IMPROVEMENT OF OPERATIONAL EFFICIENCY OF COLD ROLLING MILL WORK ROLLS

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ABSTRACT

The paper presents the results of development and implementation of improved cold rolling process conditions and modified cooling system to allow making operation of work rolls more efficient. The optimal metal removal depth, which depends on the depth of structural defects in the material of rolls detected by the eddy current inspection, during grinding of work rolls has been determined. Adoption of the developments has made it possible to significantly increase the service life and reduce consumption of rolls at the continuous cold rolling mill 2100.

Keywords: work rolls, cold rolling, rolling conditions, roll grinding, roll consumption.

INTRODUCTION

In the conditions of increasing rolling speed, growing share of thin metal, production of demanding product mix of special and alloyed steels at the modern continuous rolling mills, operation of the main rolling tool – work rolls – is marked by significant increase of loads. Therefore, it is essential to ensure long service life of work rolls to be able to implement technologies allowing intensification of the rolling process at the continuous mills. Roll service life has a considerable impact on productivity, regularity of the production pace, product quality and production costs of rolling mills. In addition, controlling the amount of metal removed during grindings and the number of roll changes makes it possible to estimate consumption of rolls and identify possibilities to increase productivity of cold rolling mills.

Analysis of the literature dealing with operational reliability and service life of work rolls of cold rolling mills [1 - 5] shows that it is possible to improve work roll performance by means of implementation of a set of technical measures aimed at improvement of the roll preparation and operation process, including optimization of grinding modes and time between roll changes, differentiated use of rolls of different design according to the product mix, timely detection of defects of the hardened layer, maintaining the required turnover stock of rolls. As to the issues related to the study of the influence of the rolling process conditions on roll damage and failure rate, the literature sources give recommendations on minimizing the severity of the rolling conditions,
which means reduction of the rolling force in the stands, prevention of surface and internal defects in incoming hot-rolled metal, observance of requirements to the limit thickness deviation from the nominal value [6 - 8].

Thus, in order to improve performance of work rolls, in parallel with diagnostics, focus should be placed on improvement of the rolling process conditions together with evaluation of the work roll operational parameters and control of the amount of metal removed during grinding of work rolls.

MODELLING AND EXPERIMENTAL RESEARCH

In order to identify operating parameters of rolls and factors influencing appearance of the surface layer defects, the rolling process parameters at the 4-stand mill 2100 were analyzed. The analysis was performed for 0.45 mm thick, 1,254 mm wide strip of conventional steel grades 08ps and 08Yu. In all cases the incoming strip thickness was 2 mm. The analysis showed that interstand specific tensions \( \sigma_1 \), \( \sigma_2 \) and \( \sigma_3 \) in interstand spaces No.1, No. 2 and No.3, respectively, were practically equal, and in some cases the tension in the second space \( \sigma_2 \) was lower than in the first space \( \sigma_1 \) (Fig. 1), despite the fact that specific tensions in each subsequent space should increase due to cold work hardening of the strip [9]. Rolling process in stand No.1 is always with front tension, the difference in the volume of metal rolled per second in stand No. 1 and No. 2 (Fig. 2) is in the positive range of values, which results in significant increase in the rolling force [10], as well as causes frequent slipping of rolls. In order to prevent these negative impacts it is required to decrease the particular percent reduction in stand No. 1.

In addition, it was established that a high percentage of damages of work roll barrels in stand No. 1 was caused by their frequent damaging at the moment of biting, because the condition of the roll bite (\( \tan \alpha < \mu \), where \( \alpha \) – bite angle; \( \mu \) – friction coefficient) was not satisfied. For stand No. 1: \( \tan \alpha = 0.058 > \mu = 0.038 \), which confirms that decrease in the particular percent reduction in the stand is required.

Further evaluation of the cold rolling process at the 4-stand mill 2100 included modelling of the process conditions based on the dynamic model of the cold rolling process [11, 12], which reflects a dynamic interdependence between the driveline torque system, the stand system and the deformation zone at the continuous mill. This made it possible to define the main principles of a new rolling concept for the mill.

The conditions of deformation should be set with maximum percent reduction in stand No. 2; reduction in stands No. 1 and No.3 should be 3 - 4 % and 9 - 12 % lower than in stand No. 2, respectively; reduction in stand No. 4 should be set within the range from 5 to 7 % in order to meet the specified surface quality and dimensional accuracy of cold-rolled strip. Maximum reduction in stand No. 2 is determined based on the condition of uniform loading of stands No. 1 and No. 2 in terms of the rolling force \( P_1 \approx P_2 \).

