Journal of Chemical Technology and Metallurgy, 50, 6, 2015, 629-637

IMPROVEMENT OF THE TECHNOLOGY OF WORKING S-SHAPED ROLLS GRINDING IN HOT CONDITION

Alexander A. Astakhov[1], Rozina Jordanova[2], Igor P. Mazur[1]

[1] *Lipetsk State Technical University,*
Department of Metal Forming,
Moskovskaya Street, 30, 398600 Lipetsk, Russia
[2] *University of Chemical Technologyand Metallurgy,*
8 Kl. Ohridski, 1756 Sofia, Bulgaria
E-mail: mazur_ip@mail.ru

Received 19 February 2015
Accepted 28 September 2015

ABSTRACT

The paper discusses the way to improve the methodology of S-shaped working rolls grinding by taking into account its thermal deformations, which appear during the campaign by the contact with hot strips. An algorithm of working rolls grinding in hot condition is developed by using the mathematical model of the thermal expansion, which allows one to predict changes of the profile of S-shaped rolls. The algorithm and the results of its manufacturing approbation are presented in this paper.

Keywords: hot rolling, working rolls, grinding, thermal profile.

INTRODUCTION

Improving the quality requirements of sheet metal stimulates the emergence of new and improvement of well-known approaches to improve the geometry of sheet steel. In modern mills control and management of cross-section profile are carried out by means of automatic profile and flatness control systems (PFC). The main channel of the impact on the geometrical parameters of such systems is axial shifting of S-shaped working rolls in the CVC stands [1]. Stability of the PFC is largely dependent on the accuracy of performance profile of the rolls.

During rolling, due to contact with the strip, there is uneven heating of the working rolls, which causes a change in their thermal profiles. In this case it is necessary to carry out the correction for thermal bulge of the barrel of the roll, otherwise there is a deviation of profiling, which reduces the efficiency of the PFC and the geometrical characteristics of a breach of the rolled strip.

To ensure accurate execution of a given profile of the roll before grinding it is sent to the warehouse for cooling. This process, according to the current regulations, takes at least 24 hours, which exceeds the working campaign several times and requires a minimum of 8 sets of work rolls for each stand of the finishing group of the mill. To the system PFC is entered profiles of the rolls, which are obtained by grinding on a roll grinding machine after cooling. However, to ensure continuous operation of the mill in emergency situations one often needs to grind working rolls in hot condition.

Reducing uneven temperature distribution along the length of the roll barrel after working campaign, as the authors suggest in [2 - 5], can be achieved by rapid cooling water. This approach does not allow one to obtain with sufficient accuracy the desired profile of the roll on roll grinding machine in the absence of data on initial (pre-cooled) and final (after cooling) thermal profile of the roll. Also, there is a decrease due to the additional durability of rolls of thermal stresses resulting from the forced cooling.

For working rolls of broadband mills with convex or

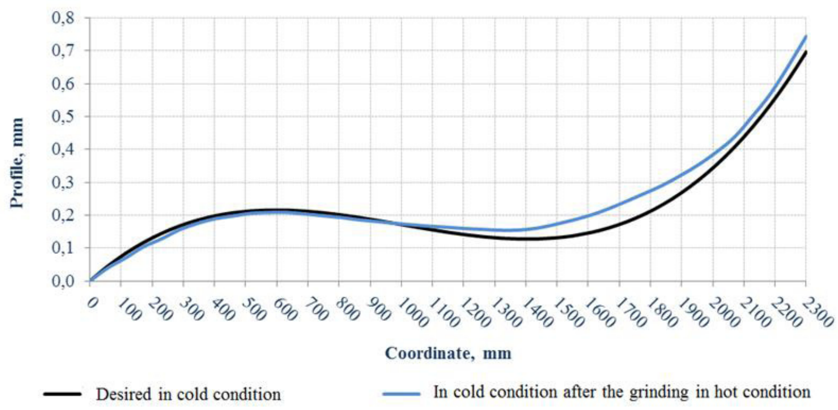

Fig. 1. Deviation of the rolls profile from the specified value after the grinding in hot condition according to methodology, given in[8].

concave profiling the authors [6, 7] proposed a technology based on the measurement of the surface temperature along the length of the roll barrel after dumping from the stand. Then, the temperature difference and the average for the labor campaign bandwidths determined correction for thermal profile, which takes into account when rounding the machine. This technology cannot be applied to the rollers, the profile of which is formed by a polynomial curve, as it has no concavity or convexity unambiguous.

