Improving the mechatronic system for automatic control of the reversing stands of mill 5000

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Abstract. It is noted that when extending the range of products made by plate rolling mills, it becomes relevant to improve the algorithms of the automatic parameters control systems. We hereby present a structure that explains the SMS Demag AG concept of automatic control over stand roll gauge and gaps. This concept is implemented in the automatic gauge control system (AGCS) of Mill 5000, Magnitogorsk Iron and Steel Works. We describe the drawbacks of the AGCS that manifest when rolling <10 mm plates. The most serious drawback is the tear of metal pieces from the trailing edge, which is caused by the inappropriate functioning of the gauge assignment and adjustment system. We present the structural diagram of the gauge calculation system. We also describe the functions of a system for dynamic compensation of disturbances. We provide rationale for excluding the roll counter-bending and deformation correction signals. The paper proposes a method to control hydraulic screwdowns, which is essentially about a quick increase in the inter-roll gap at the workpiece “trailing edge” during the last pass, which must be done when rolling thin plates. We analyze the oscillograms of signals describing the gauge interference when the proposed changes are implemented. We prove the technological efficiency of using the proposed control method on Mill 5000.

1. Introduction

Mill 5000 of PJSC Magnitogorsk Iron and Steel Works (“Mill 5000”) is one of Europe’s most productive plate rolling units. According to its design, it is capable of producing 1,500 thousand tons of (10–50)×(2000–4600)×(<18500) mm per annum. At the same time, the mill is currently efficiently used to roll an extended range of products, including 7- to 10-mm plates. Generally, changing the rolling profile requires, aside from solving some technological problems, an additional configuration and improvement of the automatic parameters control system. To that end, state-of-the-art mills use algorithms run by special automatic process control systems. This is why solving this problem boils down to developing and implementing new control methods and algorithms.

The most important mechatronic automation systems of Mill 5000 are the automatic gauge and gap control systems. Their combination uses the gauge adjustment concept developed by SMS Demag AG for plate rolling mills. This concept is discussed in papers [1-4] and is fully used by the mill.

The roll gauge and gap control principles is shown in the functional diagram, see Figure 1 [5]. It consists of the following basic systems (modules):
hydraulic gap control (HGC);
• automatic gauge control (AGC);
• roll axial shifting control (RAC);
• dynamic disturbance compensation (DDC).

![Diagram](image)

**Figure 1.** Explaining the concept of automatic gap and gauge control on a Mill-5000 stand

Fundamental to the structure are the two control circuits: the internal circuit to control the positioning of hydraulic screwdowns (HS), and the external gauge control system. The ultimate function is to compensate the stand deformations and various disturbances caused by deviations in the process parameters, which might occur during rolling. Aside from these modules, the structure includes systems for electromechanical pressure screw (EMP) positioning and conicity control; however, this paper does not dwell upon such systems.

The structure and configurations of the former two systems are described in a few papers, including [6-9]. Configuring the systems of the HGC, AGC, and RAC controller of Mill 5000 is described in [10]. Below is a summary of the AGC system and a description of the DDC functions.

2. **Statement of Problem**

*Automatic Gauge Control (AGC).* When using plate rolling mills, there frequently occur gauge defects caused by various factors. Some defects are due to the slab condition, including its lengthwise gauge interference and temperature difference caused by skidding. This indicates deviations in the material hardness.

Automatic gauge control is intended to maintain a constant roll gap when altering the rolling force by affecting the HS. The system can operate in the absolute mode or in the relative mode. In the absolute mode, the roll gap is adjusted by setting the operator-determined gauge or by computing the
rolling schedule in a Level 2 automation system. In the relative mode, the slab/plate gauge attained at 0.5 s to 1 s after the rolling starts is kept constant over the entire length.

Since it is impossible to measure the actual roll gap during rolling, the system computes it. To that end, use the gap equation:

\[ h = S + g(F_w) \]

Therefore, the roll gap \( h \) depends on the hydraulic cylinder piston position \( S \) and the stand stretching \( g \), which is a function of the rolling force \( F_w \). The AGCS is tasked to compensate the stand stretching fluctuations caused by the rolling process according to the equation

\[ \Delta h = \Delta S + \Delta g(F_w) = 0. \]

Gauge fluctuations resulting from roll eccentricity can be avoided by means of special adaptive filtering procedures. An adaptive notch filter is used to passively compensate gap eccentricities [10].

