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Optimization of Technologies of Section Rolling By the Conditions of Saving Energy Resources using the Expert System

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Abstract

Sort-rolled production is a complex, multi-faceted process characterized by high fuel and electricity costs. Therefore, increasing the efficiency of production and minimizing energy costs is one of the key tasks. The use of expert systems (ES), developed on the basis of modern information technologies of artificial intelligence elements and created on the basis of modern concepts of the mechanics of a deformable body of multiple mathematical models for roll pass design and technologies of rolling, provides the quick solution of this problem.

Keywords: expert system, rolling manufacture, hot section rolling, optimum rolling-mill practice, costs for fuel and electricity, solution of technological tasks

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1. Introduction

The prime cost of rolling on continuous small-section mills is quite high. This is due to expensive fuel and electricity. Increasing the efficiency of production of section products on small-section mills is an increase in the output of products. This requires saving energy and material costs, which is a very topical technological task [1, 2].

To optimize the technological processes of rolling, it is possible to use the mathematical apparatus of Operation Research in accordance with the methodology described further [3–6].

2. Short Description of Optimization of Technologies with Saving Energy Resources

Target functions for optimization of the rolling technology of each j profile-size are represented in the following form:

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1. maximum productivity increase in the mill

$$\Delta Pr_j \rightarrow \text{max}\,, \tag{1}$$

2. minimum total costs for fuel and electricity, which constitute a significant part of the costs of the process stage

$$W_j = W_{\mathrm{T}j} C_{\mathrm{T}} + W_{\mathrm{e}j} C_{\mathrm{e}} \rightarrow \min\,, \tag{2}$$

where W_{T} and W_{e} – fuel and electricity consumption per 1 ton of good rolled steel, C_{T} and C_{e} – fuel and energy costs.

The control parameters are selected taking into account the productivity of the continuous mill, which depends on the final rolling speed U_{f}, and the fuel and electricity consumption, which depend on the temperature t_0 of the billet heating and the final rolling speed. Lowering the heating temperature of the rolling billet always leads to a reduction in fuel consumption and an increase in the energy consumption for rolling. Because of the significant excess of C_{T} over C_{e}, the target function decreases monotonically and reaches its minimum value with decreasing t_0. The effect of the same rolling speed on electricity consumption is ambiguous. On the one hand, an increase in the final rolling speed U_{f} leads to an increase in the temperature of the rolling, which leads to a reduction in the deformation stress and energy consumption, and on the other hand, due to an increase in the strain rate, an increase in U_{f} increases the power consumption. Thus, it is advisable to take both the final rolling speed U_{f} and the billet heating temperature t_0 as control parameters of the optimized system.

It is convenient to search for the extremum of target functions by the method of an ordered search of control parameters from the initial possible value with a given step in the direction of movement to the extremum under the following limitations of the rolling technology in each pass $i = 1, 2, 3, \ldots, n$:

1. on the strength of working stand equipment

$$R_i < P_{\mathrm{all}i}\,, M_{\mathrm{r}i} < M_{\mathrm{all}i}\,, \tag{3}$$

2. by the degree of loading of the motors of drive of stands

$$k_{\mathrm{en}i} = \left(M_i / M_{\mathrm{en}i}\right) < 1 \text{ or } N_{\mathrm{r}i} < N_{\mathrm{en}i}, \tag{4}$$

3. on speed of the mill rolls

$$U_{\mathrm{min}i} < U_i < U_{\mathrm{max}i}, \tag{5}$$

4. by the terms of angle of roll bite and location stability of the bars

$$\alpha_i < [\alpha], ..., [a]_{\min} < a_1 < [a]_{\max}, \quad (6)$$

5. by the productivity(capacity) of the heating furnace

$$Pr_j < Pr_h, \quad (7)$$

where R_i and M_{ri} – the reaction of the rolling force on the roll neck and the rolling torque and their allowable values $P_{\text{all}i}$ and $M_{\text{all}i}$, k_{ei} – coefficient of load of the stand drive motor, M_i, M_{eni} – the rolling torque used to the drive motor and the torque developed by the motor, N_{ri} and N_{eni} – rolling and motor power, $U_{\min i}$, U_i and $U_{\max i}$ – calculated, minimum and maximum allowable rolling speed, α_i, $[\alpha]$ – calculated and maximum allowed angle of metal roll bite by rolls, a_i, $[a]_{\min}$ and $[a]_{\max}$ – calculated, minimum and maximum permissible stability ratio of the axes of bars of unequal cross sections, Pr_j and Pr_h – mill capacity during rolling – size-profile and taking to account the capacity of the heating furnace.