Currently, when grinding rolls are still hot from previous state, the method proposed by the authors isused [8]. After dumping of the stand is measured and the surface temperature of the temperature difference is determined in the middle and at the edges of the roll body, which is rounded up to a multiple of 10°C. Thenwe determine the magnitude of the correction factors of the polynomial, which is introduced into the CNC roll grinding machine and grinding produce.

The disadvantage of this method is that there is a rounding difference of temperature, which greatly reduces the accuracy of performance profiling roll, as well as the lack of consideration of the average width of the rolled strips for the campaign, which affects the uneven temperature distribution along the length of the roll body, therefore, and thermal expansion. Profile of the roll which was ground in hot condition by this method after cooling is not correct (Fig. 1), i.e. there is a deviation, the value of which, on average, is 0,020-0,035 mm. This is one of the most likely reasons for the rejection of the transverse profile of bands from the desired values, as well as violations of the stability of the system as a whole.

EXPERIMENTAL

Influence of roll profile on the cross-section of the rolled strip

To assess the impact of deviations rolls profile on the form of strip's profile changing of square of the strip's cross-section was calculated (Fig. 1):

$$\Delta F = \int_a^b \left(f_2(x) - f_1(x) \right) dx \quad (1)$$

where $f_1(x)$ - the function of roll's profile, which was grind in cold condition; $f_2(x)$ - the function of roll's profile, which was grind in hot condition; *a, b* - position coordinates of the left and right edges of the strip in the midpoint of work roll barrel.

As it can be seen from Fig. 1 the strip edges get thinner and in this regard, the bulge of the transverse profile of strip increases. Because of this in the middle of the strip in the next mills there will be more than the edges, i.e. there occurs thedefect of the strip - unflatness.

Thus, the bulge of strip increases from stand to stand, and at the output of the mill profile of the strip is more than valid values. To test this assumption transverse profile of the strips under certain conditions was calculated and compared with the actual values.

The function of height of the gap between rolls is founding as (Bel'skiy et al., 2008):

$$f(x) = y_t - y_b = h + 6\alpha_k dx^2 + 2\alpha_k d^2 - 2\alpha_k dL^2 + 2kd \quad (2)$$

where y_b - the bottom forming of the upper work roll; yt - the top forming of the bottom of the work roll; *h* - height

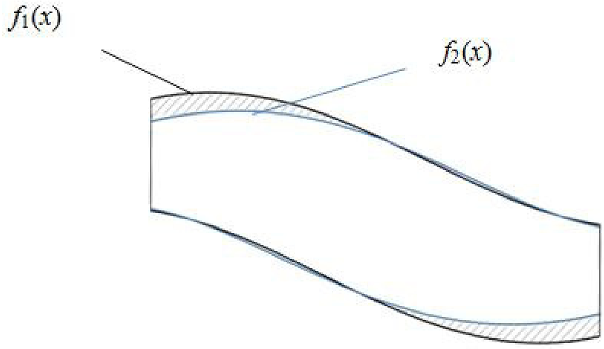

Fig. 2. The change of the strip profile due to the deviation of roll profile from the specified value.

the gap between rolls clearance; d - offset coordinates of a point of inflection from the center of working roll's barrel (Fig. 2); $\alpha_k = a_3$ and k - a constant coefficients; x - coordinate along the axis of the roll barrel with the origin at the edge of the barrel.

To specify the initial convexity the gap between rolls (Fig. 3) in the absence of axial shifting the profile of upper roll is moving on the value d and the lower - by the value (-d):

$$d = a_{max}\left(\frac{2\delta_{min}}{\delta_{max} - \delta_{min}} - 1\right) \quad (3)$$

where δ_{max} and δ_{min} - the range of change of convexity of the gap between rolls at the extreme positions of axial shifting; a_{max} - maximal value of axial shifting.

The ratio of the slope of the linear component was determined by the formula:

$$k = \frac{y_2 - y_1}{2L} \quad (4)$$

where

$$y_1 = f(-d) = a_1(-d) + a_2(-d)^2 + a_3(-d)^3 \quad (5)$$

$$y_2 = f(2L-d) = a_1(2L-d) + a_2(2L-d)^2 + a_3(2L-d)^3 \quad (6)$$

The value of the transverse profile of the strip is found by subtracting the values of the functions of the gap between rolls in coordinate corresponding to the edges of the strip - $f_e(x)$, from the values of the function of the gap between rolls in coordinate corresponding to the middle of the strip - $f_m(x)$:

$$P = f_m(x) - f_e(x) \quad (7)$$

The average of actual deviation of the transverse profile of the strips from the specified value was 21 microns, and the estimated 19.7 microns, which indicates a correlation between the deviation of machine profile of the rolls and transverse profile of the strips. This is especially true for the first strips in the beginning of the company of working rolls, and when changing one strip dimension type to another.