Successful use of such systems on Mill 5000 proves their reliability and high adjustment precision. At the same time, extending the Mill-5000 product range by rolling thin plates reveals the following drawbacks of the designed AGCS (plates are considered thin if < 10 mm):

1. There are deviations in the actual gauge measured by the thickness gauge after the last pass, whereas the indirect gauge signal used by the AGCS reveals no such deviations.
2. When rolling thin plates, the required gauge is attained by automatically setting the system to a minimum gap (in some cases, rolls are pre-converged with force). Since the plate gauge is small in last passages, the trailing edge has time to cool down. To compensate temperature losses, the gauge controller automatically reduces the gap by converging the rolls. As a result of strong pressure, some pieces are torn away from the trailing edge; such pieces have considerable kinetic energy. This damages the equipment while also endangering the personnel.

AGCS malfunctioning deteriorates the product quality, reduces the mill reliability, while also complicating the operator’s life.

In order to eliminate such drawbacks, we had to improve the AGCS structure and algorithms. Below we discuss the proposed solutions and the outcomes of implementing them. We preliminarily describe the structural diagram of the gauge computation system used by the Mill-5000 AGCS.

3. **Research Essentials**

3.1. **Structure of Gauge Assignment in Mill-5000 AGCS**

Figure 2 shows the diagram of computing and generating the gauge assignment signal. The external AGCS circuit is the automatic gauge control circuit. It is formed by the gauge controller, the input of which receives the assignment signal sent by the Level 2 model (with corrections) as well as the actual gauge signal. The actual gauge is the total of mean gaps created by the hydraulic and electromechanical screwdowns (HS and EMS) plus the stand stretching. Stretching-proportional signal is generated as a non-linear function of the total rolling force, defined by the stand rigidity [11].

The gauge controller output signal is summed with the disturbance compensation signals and the gap correction signals for the leading and trailing edge. It then goes to the intensity adjuster input, which limits the HS motion speed. The intensity adjuster output signal is the input signal for the slave HS positioning control circuit (not shown in Figure 2). Paper [10] describes the AGCS and gap control systems in detail.

Zero Point Corr is the gauge correction generated by comparing the actual gauge-metered gauge against the assigned gauge (it compensates the static error of indirect gauge computation); Agc Morigoil comp is the compensation for the oil-film thickness in the backup-roll oil-film bearings; Agc Roll Flat Comp is the compensation for roll flattening; Roll Wear comp is the compensation for roll wear (from the Level 2 model); ThermExpComp is the compensation for the thermal expansion of rolls (from the roll heating model); CvcShiftComp is the compensation for the axial roll shift; WrbBendComp is the compensation for the roll counterbending; EmpShpindleComp is the compensation for the spindle weight.
Before metal goes to the rolls, preliminary gap is set as defined on the basis of the expected rolling force taking into account the non-linearity of the stand rigidity curve.

The RAC controller, the diagram of which is shown in Figure 2, is to align the stand stretching for different forces exerted by the screwdowns on the drive side and on the operator side [10]. It aligns the resulting skew by affecting the HS cylinders.

3.2. Dynamic Disturbance Compensation (DDC)

During rolling, there occur various defects associated with gauge deviations. The DDC system compensates for such defects by correcting the roll gap. Each type of defects is compensated by an independent function.

**Lift of roll necks in Morgoil-type oil-film bearings.**

The input parameters are the measured force and rotation speed, which are taken into account when computing the actual oil-film thickness inside Morgoil bearings. It is known that at higher rolling speed and lower force, the lift of backup-roll necks in bearings is more pronounced. The actual oil-film thickness is used to compute the corrections for the gap $\Delta S$, see Figure 1, 2.

**Roll Heat Crown and Wear.**

These parameters are computed cyclically by the Level 2 profile and flatness control system. The DDC module (see Figure 1) computes the appropriate adjustments for the gap $\Delta S$.

**Roll Bending.**

The effect of roll bending is compensated taking into account the $\Delta S/\Delta WRB$ derivative, which is computed by the profile and flatness control system and is transmitted to the controller together with the stand configuration. It and the actual bending force are used to compute and generated the adjustment of the gap $\Delta S$.

For more details on the dynamic disturbance compensation, see [12,13].

Figure 2. Structural diagram of gauge assignment in the Mill-5000 AGCS:
Figure 3 shows the oscillograms of adjusting forces in the DDC system as measured on Mill 5000. These and other signals are used in the system for computing the gauge shown in Figure 2.