To simulate the technological parameters of rolling at different values of U_f and t_0, it is very effective to use the expert system for automated analysis, design and optimization of sectional rolling technological processes. ES 'Section Rolling Technology' [7, 8] allows to solve a wide range of modeling, diagnostics, optimization problems and designing new technological processes for rolling of sections. It provides an opportunity to calculate the full set of technological parameters of rolling of a given profile and carry out their expert evaluation, to determine the influence of the heating temperature of the billet on the technological parameters and loading of the mill equipment, to simulate the influence of the speed characteristics of rolling on the change of technological parameters and the operating conditions of rolling stands, to determine the parameters of the power loading of equipment and the possibility of rolling a given grade of steel in conditions of the current roll pass design, to find the causes of breakdowns of equipment of working stands, to design optimal technological processes according to the criteria speed (efficiency) of the rolling mill and the saving of material and energy resources. ES allows to determine the state of the process being optimized for different groove designs, taking into account the aforementioned system of limitations.

Characterizing the state of the process being optimized at each step (in each pass), the mathematical model of the ES uses a system for calculating the metal shaping and energy-power rolling parameters [9], which allows determining the total energy consumption in the target function (2) according to the formula

$$W_{ej} = (1/G)\sum_{i=1}^{n} 71,225_{\mathrm{r}i}/\omega_i D_{\mathrm{r}i}\,,\ \text{kWh/ton} \tag{8}$$

where G – weight of one billet (ton),ω_i – cross-section area of bar, (mm^2), $D_{\mathrm{r}i}$ – effective roll diameter (m), $_{\mathrm{r}i}$ – rolling torque (kN.m), $i = 1, 2, 3, \ldots, n$ – number (N) of the pass.

The value$M_{\mathrm{r}i}$ is calculated in each pass, depending on the temperature, speed and deformation parameters of rolling

$$M_{ri} = M_{\mathrm{r}}\left(t_i, U_i, {}^{1}/_{\eta_i}, \lambda_i, A_i, a_{0i}, a_{\mathrm{r}i}, \psi\right), \tag{9}$$

where $t_i$and U_i – rolled bar temperature and rolling speed in each pass (°C), $\frac{1}{\eta_i}$ and λ_i – reduction and rolling-out coefficients of the bar, A_i – rated diameter of rolls, a_{0i} – the ratio of the axes of the billet before the pass, a_{ri} – ratio of axes of pass, ψ – coefficient of contact friction in the deformation zone [9].

The fuel consumption for heating the billet to the required temperature t_0 in the continuous furnaces is usually determined taking into account the efficiency of the furnace η and the calorific value of natural gas q ,taken 8000 kcal/m3 (33.5 MJ/m^3)

$$W_{\mathrm{T}j} = cG\left(t_0 - t_{\mathrm{h}}\right)/q\eta\ , \tag{10}$$

where c – heat capacity of metal, t_{h} – the temperature of the load of the metal in the furnace.

The described technique was applied to optimize the technological rolling on a continuous single-strand small-section wire mill [10, 11].

We simulated the rolling of round steel with diameters from 10 to 40 mm, angular equal-steel steels from N. 2.5 to N. 5, rod and round steel from 5.5 to 13.8 mm in diameter in a wire block of stands made of carbon steel grades, as well as reinforcing bar periodic profiles from N. 10 to N. 40 from steel grades 25G2S and 35GS according to the current pass design of rolls.

Rolling technologies for these profiles regulated the heating of a continuous casting square cross-section with a side of 125 mm to a temperature of $t_0 = 1220 - 1180$°C and rolling with a specified final speed

The search of control parameters started from the values t_0 to the lower side in steps of 20 ÷ 50°C and U_{f} – to the larger side in 0.5 m/s increments.