Thus, it is necessary to compensate the thermal profile of the roll before grinding. Currently, working rolls are placed to the warehouse for cooling, which requires additional sets of rolls. However, from the point of view of the authors the most rational way, is to compensate thermal profile of working rolls through correction coefficients of profile of the rolls when grind-

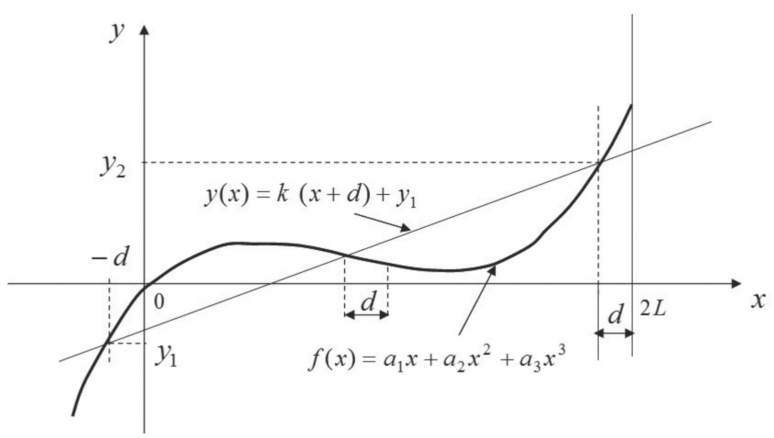

Fig. 3. Function of working roll profile: *y(x)- a* linear component of profile, *f(x)* - a polynomial component of profile.

ing in hot condition.

The algorithm of preparation of S-shaped working rolls for grinding in hot condition

Profile of the S-shaped rolls of CVC mills, as a rule, is described by the 3[rd] degree polynomial, which has the following form:

$$y(x) = a_1 x + a_2 x^2 + a_3 x^3 \tag{8}$$

where a_i- polynomial coefficients.

To account for the influence of the thermal profile on the initial profile of the roll it is necessary to determine the correction coefficients.These coefficients should express the dependence of the thermal bulge of the roll from the contact with the hot metal. On the basis of the conducted researches of the thermal state of working rolls and analysis of results a mathematical description of the dependence of the temperature distribution of the length of the roll barrel on the average width of the rolled for the campaign strips in the campaign has been obtained [10]:

$$\Delta T(x) = \frac{16\Delta t}{L^4} x^2 (x-L)^2 \left[1 + \frac{4k_B}{L^2}\left(x - \frac{L}{2}\right)^2\right] \tag{9}$$

where Δt - difference between the temperature in the middle and the temperature at the edges of the roll barrel defined by the formula (10); L - length of the roll barrel; k_B-empirical coefficient, which reflects the dependence of the temperature distribution on the average width of rolled strips.

$$\Delta t = T_M - \frac{T_{E1} + T_{E2}}{2} \tag{10}$$

where T_M- the temperature in the middle of the roll barrel; T_{E1}, T_{E2} - the temperature at the left and right edge of the roll barrel.

Papers [10, 11] present the solution of system of equations relatively new polynomial coefficients of the profile of the working rolls in a hot condition. From the solution of the system it follows, that when grinding S-shaped rolls in hot condition the coefficient of the polynomial a_1 it is necessary to increase and the coefficient a_2 reduced by the amount of:

$$\Delta a_1 = \frac{32\alpha R\Delta t}{9L}\left(1 + \frac{k_B}{9}\right)$$

$$\Delta a_2 = \frac{32\alpha R\Delta t}{9L^2}\left(1 + \frac{k_B}{9}\right) \tag{11}$$

where α - coefficient of linear thermal expansion of the roll material; R - radius of the roll barrel.

For the verification of the developed method and comparison with the existing methodology an experimental study was conducted. S-shaped working rolls were divided into 2 groups:

- group 1: correction temperature coefficients are determined in accordance with the method, show in [8];
- group 2: correction temperature coefficients calculated by the proposed algorithm.