**Figure 3.** Oscillograms of signals used in gauge computing: 1, 2 are the assigned and the expected rolling force values; 3 is the total gap and stand stretching signal; 4 is the total of gauge compensations; 5 is the indirectly measured gauge; 6 is the total compensation signal for the oil film, roll deformation and bending; 7, 8 are the compensation signals for the oil film and the roll deformation; 9 is the roll bending compensation; 10 is the gauge-metered gauge; 11 is the total of gap and stand stretching; 12 is the total of all correction signals; 13 is the total signal of indirectly measured gauge.

Their decoding is given in the Figure caption. Independent correction signals are sent to the adder block input. The block output is summed up with the gap correction signal for the leading edge and the trailing edge, which signal is received from the EFC output; it is also summed up with the ACS signal controlling the motion of HS during profiled rolling [14,15]. The total AGC and HGC correction signal is sent to the inputs of closed circuits adjusting the positioning of HS on the drive side and the operator side (not shown in Figure 2).

Oscillograms are shown for the case where roll deformations and counterbending compensation signals are computed on the basis of the actual force. This is due to the fact that real signals are computed based on the actual rolling force \( f(F_{rl.act}) \), signals 8 and 9. When rolling thin plates, the 13-gauge signal in the initial circuit does not respond to the actual gauge deviations, as can be seen from the comparison of oscillograms 10 and 13. For the AGCS to compute these signals correctly, we
propose using the Level 2 model-predicted values rather than actual values. Experiments have shown this improves the gauge adjustment quality.

3.3. Improving the AGCS for Thin-Plate Rolling

As noted above, rolling thin plates might result in tearing metal pieces away from the trailing edge during the last pass. To avoid such situations, we propose an HS control method that essentially consists in rapidly increasing the roll gap by 0.5 mm to 2.5 mm depending on the gauge. Roll retraction must be performed if the following conditions are met:

- plates being rolled are <10 mm thick;
- the mill is running the last pass;
- the unrolled portion of the plate remaining in the stand is less than 1.0 meters long.

To ensure fast roll retraction, we propose that the controller program generates signals:

- to increase the assigned gauge at the gauge adjustment circuit input;
- to move the HS to “bypass the gauge controller”.

Additional blocks that are placed to meet these conditions are outlined in Figure 2.

Figure 4a shows the oscillograms obtained when testing this method. Window 1 shows the “trailing-edge” position oscillogram (the oblique line) relative to the stand (the horizontal line). One meter before the metal leaves the stand (Window 2, timepoint ~13.35.29.75) the gauge assignment signal is boosted. As a result, we can observe the repositioning of hydraulic cylinder pistons on the drive side and on the operator side (Window 3) in the time interval from 13.35.29.75 to ~13.35.30.00. The total rolling force (Window 4) decreases, which also decreases the chance of tearing away the “trailing edge”.

4. Discussion of Results

Figure 4b presents the gauge alteration oscillograms based on the thickness-gauge signals. Gauge deviation resulting from additional roll retraction does not exceed 1 mm or 10% of the final plate gauge. This is proven by the assigned and actual gauge oscillograms shown in Window 2, Figure 4a. Besides, the oscillograms shown in Figure 4b allow us to conclude that the gauge on the plate edges and in the plate center alters in a near-uniform fashion. This proves that the RAC-controller is configured appropriately [10].

The trailing edge of a deviating gauge (~ 0.4 meters long) is cut by the finishing line. Experience shows that such an edge of the plate is cut in nearly all cases, as it often has defects. Therefore, the proposed method hardly increases the loss of metal that could be attributed to cutting.

The proposed method improves mechanism reliability as well as personnel safety.

5. Conclusion

The papers [1-9,12-14] mentioned herein present the structure and the results of mathematical modeling of system that use the known concepts of automatic gauge control. However, there are virtually no publications on the configuration and use of such systems. This paper seeks to fill that gap. We do not claim to have made any improvement to the concept of SMS Demag AG developed for plating rolling mills, the one we covered in the first part hereof. We herein discuss the experience of configuring and using the Mill-5000 AGCS in the context of constantly changing product range. In combination with improvements in CVC systems and roll counterbending systems [16–19], the obtained results become generalizing in nature. This research might be deemed comprehensive, as it addresses the problems of improving the profile and flatness of the rolled metal produced by modern plate rolling mills.
Figure 4. HS parameters oscillograms, (a) and gauge over the plate length, (b) when implementing the proposed changes: Window 1 shows the trailing edge position (from the tracking system) relative to the stand position; Window 2 shows the actual gauge in the AGCS; Window 3 shows the actual position relative to the calibration point; Window 4 shows the rolling force.

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