The results of modeling, and optimization of the temperature-speed characteristics of the rolling of round steel with a diameter of 16 mm of grade St3 are given further, the profile is rolled for 18 passes. The finished profile is taken from the finishing mill stand N. 20. Two rolling schemes are used: the first with the skipping of stands N. 13 and N. 14 (intermediate group), the second with the skipping of stands N. 17 and N. 18 (finishing group). We simulated the rolling profile technology for both schemes with a regulated finite speed U_f=16 m/s and billet heating temperature $t_0 = 1180°C$. With the regulated rolling technology, the entire system of constraints (3–7) is satisfied. The electric motor of the final stand is most loaded, but the value of its load coefficient k_{en} does not exceed 0.7 (70%) (Figure 1).

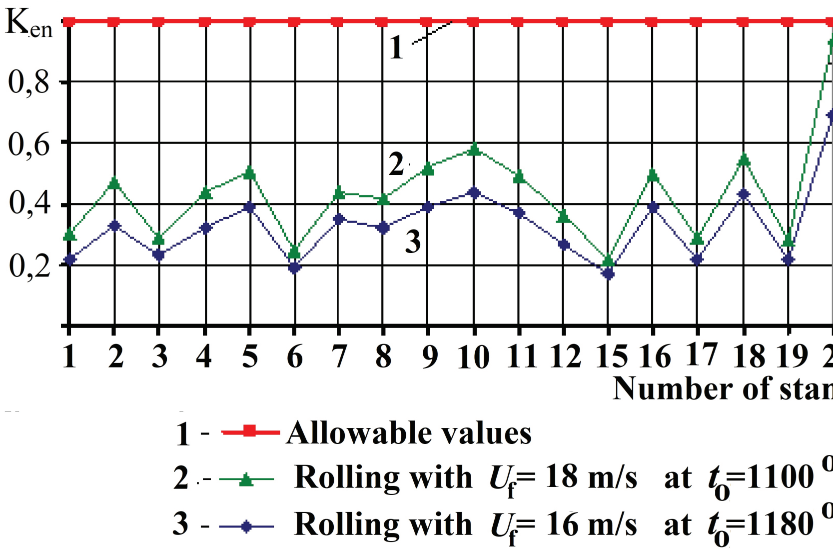

Figure 1: Coefficients of loading of electric motors of the main drives during rolling of round steel d 16 mm.

Figure 2 shows the characteristic dependences of changes in rolling speed on mill stands. When rolling with the skipping of stands N. 17 and N. 18, the maximum possible final rolling speed is limited by the speed of operation of the flying shears N. 52: 9,5 m/s, while the speed of the rolling out of the stand N. 14 at U_f=16 m/s is 9,0 m/s. In the case of rolling with skipping of stands N. 13 and N. 14, the maximum possible final rolling speed can be increased to 18 m/s (see Figure 2, curve 4), and the heating temperature of the initial billet is reduced from 1180°C to 1100°C. In this case (as can be seen from Figure 3), the difference in the rolling temperatures decreases from 80°C at the beginning of rolling to 25–30°C at the finish of rolling as a result of a decrease in the heat losses of the bar by radiation and an increase in heat increment due to high-speed hardening of the bar increasing the rolling speed. At the optimum values $U_f^* =$ 18 m/s and $t_0^* = 1100°C$, all technological parameters are within acceptable limits and do not limit the rolling technology. The main limitation of the final rolling speed is k_{en} of the final stand of the mill, which in this case reaches a value of 0,9 (90%) (see Figure 1).

