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Improvement of Electric and Mechanical System for Automated Strip Tension Control at Continuous Wide-Strip Hot-Rolling Mill

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Abstract

It is known that a modern trend in development of wide-strip hot-rolling mill technologies is gauge diversification owing to production of thin strip. Engineers are mastering methods of rolling 0.8–1.5 mm strip that was earlier manufactured at cold rolling mills only. Tension in inter-stand gaps of the continuous train is found to influence thin strip gauge greatly. Based on the example of the 2,500 mm mill at OJSC Magnitogorsk Iron and Steel Works, it has been proven that existing tension and loop size indirect control systems (TLSCSs) does not meet increasingly stringent requirements for accuracy of tension control. Here, improvement of control algorithms does not result in a significant quality rise. Thus, capabilities of the high-speed system for automated gauge control based on the Hydraulic Gap Control (HGC) may be useful. The improved TLSCS has been developed that enables control of the roll speed and HGC location of the previous stand. The system provides improvement of dynamic data due to compensation of the impact of the loop gear location of tension. Mathematical modeling has proven that the system developed ensures control of specific tension to a tolerance of ±10%. A dynamic component of the strip gauge deviation is within 3%. The TLSCS developed is recommended for implementation at 2,500 mm mill of OJSC Magnitogorsk Iron and Steel Works within the framework of the current reconstruction.

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Keywords: wide-strip hot-rolling mill; thin strip; gauge; tension; Hydraulic Cap Control; automated control system; improvement; mathematical modeling; response speed; accuracy; commercialization.

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1. Introduction

A trend at development of wide-strip hot rolling (WSHR) is switching to the manufacture of 0.8–1.5 mm thick hot-rolled strip, which geometry is similar to that of the cold-rolled products [1, 2]. Existing local systems for geometry control are designed for rolling thicker, 2 to 10 mm strips and do not meet specifications because of the influence of specific tension on roll gauge [3]. This influence is mostly expressed within the last inter-stand gaps of the continuous (finishing) train.

The highest demands imposed upon the systems for tension and strip loop control of the modern WSHR systems include provision of continuous control and maintenance of accuracy of tension control in steady-state and dynamic modes. Existing systems based on the principle of indirect tension control do not fulfill increased requirements to gauge interference. The simplified algorithms of tension setting and control implemented in the analog systems result in significant errors that are not tolerable at increasing requirements to accuracy of geometry control. Thus, the algorithms of calculation and control of tension-relevant parameters should be improved that may be implemented at switching to digital control within the systems based on the industrial controllers [4–8].

2. Problem statement

As accuracy of geometry control should be improved, electric equipment and systems of technology automation of the 2,500 mm hot-rolling mill at OJSC Magnitogorsk Iron and Steel Works is being reconstructed. Reconstruction is accompanied by switching to digital systems for control of electric drives. The operated indirect-type TLSCS provides the required accuracy of thin strip gauge control in the steady-state rolling mode only.

According to the operating procedure, the TLSCS of the 2,500 mm mill shall meet the following requirements:

- stable rolling in all process modes due to the maintenance of the minimum possible level of specific tension;
- independent control of specific strip tension in each inter-stand gap of the finishing train;
- strip quality improvement because of the reduction of longitudinal gauge deviations;
- reduction of possibility of emergency situations and increase of mill performance;
- at rolling, specific tension is within the range of 2–7 N/mm², allowable deviations may amount ±10% or maximum ±0.2 N/mm².

However, due to the gauge diversification, the tension control range has been significantly changed and is within 0.5–17 N/mm² [9]. Correspondingly, the tolerance range of specific tension has also been changed, within ±0.05 N/mm². After the HGC has been installed at the 10th and 11th stand and a new Automatic Gap Control (AGC) system has been commissioned, strip gauge interference shall not exceed 0.075–0.09 mm (before reconstruction, the gauge interference was 0.1–0.14 mm). At rolling 1.0–1.5 mm thick strip, it is 3.7–5%. Furthermore, switching to thin gauge is associated with rising rolling speeds. While speed at the output of the finishing train amounted 13 m/s at rolling 2 mm thick strip, it makes up 20 m/s at rolling 1.5 mm thick strips.

Experiments carried out at the mill showed that more strict requirements to dynamics of the TLSCS could not be met due to the increased accuracy of calculation and control of process parameters only [10]. There is a challenge to increase response speed with the capabilities of the hydraulic AGC. The most reasonable is to form a system of correlated tension and gauge control similar to that of the cold-rolling mills. A principal difference of the WSHR finishing train is a presence of loop gears in the inter-stand gaps.

3. Main part

Ensure Specialists of the South Ural State University, Magnitogorsk State Technical University and OJSC Magnitogorsk Iron and Steel Works have developed in collaboration a number of solutions aimed at improvement of the TLSCS of the 2,500 mm mill at its switching to digital version [11]. The main results are as follows [12]:

1. Algorithm for calculation of setting the torque of electric drive of the loop gear and analytical dependencies for calculation torque components that provide improvement of accuracy of tension setting and control [4].

2. Method of indirect correlated strip tension and gauge control, distinctive feature of which is an additional correction action on the HGC of the previous stand applied together with correction action on motor speed of this stand [13].
3. The electromechanical TLSCS with internal cross coupling and circuits of specific tension control acting both on the roll speed and on HGC location of the previous stand (Fig.1) [14].