The conditions of tension should be set according to the following scheme: \( \sigma_1 < \sigma_2 < \sigma_3 \) or \( \sigma_1/\sigma_{a1} = \sigma_2/\sigma_{a2} < \sigma_3/\sigma_{a3} \), where \( \sigma_{a1}, \sigma_{a2}, \sigma_{a3} \) – actual yield strength of the strip material at the exit from stand No.1, No. 2 and No. 3, respectively. In order to prevent breakages and tightening of the cold-rolled strip, specific tensions dur-

![Fig. 1. Distribution of specific tensions in interstand spaces.](image-url)
ing the process in a steady state shall not exceed 27% of the corresponding yield strength of the strip material.

The developed conditions of reduction and tension are substantially different from the ones applied at the mill. Adoption of them made it possible to:

- prevent slipping of rolls in stand No. 1 and damaging roll barrels due to the decrease of the percent reduction in the stand and the fulfillment of the condition $\sigma_1 < \sigma_2$. For instance, for conventional steel grades 08ps and 08Yu $\sigma_2$ began to exceed $\sigma_1$ by about 20 MPa, previously this condition had not been met (Fig. 1);

- decrease the rolling force in the stands, reduce the roll barrel damage rate and, above that, decrease the total energy consumption due to implementation of the reduction and tension conditions with a gradual increase of specific tensions from the first interstand space to the last one. For example, for steel grades 08ps and 08Yu $\sigma_2 - \sigma_1 = \sigma_3 - \sigma_2 \approx 20$ MPa, before the rolling conditions were enhanced, the tension difference had not exceeded 10 MPa (Fig. 1). The exceptions were the rolling conditions for strip more than 1.5 mm thick, for which $\sigma_2 - \sigma_1 = \sigma_3 - \sigma_2 \approx 5$ MPa, which is linked to the characteristics of the existing drive of the roll stands.

The developed conditions were tested in two stages. At the first stage, simulation of the rolling process was performed based on the software of the mill. The simulation showed that it was possible to implement the proposed concept at the rolling mill for the entire product mix. At the second stage, the developed rolling conditions were validated. The average rolling speed for strip up to 1.00 mm amounted to 17 m/s, for strip above 1.0 mm - 15 m/s, with no damage and delamination of work rolls recorded during testing.

Based on the results of the modeling it was established that the proposed rolling concept allowed a reduction in the total rolling power of up to 1% for strip thickness $h_2 \leq 1.2$ mm and of no less than 4% for strip thickness above 1.2 mm. These conclusions were confirmed in a full-scale experiment at mill 2100.

In parallel with the development of process conditions, improvement of the cooling system of the mill was considered, since roll barrel overheating was recorded for work rolls of stands No. 1 - No. 3 during roll grinding operations. The literature sources [9, 13] suggest that, considering the severe operating conditions of rolls, it is reasonable to apply two-side roll cooling system. Therefore, it was proposed to change the single-row configuration of the headers at the entry of stands No. 1 - 3 to the double-row configuration with a possibility to feed emulsion not only to the deformation zone, but onto the roll barrel as well (Fig. 3). It was also proposed to replace nozzles in all the headers with bigger diameter ones to increase the flow rate. In addition, feeding of emulsion by zones according to the strip width was implemented. The central section I, which includes 24 nozzles, is switched on for the strip width up to 1,280 mm inclusive, the two extreme zones III, each having 3 nozzles, are activated for the strip width above 1,600 mm, and the two zones II between the central section and the two extreme zones have 3 nozzles each and are activated for the strip width from 1,280 mm to 1,600 mm.

As a result, with all nozzles of the entry and exit
Fig. 3. Schematic illustration of thermal boundary conditions for work rolls: 1 – work roll; 2 – back-up roll; 3 - strip; 4, 5 – entry and exit headers.

Fig. 4. Distribution of the values of actual metal removal depth during grinding of work rolls and depth of defects determined by the eddy current inspection.
header fully operational, with the pressure of emulsion at the exit from the nozzles no less than 5 bars, and with sufficient power of the feeding pump, high-rate heat removal was ensured at the 4-stand mill, which reduced the risk of overheating of rolls and, consequently, reduced the growth of equivalent stress in the work rolls under the influence of temperature stress. The measurements of the temperature of the work roll surface layer in the middle of the roll body in stands No. 1-3 at the end of the work roll campaign showed that the average temperature in stand No. 1 was 73 °C, in stand No. 2 - 72°C; in stand No. 3 - 69°C, and immediately after removal from stand No. 1 - 44°C; from stand No. 2 - 55°C; from stand No. 3 - 35°C. Analysis of the results makes it possible to conclude that the influence of the temperature stress is minimal, while the contact stress is critical to the service life of rolls.