After dumping from the mill and dismantling of the chocks, rolls are installed on the machines «Herkules WS

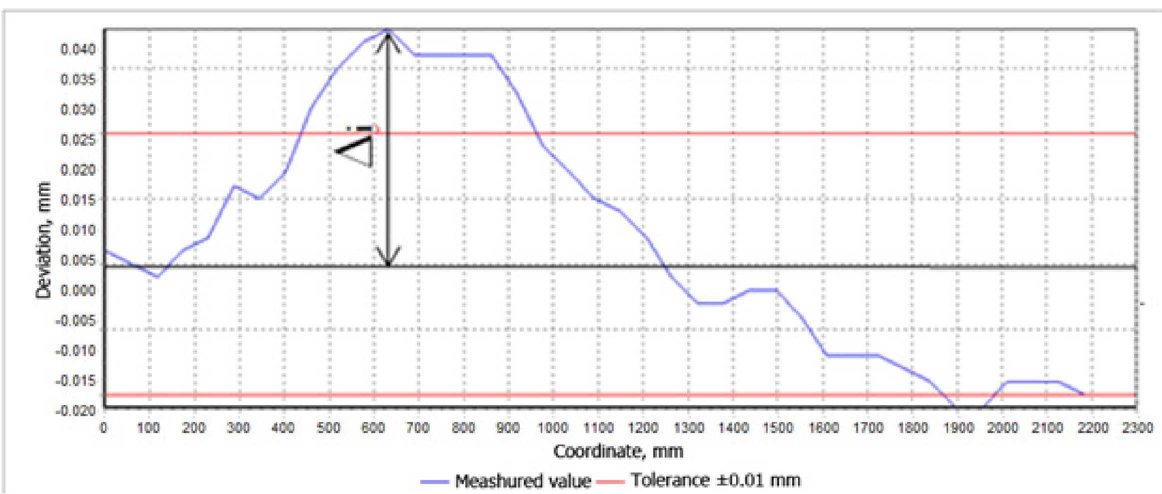

Fig. 4. Deviation of the profile of the roll from the desired value.

600/450-20x6000 CNC» and the surface temperature of the roll in three points was measured: in the middle and at the distance of 100 mm from the edge of the barrel. For the first experimental group measured the temperature was used for selection of the grinding program from the memory of the machine in accordance with the method given in [8], for the second experimental group - for calculation of correction factors by the proposed algorithm. 24 hours after the grinding there was produced a control measurement of the temperature and the profile of the rolls, which were recorded in the database for further analysis.

As the criteria for the effectiveness evaluationof the proposed methodology the parameter of the average of the deviations of the profile from the required value is used. The deviation of the profile:

$$\Delta_i = p_{meas_i} - p_{req_i} \quad (12)$$

where $i = 1 \div n$; n - the number of measurement points; p_{measi} - measured profile; p_{reqi} - required profile.

The average deviation is:

$$A = \frac{1}{n}\sum_{i=1}^{n}|\Delta_i|. \quad (13)$$

To perform the conditions of the satisfactory execution of the rolls profile parameter A should not exceed 0.01 mm, which corresponds to the accuracy of grinding provided by machines «Hercules» (± 0.01 mm).

During the conducted work 20 sets of working S-shaped rolls in hot condition were ground (10 of them in accordance with the existing methodology and 10 - in accordance with the method [8]). The results of the comparison of experimental data for the parameter A are presented in Fig. 5.

Analyzing the current results of experimental testing and comparing the methods of grinding working S-shaped rolls in hot condition, it should be noted:

- the existing method allows one to achieve the precision required profile of working rolls at the level ± 0.01 mm only in 10 % of cases even at low values of the temperature gradient (10 - 25ºC) the length of the barrel;

- the proposed method ensures the accuracy of a desired profile at the level ± 0.01 mm in 100 % of cases, and profile at the level ± 0.005 mm in 40 % of cases in the range of the temperature difference in the middle and at the edges of the roll barrel 0 - 37ºC.

As it can be seen from equation (9), curve describing the thermal profile of the roll has even degree (fourth). Therefore, maximum accuracy of performance at a given profile grinding rolls in hot conditions can only be ensured by increasing the polynomial degree profiling of S-shaped rolls to 4th (methodology «n +1»):

$$y_{h.c.}(x) = a_1x + a_2x^2 + a_3x^3 + a_4x^4 \quad (15)$$

Coefficients of the polynomial of 4th degree are determined using three coefficients of the original (the required cold) profiling rolls. It should be noted that after complete cooling, i.e. after removing the heat convexity degree profiling spontaneously drops to third.

