A New Automatic Gauge Control System for a Reversing Cold Mill

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Synopsis

Fundamental study on automatic gauge control (AGC) of reversing cold rolling mill was carried out. The study includes the method of evaluating performance of AGC system and designing a control system according to the results of the study.

It was concluded that the response of AGC system depends on the dynamic characteristics of a reel motor current control in either case of controlling reel motor current or roll position. The AGC system controlling the reel motor current is better than the AGC system controlling the roll position even with a hydraulic screwdown system.

A new AGC system controlling reel motor current and roll position has been developed based on the above results. This system has been applied to Sendzimir and 4-high reversing mills.

Key words: cold rolling; reversing cold mill; automatic gauge control; simulation; dynamic characteristics; thickness change

I. Introduction

Requirements for gauge accuracy of cold rolled strips have been increasing year by year and automatic gauge control systems (AGC) with high performance are also requested for reversing cold reduction mills.

Manipulating variables of a rolling mill for controlling the exit thickness are strip tension (reel motor current) and roll position. There are two well known types of AGC which controls each of variables as shown in Fig. 1. Because high speed response of roll position is available by a hydraulic screwdown system, the roll position AGC is mainly used in these types of AGC.1-3)

However, manipulation of roll position during rolling brings about not only change of exit thickness but change of front and back tensions which influence further the exit thickness change. Therefore, it is necessary to evaluate AGC in terms of the characteristics of final change of exit thickness.

From the above standpoint, the characteristics of thickness variation was investigated by computer simulation of a reversing cold mill. From these studies, it was found that the response of thickness changing by the hydraulic screw down system depended on the motor current control which responded more slowly than the roll position control. Based on this conclusion, a new type of AGC which includes both the motor current and the roll position was studied. The new AGC proved better performance than the conventional types of AGC and has been used in practices.4-6)

II. Dynamic Characteristics of Thickness Change

1. Simulation Model

Figure 2 shows the model for simulating the dynamic characteristics of thickness change. A digital
A computer was used for the calculation and the necessary numerical values for rolling processes were obtained from rolling equations.

For comparison with the actual data to be described in the later part of this paper, the work roll diameter and the deformation resistance of material were determined according to the actual conditions of rolling stainless steel in a Sendzimir mill. The hot band thickness was 2.5 mm in the simulation.

A reel motor in the model was driven by a motor-generator (M-G) set. The control gain of the motor was determined so that the response time (step response) of the current control was 0.7 s. The control gain of the hydraulic screwdown system was determined so that the response time of the roll position control was 0.05 s.

2. Fundamental Property of Thickness Change

Figure 3 shows the simulation result of the fundamental characteristics of thickness change. The roll position was changed stepwise under a constant circumferential speed for both front and back reel; the reel motor current was not controlled and the reel circumferential speed is constant in calculation.

In Fig. 3, the exit thickness deviates at the beginning of the change of roll position and returns to the initial thickness with the accompanied increase in front and back tension, because the exit thickness follows constant mass flow as evident from the equation mentioned in Fig. 3. Therefore, if the entry thickness and the circumferential speeds of front and back reels remain constant, the exit thickness does not change. Consequently the final change of exit thickness will not be a result of the high speed movement of roll position but of the change in reel circumferential speeds induced by the roll position change.

Under normal rolling conditions in a reversing cold mill, the constant current control system of reel motor is operated to change the reel circumferential speed, as shown in a block diagram of Fig. 4. The roll position change causes a change in entry speed of strip into roll bite and strip tension. The current control system undertakes to correct the motor current change due to this tension change so that the motor terminal voltage, or the motor revolution speed, changes. The reel circumferential speed changes only after these changes; the response of thickness change depends on the response of motor current control to adjust the reel circumferential speed. Therefore, a response of the roll position control faster than of the current control is not significant for the exit thickness control.

3. Response of Thickness Change by Motor Current or Roll Position

The simulation model shown in Fig. 2 was used to calculate the response of thickness change when the motor current reference and the roll position reference were changed separately. It was assumed in the model that the rolling mill was operated by a reel motor driven by an M-G set with slow response.

1. Simulated Result of Step Response

Figure 5 shows the simulated results when the reference of motor current or roll position was changed stepwise. When the motor current is changed, the dynamic characteristics of the exit thickness change is similar to the current change and the reel circumferential speed change. On the other hand, when the roll position is changed, the roll position moves quickly but the response of exit thickness change is almost same as the response when the motor current is changed, because the response of the reel circum-
2. Actually Measured Data of Step Response

Figure 6 shows actual step responses measured under the same conditions shown in Figs. 2 and 5 in a Sendzimir mill at Naoetsu Works of Nippon Stainless Steel Co., Ltd. Actually measured curves in Fig. 6 represent averaged data of 3 measurements, which are processed by a computer. The thickness deviation at work roll bite was obtained by calculating the difference between the thickness deviation measured by exit gauge and the thickness deviation by entry gauge taking into account the thickness reduction and the time delay from entry to exit. The equation for calculating the thickness deviation is

\[ \Delta h(t) = h(t) - \left( \frac{h_0}{H_0} \right) H(t - T_d), \]

where, \( \Delta h(t) \): thickness deviation at work roll bite
\( h(t) \): thickness deviation measured by exit gauge
\( H(t) \): thickness deviation measured by entry gauge.
$h_0$: nominal thickness at exit
$H_0$: nominal thickness at entry
$T_d$: delay time between entry and exit
gauge.

It is proved from Fig. 6 that the characteristics of thickness change in actual rolling mill is identical to the calculated results shown in Fig. 5.