For the purpose of reduction in the roll consumption at the 4-stand mill the issue of determination of optimal metal removal depth during roll grinding was studied. The eddy current inspection, including check of the roll structure uniformity, is performed in parallel with grinding of rolls at the roll grinding machines. This inspection allows detection of such defects as cracks and indentations (change of the structure). A comparative analysis between the depth of defect determined by the eddy current inspection and actual metal removal depth during grinding of over 600 rolls was conducted. Fig. 4 illustrates the results of comparison for 176 rolls. The following defects with a depth of less than 0.3 mm were considered: cuts, tail marks, marks, slips, overheating, scratch marks and pimples. Actual metal removal depth per radius during grinding was 0.44 - 0.65 mm, metal removal depth exceeded the depth of defect by 0.2 - 0.5 mm. Based on this comparison, it was proposed to reduce metal removal depth at the work rolls down to 0.35 mm per radius for a depth of surface defects not exceeding 0.20 mm by the results of the eddy current inspection. Grinding of rolls with defects at a depth exceeding 0.2 mm remained as before, including metal removal depth of 0.5 mm per radius. Machining of rolls with built-up tread also remained as per the established procedure – rough grinding, eddy current and ultrasonic inspection, complete removal of a defect. The difference between the average actual metal removal depth and the average depth of defects by the results of the eddy current inspection was 0.21 mm, before the trials it was 0.37 mm.

Over the three months of trials on reduction of metal removal depth, the rate of the work roll surface defects and the number of regrindings has not increased, no deviations have been detected by the eddy current inspection, no failures of work rolls have taken place. Therewith, the average metal removal depth during grinding of all the work rolls has been reduced from 0.92 mm to 0.65 mm per diameter.

As a final solution, a differentiated approach has been applied to determination of the depth of metal to be removed during grinding of work rolls: for surface

<table>
<thead>
<tr>
<th>№</th>
<th>Performance indicator</th>
<th>Period of comparison</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>First year</td>
</tr>
<tr>
<td>1</td>
<td>Share of rolls discarded due to wear, %</td>
<td>7</td>
</tr>
<tr>
<td>2</td>
<td>Share of rolls discarded due to built-up tread, cracks, delamination, %</td>
<td>92</td>
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<tr>
<td>3</td>
<td>Efficiency of the use of the hardened layer of rolls (t/mm)</td>
<td>1,316</td>
</tr>
<tr>
<td>4</td>
<td>Average number of installations of a roll into the stand</td>
<td>34</td>
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<tr>
<td>5</td>
<td>Mean operating time of work rolls till discarding (t/roll)</td>
<td>44,014</td>
</tr>
<tr>
<td>6</td>
<td>Average metal removal per one installation of a roll into the stand, mm</td>
<td>2.03</td>
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<tr>
<td>7</td>
<td>Mean operating time of work rolls per one campaign (t/roll)</td>
<td>1,275</td>
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<tr>
<td>8</td>
<td>Total metal removal from discarded rolls, mm</td>
<td>5,510</td>
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<tr>
<td>9</td>
<td>Weight of metal removed during grindings, kg</td>
<td>347,130</td>
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*Weight of one millimeter of the working layer is 63 kg.

Table 1. Performance of the work rolls of the 4-stand mill 2100.
defects at a depth not exceeding 0.20 mm by the results of the eddy current inspection 0.3 mm per radius is removed, for defects at a depth from 0.21 to 0.30 mm the depth of metal to be removed equals 0.35 mm.

RESULTS OF IMPLEMENTATION OF THE DEVELOPMENTS

Work roll performance evaluation was conducted based on the analysis of the performance characteristics of the discarded rolls over the two years after the upgrade of the mill (Table 1). It can be seen that the second year of operation after implementation of the developments versus the first year is characterized by 13% less quantity of failures of work rolls, a two-fold reduction in the average metal removal per one roll installation, increase in the average roll service life till discarding by a factor of 1.4, 18% increase in the efficiency of the use of the hardened layer of rolls and 20% increase in the average number of installations of a roll into the stand.

Comparison of the performance parameters of rolls of mill 2100 for the past two years allowed making a conclusion on positive dynamics in all indicators. Implementation of the measures aimed at increasing the service life of the 4-stand mill rolls, including improvement of the process conditions and the roll cooling system, made it possible to increase the length of the work roll campaign, to reduce the roll barrel damage rate, as well as to reduce the failure rate at the mill. It is also worth mentioning that the consumption of work rolls of the 4-stand mill was reduced by 42% from 0.624 kg/t down to 0.365 kg/t, and the average number of grindings of work rolls per month was reduced from 504 to 463.

CONCLUSIONS

The rolling process conditions and the arrangement of the cooling system for rolls of mill 2100 have been improved, which has made it possible to increase the operational reliability and service life of work rolls.

The optimal metal removal depth, which depends on the depth of structural defects in the material of rolls detected by the eddy current inspection, has been determined.

Implementation of the developed measures at mill 2100 of PAO Severstal has made it possible to reduce the rate of failures of work rolls, to increase the efficiency of the use of the hardened layer by 18% and to increase the average service life of rolls till discarding by a factor of 1.4.

Acknowledgements

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