RESULTS AND DISCUSSION

This method was tested on a single pair of work rolls. The comparison result is corrected techniques «n + 1» to its original shape, shown in Table 1 and Figs.6 and 7.

The results presented in Table 1 and Figs. 6 and 7,

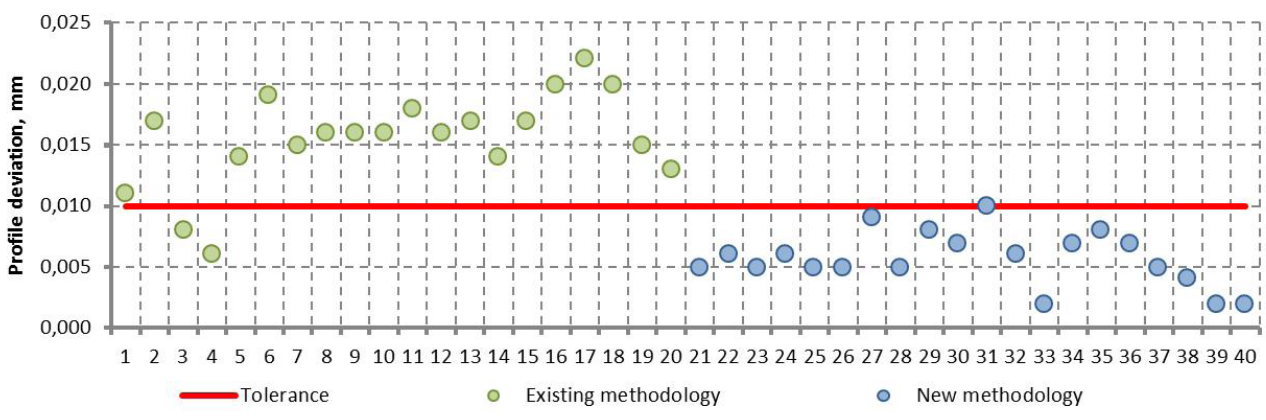

Fig. 5. Average deviation of rolls profile in accordance with the new methodology.

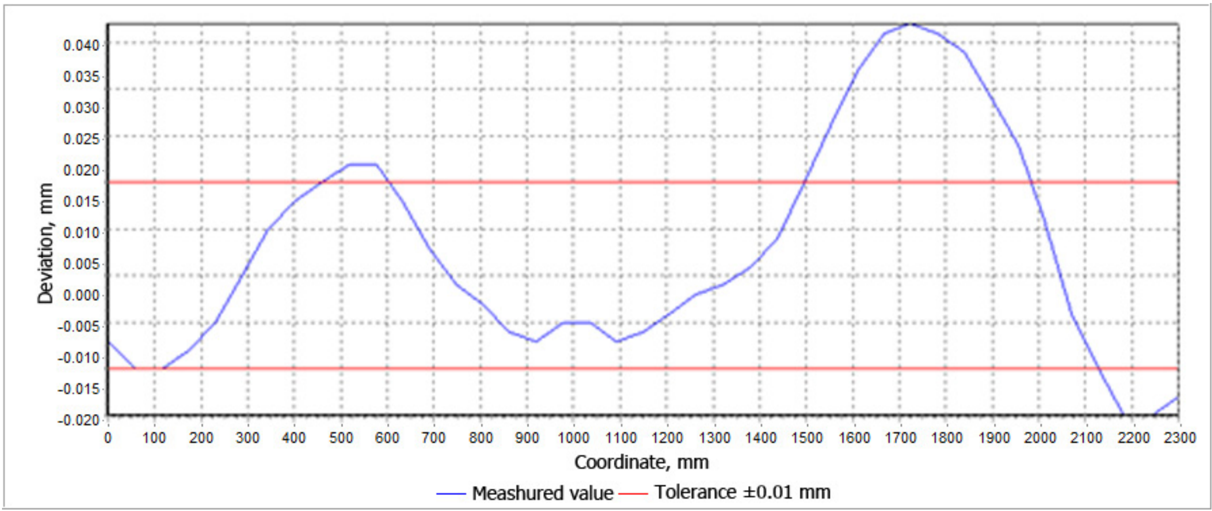

Fig. 6. Deviation profiling roll cold after grinding hot curve third degree: the temperature differences in the barrel roll Δt = 37°C, A = 0.0097 mm.

