Experience of Application of Liquid Lubricating Materials during Wide Strip Hot Rolling

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Abstract. The paper presents the results of the scientific and practical research of roller systems operation at feed of liquid lubricating materials through the example of the wide strip hot rolling Mill-2000 at PAO MMK. The experiments proved that application of lubricating materials leads to decrease of energy-power parameters of the process by 12 to 15 %, and reduction of work roll wear by 10 to 12%. The practical results of the study are developed recommendations on determination of consumption-volumetric parameters of the supplied lubricating material depending on rheological and geometrical parameters of the rolled strip and current wear of work rolls.

Nowadays, PAO MMK performs considerable work on assimilation and implementation of new steel grades of high strength classes capable to withstand high loads and operation in rough environments, etc. During manufacture of such products, the production equipment, in particular hot rolling mills, is subject to high loads with respect to energy-power parameters close to critical values. One of practical ways aimed at reduction of energy-power parameters of the process is application of systems of liquid process lubricant supply (SLS) in hot rolling production technology.

Application of lubricating materials in hot rolling technology has been known for a long time [1–3]. It is known from the literature that application of lubricating materials during hot rolling leads to significant reduction of energy-power parameters of the process [1]. However, application of the technology of lubricant supply on to the rolls surface has not been widely used, since solid lubricants and graphite-based greases (rarely, liquid ones) were used as lubricants most frequently. Application of graphite-based lubricating materials results in inequal friction forces along the perimeter of the deformation zone, which in turn leads to deterioration of rolled strip shape [3]. Currently, the wide strip rolling technology with application of process lubricant has been given new impetus. First of all, it is related to assimilation of a new range of high-strength steels, and simultaneous development of new liquid lubricating materials with high adhesive properties capable to withstand high temperatures for short moments [4, 5].

In 2008, the system of liquid process lubricant supply to the first three stands (7, 8, 9) of the continuous finishing train of the rolling mill was installed on the continuous wide strip hot rolling Mill 2000 at PAO MMK. A special feature of the installed SLS is that the lubricating material (LM) is supplied as prepared
water and oil dispersion to surfaces of work rolls at the side of metal exit from the stand. The machine overview diagram is provided on Figure 1.

Figure 1. The system of process lubrication installed on the continuous wide strip hot rolling Mill 2000 at PAO Magnitogorsk Iron and Steel Works.

Practical application of the SLS demonstrated decrease of energy-power parameters and increase of service life of mill rolls during rolling [6–8]. Figure 2 presents comparative graphs describing the decrease of energy-power parameters of the rolling process with application of the SLS in average by 3 to 6%.

Figure 2. Averaged value of torque of the motor ($T_m$) depending on thickness (a) and width (b) of rolled steel for the 7th, 8th and 9th stands of the finishing train of the continuous wide strip hot rolling Mill 2000 at PAO MMK.

One of major deficiencies of the SLS is lack of a mathematical tool describing the correlation between the amount of the LM supplied and properties of rolled material; lack of recommendations and clear procedures for determination of process modes of LM supply. Thus, during first experimental adjustments of this system it was found that slip of work rolls against the rolled strip is possible at excessive LM supply, and in case of insufficient supply, the effect stated by a manufacturer of this unit is not observed [9]. In the early stage, the installed SLS was operated in the limited mode, and reduction in energy consumption was insignificant and averaged to 3 to 6% [4, 5].
Since 2008, the team of Federal State Budgetary Educational Institution of Higher Education G. I. Nosov Magnitogorsk State Technical University has been actively studying the process of wide strip hot rolling with application of the lubrication system. Based on the results of conducted studies, practical recommendations on adjustment of the SLS were received:

1. An adequate mathematical dependence, which determines consumption-volumetric parameters of the supplied LM depending on rolling process parameters, was received [15]:

\[
Q = L_{hr} \left[ \left( \frac{\beta}{180\pi} + \left( \frac{90 - \frac{2l}{D}}{D} \right) K_c \Sigma R_c \right) + \left( \frac{2.256 \cdot \eta m \cdot R_1 \cdot R_2}{R_1 + R_2} \left( \frac{3.17 \eta_0^{0.75} \alpha^{0.6} \nu_{rl}}{q_m^{0.15} \rho_r^{0.4} \nu_{m}} \right) \right) \right. \\
\left. + \left( \frac{3\eta_0 \cdot \alpha \cdot \nu_{rl}}{\alpha_{cap} \cdot [1 - e^{-\alpha \tau}]} + k_c \Sigma R_c \left( \frac{\omega_b + \alpha \omega_w}{\omega_b + \omega_w} \right) \right) \right] \left( Q_a - \frac{h_l - h_c}{h_a} \right) Q_a.
\] (1)

