled by changing the frequency mode with $a = 1$, respectively. Among these frequency

Table 1. Simulation results ($a = 1$)

	No	Conv.	Mod. rep. cont.(mode)		
			1st	2nd	3th
Max. peak	2.117	1.008	0.665	0.655	0.668
Int. error	18.217	5.660	2.532	2.528	2.578

modes, the 2nd mode attenuate the variation of thickness about 35% as compared with the conventional repetitive control method very well. But, the metal-in point and low frequency mode has to be attenuated still.

5. CONCLUSION

In this paper, we have dealt with a modified repetitive control method with time varying periodic disturbance for compensating the AGC system to attenuate the variation of thickness. On the analysis of the AGC system and plate mill process, the control functions are described to use the design of compensator. Using the on-line FFT analysis, the variation of frequency which effected by skid mark has been obtained.

Furthermore, a modified repetitive control method with time varying periodic disturbance has been presented. On the simulation, the maximum peak value is attenuated about 35% as compared with the standard repetitive control case. From the simulation results, it can be concluded that the modified repetitive control method can attenuate the variation of thickness in given specified frequency domain.

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