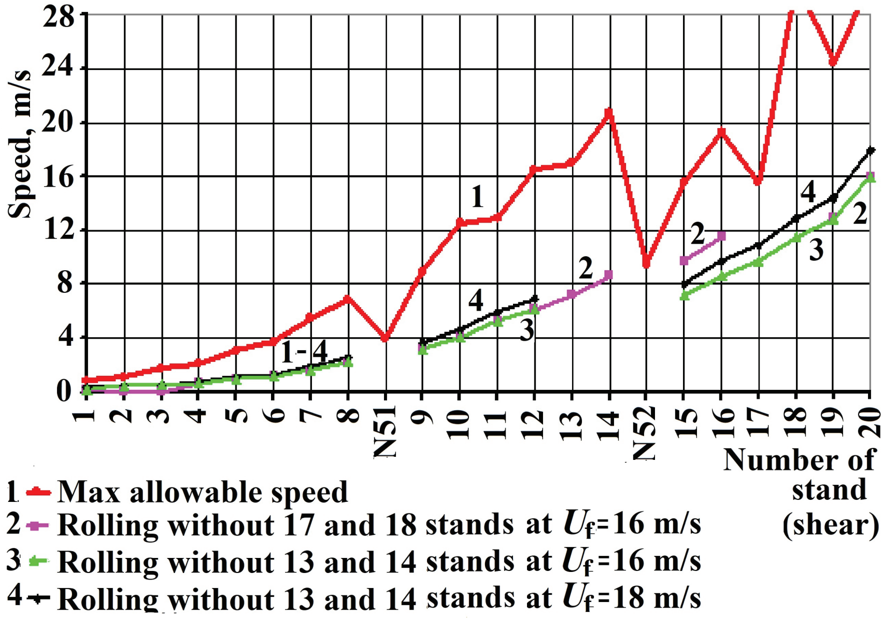

Figure 2: Speed dependencies during rolling of round steel d 16 mm.

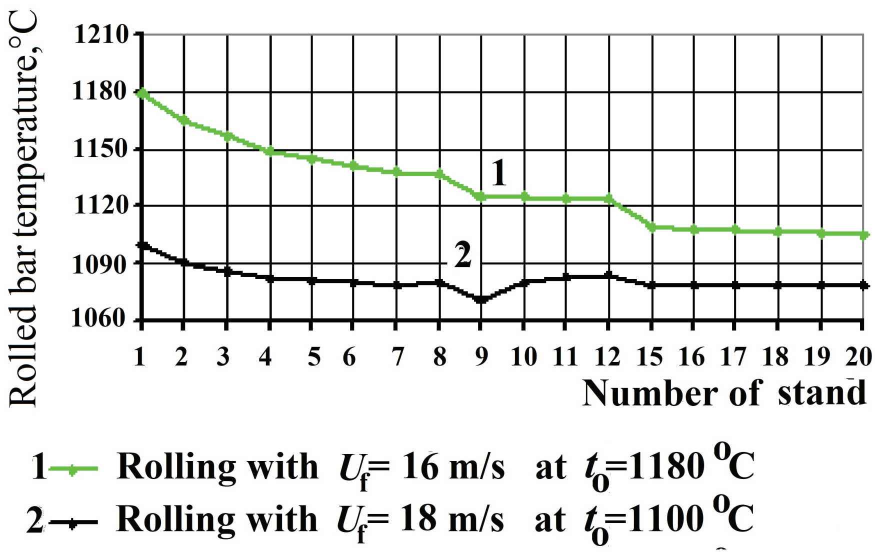

Figure 3: Temperature dependences during rolling of round steel d 16 mm.

3. Summary

The mill's capacity for rolling round steel d 16 mm with $U_f^* = 18$ m/s instead of 16 m/s will increase by 12.5% and amount to 83.12 t/h.

As a result of similar calculations, it is established that the operating final rolling speeds of round, reinforcing, angular steel and wire rod can be increased by 5–30% depending on the rolling profile. The main limitations (depending on the size of the profile) are the power of the drive motors of the working stands of the finishing group of the mill, the speed of operation of the flying shears, the capacity of the tail section of the mill, and the productivity of the heating furnace, equal to 105 tons per hour.

Realization of new high-speed rolling technologies allowed to increase the average hourly capacity of the mill from 63,25 to 72,07 tons and to do capacity more on 14%.

Optimization of the heating temperature of the initial billet showed that when rolling round, angular steel and rod, the temperature of the billet heating can be reduced from the regulated 1180 ÷ 1220°C to 1100 ÷ 1150°C, and when rolling reinforcing bar to 1150°C. This makes it possible to obtain a total saving of fuel and electric energy costs in the range 1.2–2.1%, while increasing the productivity of the heating furnace.

Thus, the application of methods of Operation Research, a modern expert system of the section rolling process and information technology has made it possible to determine the optimal technologies by the criterion of saving energy resources

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