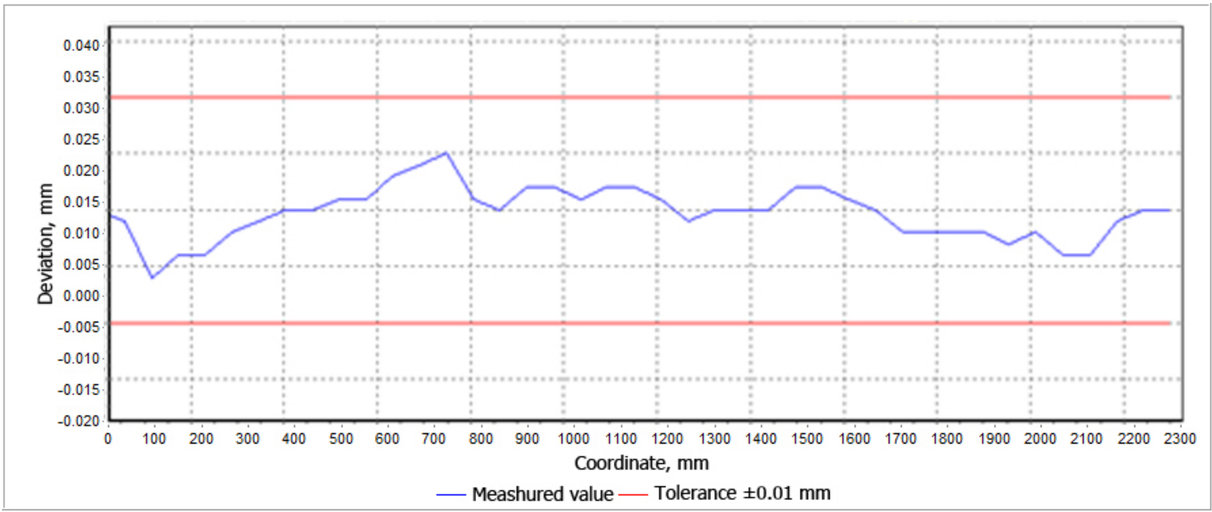

Fig. 7. Deviation profiling roll cold after grinding hot on a curve of degree 4: the temperature differences in the barrel roll Δt = 34°C, A = 0.0018 mm.

Table 1. Comparison of the results of experimental approbation adjusted methodology.

Methodology	Stand number (position of the roll)	Δt	A
Initial (3rd degree)	8 (top)	37	0,0067
	8 (bottom)	34	0,0097
«n + 1»	8 (top)	34	0,0018
	8 (bottom)	35	0,0024

prove conclusively that the method of «n + 1» provides the required profiling rolls with virtually no deflection even at high temperature difference along the length of the barrel and its accuracy is comparable to the precision grinding machines for «Hercules».

Technological effect on the optimization method of grinding working S-shaped rolls hot is to improve the accuracy of performance required profile compared to the existing algorithm. The cost effectiveness of this method is to reduce unproductive stock removal work rolls by reducing deviations from the source profile is a disadvantage of the existing method.