Fig. 1. Function chart of the developed TLSCS
The system contains two closed circuits: external circuit for specific tension control and internal one for HGC location control [15]. The signals of difference $\Delta t_i$ between the set and actual specific tensions is supplied to the input of the controller of specific tension SDNC. From the output of SDNC controller, the actuating signal $u_{ahd,i+1}$ is supplied to the input of the HGC system for automated location control as a main setting signal. This signal $u_{ahd,i+1}$ is added to the setting signal $u_{shd,i+1}$; the value being proportional to the actual HGC location supplied by the $SPH_{i+1}$ location sensor is deducted from the total obtained. The resulting signal is fed to the input of HGC location controller $HPC_{i+1}$. The output voltage of this controller is an actuating signal $u_{ah,i+1}$ for servo-valve, which value defines the flow rate $Q_{i+1}$ supplied to the head end of the hydraulic cylinder.

Traveling loop gear at control actions of the location control system is a disturbance factor for the system of specific tension control. Moreover, as the investigations at the mathematical model has shown, this influence is great and requires corresponding compensation in dynamic modes. Thus, the developed TLSCS ensures compensation of the influence of the system for automated control of loop gear position. For this purpose, an additional signal is fed from the output of the loop gear position controller through the cross-controller CC to the input of the system for stand speed control. It results in dynamic component of the stand speed that compensates linear speed of the loop gear.

4. Research results

To enable study of electromechanical stand systems, loop gears and HGC within the AGC structure, a dynamic mathematical model of the inter-stand gap has been developed [16, 17]. This model considers a correlation between electromechanical systems through the rolled strip and interference between of the stand electric drive and hydraulic drive of the screw-down mechanisms through the deformed metal.

The study of the developed TLSCS were carried out at the mathematical model for the following dynamic modes appearing during the rolling cycle:
- rolling the front strip end (strip gripping by rolls of the next stand, elevation of the loop gear into operation position with contemporary control of specific tension);
- rolling the rear strip end (lowering the loop gear into initial position at constant setting specific tension);
- changing settings of loop gear position;
- changing settings of specific tension;
- changing speed of a stand of the inter-stand gap;
- changing the inter-roll gap of a stand.

As an example of the study results, Fig. 2 shows curves of changing specific tension (a), loop gear position (b) and gauge increment (c) at increasing setting for elevation angle of the loop gear.

An operation angle of the loop gear is changed by 5 degrees (from 15 to 20 degrees). The period of the transient process is $0.8 - 0.9$ s in the operated system, while it is $0.45 - 0.5$ s in the developed system. Overcorrection of specific tension (Fig. 2, a) amounts 50–57% in the operated system, whereas the developed system requires no overcorrection. This significant improvement of the control indexes is due to the introduced cross-coupling compensating disturbance resulted from traveling loop gear. Strip gauge increment due to the deviation of specific tension (Fig. 2, c) amounts 3–3.5 % in the existing system. The developed system features practically no gauge deviations.

It follows from the analysis of the provided time dependencies that the system with the combined action proposed ensures the required accuracy of specific tension control and increase response time by 2–3 times compared to the system acting on the speed of the stand electric drive only.

The results of comparison of the control indexes in the existing and proposed TLSCS in dynamic modes under consideration are provided in the following table. Dynamic deviations of specific tension do not exceed the required limits ±10%; a dynamic component of strip gauge deviation does not exceed 3.2%. Obtained technical outcome is provided as diagrams in Fig. 3 [18-25].
Table 1. Control indexes for existing and developed systems.

| Process mode                                | Period of specific tension control, s | Overcorrection, % of specific tension | of loop gear angle | of gauge increment |
|----------------------------------------------|---------------------------------------|---------------------------------------|--------------------|-------------------|
| Rolling front strip end                      | Existing control system: 0.8-1.1     | 68-79                                 | 3-4.2              | 3.5-4.5           |
|                                             | Developed combined system: 0.15-0.3   |                                      | 0.4-0.7            | 2-2.1             |
| Rolling rear strip end                       | Existing control system: 0.7-0.9     | 65-80                                 | 2.5-4              | 4-4.5             |
|                                             | Developed combined system: -          |                                      | 0.2-0.5            | 2.8-2.9           |
| Changing setting of loop gear position      | Existing control system: 0.9-1.0     | 50-57                                 | 4-5                | 3.2-3.8           |
|                                             | Developed combined system: -          |                                      | 0.5-1              | 1.9-2.1           |
| Changing inter-stand gap of the next stand  | Existing control system: 0.4-0.6     | 25-32                                 | 3.2-5              | 3.6-3.9           |
|                                             | Developed combined system: 0.15-0.2   |                                      | 0.2-0.4            | 3.0-3.2           |
| Changing speed of the next stand            | Existing control system: 0.6-0.8     | 22-29                                 | 3-4.2              | 3.5-3.7           |
|                                             | Developed combined system: 0.14-0.2   |                                      | 0.3-0.46           | 3.1-3.2           |
4. Conclusion

The use of cross-controller in the developed system enables elimination of impact of the system for control of loop gear location on the system of specific tension control.

Based on results of the developments done, the following decisions relating to reconstruction of the TLSCS of the 2,500 mm mill have been made:

- replacement of the existing TLSCS in the last three inter-stand gaps with the developed system, provided the installed mechanical and power equipment is maintained;
- technical implementation of the system on the basis of the industrial controllers being introduced.

Complete commercialization of the developed system is aimed at reconstruction of the mill facilities. The installed mechanical and power equipment of the stands and loop gears shall be replaced during reconstruction; electric drives shall be switched to digital control.

General technical benefits from the commercialization are as follows:

- reduction of the material consumption (resource saving) due to the increased accuracy of the gauge control at the coil tails;
- improvement of conditions of strip gripping by rolls thanks to implementation of the control algorithms providing coordination of the TLSCS and hydraulic AGC in dynamic modes;
- increase of dimensional strip accuracy due to high-speed tension and gauge control.

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