where \( \beta \) is an angle of LM application to the horizontal axis of the backup roll (degrees); \( R_1, R_2 \) are the radii of the backup roll and work roll respectively, mm; \( l_c \) is half-width of the contact area, mm; \( D \) is backup roll diameter, mm; \( n_{hr} \) is the number of revolutions of the backup roll, 1/min; \( q_m \) is load per unit of length (metal pressure onto the roll), N/m; \( \eta \) is oil dynamic viscosity at atmospheric pressure and operating temperature, Pa·s; \( \nu_{rl} \) is rolling speed, m/s; \( \alpha \) is pressure-viscosity coefficient; \( \rho_r \) is relative curvature of rolls surfaces, m; \( \omega_b \) is backup roll angular speed, s\(^{-1}\); \( \omega_w \) is work roll angular speed, s\(^{-1}\); \( \omega_m \) is average speed of backup and work rolls, s\(^{-1}\); \( \eta_0 \) is LM dynamic viscosity, Pa·s; \( \theta \) is pressure-viscosity coefficient, Pa\(^{-1}\)·s\(^{-1}\); \( \alpha_{cap} \) is LM capture angle, rad.; \( \sigma_T^* \) is yield strength of rolled billet considering hydrodynamic effect in the near-contact zone, MPa; \( \Sigma R \) is total roughness, \( \mu m \); \( h_l \) is LM thickness at the exit from the interroll contact, mm; \( h_c \) is thickness of the LM adhesive layer.

2. The mathematical algorithm of SLS operation implemented numerically was developed and adopted considering technical special features. This mathematical algorithm performs automatic adjustment of the system depending on the type and size of the billet being rolled. Table 1 provides recommended modes of SLS operation.

**Table 1.**Recommended and permissible values of LM consumption per stand of the continuous wide strip hot rolling Mill 2000 at PAO MMK [15].

| Classification of rolled products range based on deformation resistance parameter \( (\sigma_0) \)* | Recommended and [permissible] consumption per stand \((l/min)\) |
|---|---|---|
| | Stand 7 | Stand 8 | Stand 9 |
| \(< 76 \text{ MPa}\) | 0.10 to [0.11] | 0.15 to [0.16] | 0.31 to [0.32] |
| \(76 - 82 \text{ MPa}\) | 0.14 to [0.16] | 0.13 to [0.15] | 0.21 to [0.24] |
| \(82 - 94 \text{ MPa}\) | 0.08 to [0.10] | 0.10 to [0.12] | 0.15 to [0.17] |
| \(94 - 102 \text{ MPa}\) | 0.07 to [0.09] | 0.11 to [0.12] | 0.13 to [0.16] |
| \(102 - 116 \text{ MPa}\) | 0.06 to [0.08] | 0.09 to [0.10] | 0.14 to [0.19] |

* deformation resistance of the range of rolled products \((\sigma_0)\) was determined according to the Andreyuk-Tyulenev method.
The implementation improved the system performance by 12 to 15% in average.

Further operation and study of the SLS demonstrated that application of the lubricating material at hot rolling leads to reduction of wear of work rolls. Based on the studies described in papers [10–13], the authors theoretically determined and justified reduction of energy consumption in the area of deformation during rolling with application of the lubricating material [14, 15]. In such a case, it was determined that wear reduction was observed not only in the first three stands, where the SLS was installed (Figure 3), but in all other stands of continuous finishing train of Mill 2000 at PAO MMK. The results of comparative measurement of the volumetric wear (weight loss) of work rolls with LM supply indicate that roll wear reduction averages 10 to 15%.

Figure 3. Averaged values of changes in profiling of upper work rolls of stand 7 of the continuous wide strip hot rolling Mill 2000 at PAO MMK.

In addition to wear reduction, it was determined that the SLS also has a positive impact on reduction of the amount of metal removed from the surface of work rolls during further regrinding by 3 to 5% in average.

Practical results of the research are:

– Development and implementation of the upgraded mathematical apparatus capable to perform adjustment and control of the SLS depending on the degree of wear of work rolls.

– Reduction of energy-power parameters during rolling by 10 to 18% in average depending on the range of rolled products.

– Reduction of work rolls wear by 10 to 12%.

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