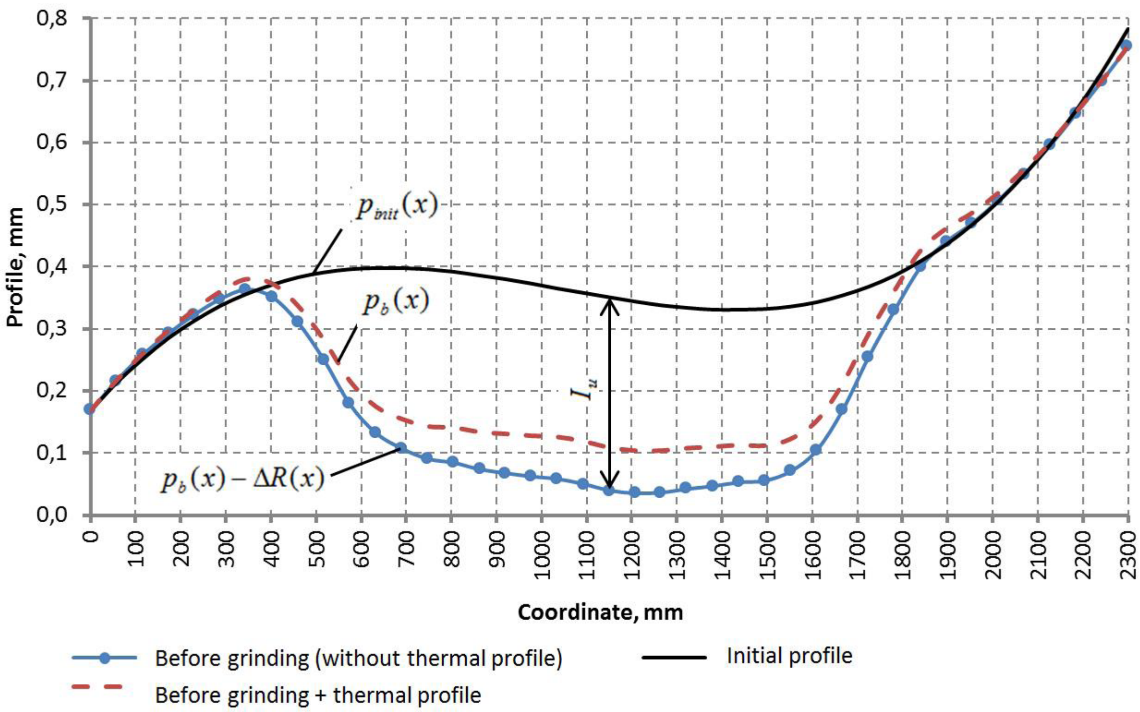

Fig. 8. Determination of maximum wear barrels of «black» roll.

Average value of unproductive stock removal can be estimated as follows: the amount equal to the guaranteed removal wear barrels (excluding thermal crown) plus blister removal and finishing (finish); everything else - unproductive rent, obtained at the exit of the mortgaged in CNC profiling. The magnitude of this removal depends on the accuracy of the calculation of the curve forming the contour profile of the roll in the hot condition.

In the course of producing an estimate of the non-productive stock removal rolls is based on existing methods and in accordance with the proposed algorithm. After installation of the next roll in the machine «Hercules» as measurements of surface temperature and the profile of the «black» roll ph(x), a printout of the measurement data was carried out. According to the formula (9) and according to the temperature measured temperature gradient along the length of the barrel and the thermal profile of the roll were determined:

$$\Delta R(x) = \alpha R \Delta T(x) \tag{16}$$

Further was calculated the value of the maximum relative to the initial wear barrels roll profile (Fig. 8):

$$I_u = \max\left(p_{init}(x) - p_b(x) - \Delta R(x)\right) \tag{17}$$

Profile of the roll before grinding without linear component of S-shaped curve was:

$$P_u(x) = p_{meas}(x) - p_{meas}(n) - \left(p_{meas}(1) - p_{meas}(n)\frac{L-x}{L}\right) \tag{18}$$

where $p_{meas}(1)$ and $p_{meas}(n)$ - a profile in the first and last points of measurement.

Roll's diameter in the x-coordinate along the length of the barrel is:

$$D(x) = D_{init} + \frac{x}{L}\left(D_{init} - D_p\right) + 2P_u(x) \tag{19}$$

where $D_{init}(x)$ and $D_p(x)$ - diameter of the roll from the back and headstock, respectively.

Similarly, the formulas (11) and (12) were determined in the roll diameter x coordinate after cooling. Value of the unproductive removal was calculated as follows:

$$S_u = D_{hot}(x) - D_{cold}(x) - I_u - s_b - s_c \tag{20}$$

where $D_{hot}(x)$ and $D_{cold}(x)$ - diameter of the roll in the

x coordinate before grinding and after cooling, respectively; s_b and s_c - removal for roughing and finishing, respectively.

As a result, the average non-productive removal when grinding the existing method was 0.466 mm, and when grinding at the proposed algorithm 0.386 mm, which is less than 17.16 %.

The algorithm of calculating the correction coefficients of S-shaped rolls profile was implemented as software «Program for calculation of the profile of the working rolls of the mill 2000» [13].

CONCLUSIONS

Based on the mathematical model of the thermal state the algorithm determines the correction coefficients of the profile S-shaped rollers depending on the average width of the rolled strips for the campaign, the algorithm is implemented as a software (St. Number 2013617839).

Testing of the proposed method in industry was successful. The experimental results suggest that the proposed method, in contrast to existing, provides a predetermined roll profile at ± 0,01 mm at any point of time after dumping from stand.