3. Calculation Result of Frequency Response

The frequency response was calculated by the above model. The amplitude gain of the thickness change is shown in Fig. 7. The frequency response upon changing the motor current reference gives the characteristics similar to those of the second order delay system. On the other hand, the frequency response curve has a downward peak at 1.35 Hz upon changing the roll position reference. Therefore, the motor current correction is more suitable for AGC than the roll position correction.

The response curve to the roll position reference change at an input frequency of 1.35 Hz is shown in Fig. 8. The figure shows that the thickness change has a minimum amplitude because the phase of the entry and exit tension change tends to suppress the thickness change due to the roll position change.

4. Results of Studies

The following is a summary of the study on the dynamic characteristics of thickness change.

(1) The final change of exit thickness in a reversing cold mill has to be accompanied with the change of the reel circumferential speed.

(2) Even if a hydraulic screwdown system with quick response may be used, the response of thickness change depends on the dynamic characteristics of the motor current control that changes the reel circumferential speed.

(3) Dynamic characteristics of the exit thickness change is better with the motor current control than the roll position control. Therefore, the motor current control is more effective than the roll position control for automatic gauge control.

(4) The following is recommended as a guide for remodeling an existing mill. It is not necessary to replace the motor screwdown system of an existing mill by the hydraulic screwdown system if the object of the remodeling is only to improve the response of AGC.

(5) However, because big tension change induced by the motor current control for AGC is not desirable for the operation of rolling mill, some consideration is necessary to reduce the tension change in the AGC system.

III. Examples of New Automatic Gauge Control

1. Study on New AGC System

1. AGC System Controlling Motor Current and Roll Position

The AGC system which controls the reel motor current is more desirable than the AGC system which controls the roll position, but the amplitude of current change is limited in the former system because of possible disturbance to rolling operation. An AGC system controlling both the motor current and the roll position has been developed to solve this problem. Construction of the new AGC system is shown in Fig. 9.

Combination of the motor current and the roll position control for AGC system can be achieved from the following concepts. A gauge control reference signal is separated into 2 reference signals by a reference analysis control. One is the motor current reference

![Fig. 7. Frequency response of thickness change in a reversing mill.](image)

![Fig. 8. Simulated result of sinusoidal roll position change. (Frequency: 1.35 Hz)](image)
signal which has high frequency but small amplitude. The other is the roll position reference signal which has low frequency but large amplitude. The reference analysis control works by transferring the reference from motor current to the roll position, when the motor current reference exceeds a limit as presented in the later part of this paper.

2. Study on M-G Set Power Source for Reel Motor

Figure 10 shows the results of simulation in which the thyristor power source is used for the rolling mill shown in Fig. 2. For this purpose, the gain of the motor current control was determined for its response time to be 0.11 s. Step response of exit thickness change shown in Fig. 10 is similar to that shown in Fig. 5; the response of thickness change is better in the motor current change than in the roll position change.

The response time of thickness change to the motor current change is shown to provide no significant improvement on the response time when the M-G set power source is used (Fig. 5). Therefore, it is judged for cost saving that replacement of an M-G set power source with a thyristor power source is not necessary in an existing reversing cold mill.

2. Sendzimir Mill AGC System

Based on a new design concept of AGC system described so far, an AGC system with excellent cost performance has been developed for the Sendzimir mill at Naoetsu Works of Nippon Stainless Steel Co., Ltd.

Schematic diagram of the AGC system is shown in Fig. 11 and an example of thickness accuracy in Fig. 12. Their features are as follows.

(1) An existing M-G set power source is also used for the new AGC because replacement of M-G set power source with a new thyristor power source is not effective in comparing with the required investment. An existing follow valve for cylinder position control was replaced with a servo valve, because the existing cylinder position control can not be used for precise roll position control.

(2) To obtain the maximum response of exit thickness change, a new AGC system controlling the motor current and roll position has been developed to put into practical use. The AGC includes the reference analysis control which transfers the reel motor current reference to the roll position reference when the motor current reference exceeds a limit.

(3) A microcomputer is used for the control system to perform data processing such as the direct...
digital control for AGC, gauge classification, etc.

(4) It is clear from Fig. 12 showing operation of AGC that the AGC system controlling the motor current and roll position works satisfactorily by achieving high accuracy of exit thickness.

3. Four High Reversing Cold Mill AGC System

An AGC system for 4-high reversing mill at Igeta Steel Sheet Co., Ltd. was developed based on the same design concept of AGC system. Figure 13 shows the schematic diagram of the AGC system and Fig. 14 shows an example of thickness accuracy. Their features are as follows.

(1) The reel motor current control system driven by an M–G set power source is used without remodeling. The existing screwdown motor with M–G set power source was replaced with a new motor with thyristor–Leonard system because the old motor is not capable for the highly accurate roll position control.

(2) A new AGC system controlling the motor current and roll position has been adopted and works on the basis of the reference analysis control.

(3) Rolling tends to be unstable sometimes at the final pass of thin strip rolling because the accuracy of
reel motor current control is not sufficient for thin strip. Therefore voltage compensation control was developed to overcome this problem by correcting the current reference according to the reel motor voltage deviation.

(4) A microcomputer was used as a control device.

(5) The actually measured data in Fig. 14 show that the AGC system operates effectively to provide high accuracy in thickness.

**IV. Conclusion**

Study for evaluating the performance of AGC system for reversing cold mill was carried out. It was concluded that the response of AGC system depends on the dynamic characteristics of the motor current control in either case of controlling reel motor current or roll position as a manipulating variable of reversing mill. An additional conclusion is that the AGC system controlling reel motor current can be more effective than the AGC system controlling roll position even with a hydraulic screwdown system.

A new AGC system controlling both reel motor current and roll position has been developed based on the above result. This system has been applied to Sendzimir and 4-high reversing mills and continues to operate satisfactorily.

**REFERENCES**