Criteria for impact analysis of the proposed method to change operating parameters of PFC in conditions of manufacture in the hot rolling mill 2000 were:

- the number of cases of deviation of cross-section of the strips;

- the number of cases of transition of the axial shifting in the mode of saturation (the stop in the end positions);

- precision of settings PFC on the specified profile.

When comparing the reporting period, within which was conducted experimental verification of the new algorithm of preparation of rolls, with the period before work, the following results were obtained:

1) there was a decrease in the number of cases of deviation of cross-section of the strips for limits of 25 % on all assortment;

2) there is a decrease in the number of transition axial shift in the mode of saturation by 10 % in total for 6 finishing stands of the mill;

3) improvement in the accuracy of settings PFC on the specified profile from 84 % to 86 %.

In carrying out the method of correction adjustments are made for thermal bulge by increasing the degree of polynomial profile of the rolls, allowing further increase the accuracy of the given profile rolls.

A decrease in the magnitude of unproductive working layer removal rollers for grinding the proposed algorithm to 17.16 % compared with existing ones.

REFERENCES

1. SMS Siemag. http://www.sms-siemag.com
2. AS.1268225 USSR, Profiling method of flat-rolled mill work rolls, V. Konovalov, O.N. Soskovets, A.A. Budakva, etc., Donetsk Scientific-Research Institute of Ferrous Metallurgy and Karaganda Metallurgical Combine, № 3842358/22-02. Appl. 15.01.1985. Publ.07.11.1986. Bulletin No 41, (in Russian).
3. AS.1235570 USSR, Profiling method of rolling mill rolls, B.A. Poles, S.L. Kotsar, Sergei V. Lipetsk Polytechnic Institute, № 3767536/22-02. Appl.06.07.1984. Publ.7.7.86. Bulletin No 21, (in Russian).
4. AS.994068 USSR, Control device thermal profile of the roll rolling mill, Y.I. Bulatov, A.G. Butkovskiy, E.A. Garber, etc., Research Institute of Heavy Engineering and Production Association «Uralmash», Cherepovets Branch Northwest Correspondence Polytechnic Institute, Institute of Control Sciences of USSR and the Cherepovets Metallurgical Plant. № 3291397/22-02. Appl.18.05.1981. Publ.07.02.1983. Bulletin No 5, (in Russian).
5. AS.1342548 USSR, Profiling method work rolls, V.L. Mazur, D.L. Romanovsky, L.V. Tymoshenko, etc., Institute of Ferrous Metallurgy, № 4077659/22 - 02. Appl.20.06.1986. Publ.07.10.1987. Bulletin No 37, (in Russian).
6. Method of preparation of the working rolls broadband hot rolling mill: stalemate.1600881 Ros. Federation: IPC V21V28/02 L.V. Tymoshenko; patentee of «Karaganda Metallurgical Plant». - № 4442907; appl.17.05.1988, publ.23.10.1990, (in Russian)
7. W.Y. Chien, Y.J. Hwu, W.M. Yang, C.C. Hsieh, 2008, Thermal Compensation of Work Roll Grinding in Hot Strip Mills No. 2 Hot Strip Mill, China Steel Technical Report, 21, pp. 34-37.
8. Method of preparation of the working rolls of mills with axial shifting: pat. 2370330 Rus. Federation: IPC V21V28/02, S.M. Bel'skiy; patent owner JSC «Novolipetsk steel». № 2008109309/02; statem. 11.03.2008; publ. 20.10.2009, (in Russian).

9. S.M. Bel'skiy, About some effects of using axial shifting, Rolling production, №7, 2008, 21-24, (in Russian).
10. A.A. Astakhov, A. Kawalek, I.P. Mazur, Grinding Working Rolls of Hot Rolling Mills, 21st METAL 2012, Conference proceedings, International Conference on Metallurgy and Materials, 2012, p. 343-348.
11. A. Astakhov, I. Mazur, D. Dunaev, Machining Profiling of the Working Rolls as a Way to Control Cross-Section of the Rolled Steel, Materials Science Forum, v. 762. Trans. Tech. Publications, Switzerland.,2013, pp. 337-342. (doi:10.4028/ www.scientific.net/MSF.762.337, indexed by Elsevier: Scopus and Ei Compendex (CPX).
12. Herkules Group, http://www.herkules-group.com.
13. A.A. Astakhov, I.P. Mazur, Software of the calculation of the polynomial coefficients of the working rolls profile of the mill 2000. Inventory registration number of the software of ASTIC 50201250307 from 21.03.2012, (in Russian).