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THE EXPLOATATION OF FRICTION FORCES FOR IMPROVING THE ROLLING PROCESSES

IZKORIŠČANJE TORNIH SIL ZA IZBOLJŠANJE PROCESA VALJANJA

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A method of implementation of the conditions of a non-traditional rolling process is proposed. The bounds of implementation depending on the friction force reserve and on strip bending stability before the non-drive stand are obtained analytically.

Key words: rolling, friction force, non drive stand, strip bending stability

Predložena je metoda za implementacijo pogojev za netradicionalni proces valjanja. Pogoji za implementacijo so odvisni od rezerve torne sile in upogibne stabilnosti traka pred valjalniškim ogrodjem brez pogona so določeni analitično.

Ključne besede: valjanje, torna sila, upogibna stabilnost trakov, orodje brez pogona

1 INTRODUCTION

Among all types of metal processing the process of rolling has a special place. The friction forces ensure the possibility of implementing this process and, on the other hand, these forces hinder the metal leaving the deformation site. Besides that, when the rolling becomes a steady state process, the energy transmitted from strip to rolls, causes a surplus of pulling friction forces. From the technological point of view, this energy is useless. Therefore, any attempt of making use of this surplus leads to increasing the efficiency of the process of rolling.

In the past, several attempts of making use of this surplus for raising the rate of the deformation process were proposed. However, technological problems arise in connection with ensuring the process stability (when rolling with extra reduction) or with the dimension stability along the strip length (when rolling with big inter-stand tension).

During the last years non-traditional technological processes began to be used, which includes the application of auxiliary equipment with a non-drive tool for deforming the metal in continuous rolling stands (such as edging and controlling rolls, separating rolls etc.). One of the methods for a more complete use of drawing friction forces is the implementation of non-drive service stands in a line of continuous rolling stands[1]. It required the development of simple and reliable methods for the estimation of process parameters and factors determining the possibility of implementing those processes, such as the reserve of friction forces at the deformation site of drive stands and the longitudinal workpiece stability in inter-stand spacing before non-drive service tools.

2 MATHEMATICAL DESCRIPTION AND RESULTS

By rolling in a continuous finishing unit using "drive stand - non-drive stand" (DS - NDS) sets the interaction of the factors mentioned above can be described on the base of relationships between the pulling capacity of DS, the friction force reserve at the site of deformation, the strip bending stability before NDS, and the resistance force in NDS.

If the strip widening is not taken into account, these relationships can be written as

$$\sigma_{res} = \sigma_{RD} \frac{\varepsilon_N}{1-\varepsilon_N} \left(2 f_D \sqrt{\frac{R_D}{h_D \varepsilon_D}} - 1 \right), \tag{1}$$

$$\sigma_b = \frac{4\sigma_y}{\left(1 + \frac{2\sqrt{3} k_L L}{\pi h_D (1-\varepsilon_D)} \sqrt{\frac{\sigma_y}{E}} \right)^2}, \tag{2}$$

$$\sigma_{NR} = 2 p_N \varepsilon_N \left(1 + 2 f_F \frac{r_F}{R_N} \sqrt{\frac{R_N}{h_N \varepsilon_N}} \right), \tag{3}$$

where σ_{res} is the stress in the strip caused by the friction force reserve, σ_b is the critical stress of strip buckling in the DS-NDS spacing, σ_{NR} is the stress due to NDS resistance; σ_{RD} is the metal deformation resistance at the site of deformation of DS; $p_N = n_{\sigma N}\sigma_{RN}$ is the metal pressure to rolls in NDS; $n_{\sigma N}$ and σ_{RN} - the deformed state coefficient and the metal deformation resistance at the site of deformation of NDS; E and σ_Y are the elastic modulus and the yield stress in inter-stand spacing between DS and NDS; ε_D and ε_N is the metal deformation degree in DS and NDS; f_D and f_F are the friction factors on the contact surface between the metal and the rolls in DS and NDS; R_D, R_N, r_F are DS and NDS roll and NDS neck radii; $k_L L$ is the per-unit inter-stand length between DS and NDS taking into account strip supporting condition at the site of deformation.

The system of equations has the following independent variables: the metal deformation degrees ε_D and ε_N, and metal temperature before DS t_{D0} and the following dependent variables: the metal deformation resistance at the site of deformation of DS and NDS (σ_{RD} and σ_{RN}), the elastic modulus and yield stress at the site of deformation of DS and NDS (E and σ_Y), and the strip height before NDS (h_N). The remaining parameters are independent and non-variable.

A preliminary analysis of the conditions of the rolling process implementation in the DS-NDS system shows that the variation of σ_{res} caused by varying the metal deformation degree in DS ε_D can be described by a parabolic curve. At the beginning σ_{res} is growing when ε_D grows and then it decreases down to zero to the moment of the depletion of the DS friction force reserve when $\varepsilon_D = 4f_D R_D/h_N$. The variation of $_b$, which depends on the metal deformation degree in DS ε_D, can be described by a hyperbolic curve, in which the critical stress in strip σ_b decreases when ε_D increases. The dependence of upthrust stress on metal deformation degree can be described by a parabolic curve, in which σ_{NR} is growing when ε_N decreases. The equations (1)-(3) should be solved together to obtain the conditions of possible implementation of the rolling process. The expressions (1)-(2) determine the dependence of process implementation on friction force reserve, and the expressions (2)-(3) the dependence on strip bending stability.

The presence of three independent variables (ε_D, ε_N and t_{D0}) makes impossible the analysis of force and energy interaction between DS and NDS. For the case of a fixed temperature of strip before DS and fixed summary elongation in the DS-NDS system ($\mu_\Sigma = \mu_D \mu_N =$ const) the conversion to one variable $k_\mu = \mu_D/\mu_N$ is proposed with k_μ as the coefficient that determines the relation between the elongations in DS and NDS. The conversion of the deformation degree to elongation coefficients requires the introduction of transverse deformation factors in the equations (1)-(3). The following system is then obtained

$$\sigma_{res} = \sigma_{RD}(\sqrt{\mu_\Sigma k_\mu}\beta_D - 1)\left(2f_D\sqrt{\frac{R_D}{h_D\left(1-\frac{1}{\sqrt{\mu_\Sigma k_\mu}\beta_D}\right)}} - 1\right), \quad (4)$$

$$\sigma_b = \frac{4\sigma_y}{\left(1+\frac{2\sqrt{3}k_L L\sqrt{\mu_0 k_\mu}\beta_D}{\pi h_D}\sqrt{\frac{\sigma_y}{E}}\right)^2}, \quad (5)$$

$$\sigma_{NR} = 2p_n\left(1-\frac{1}{\sqrt{\frac{\mu_\Sigma}{k_\mu}}\beta_N}\right)\left(1+2f_F\frac{r_F}{R_N}\sqrt{\frac{R_N}{h_N}}\frac{1}{1-\sqrt{\frac{k_\mu}{\mu_\Sigma}}\beta_N}\right), \quad (6)$$

where μ_D and μ_N are elongation coefficients in DS and NDS.

The equations (4)-(6) describe the conditions of implementation of the rolling process in a more general form for the case of a three-dimensional metal deformation. The assumption $\beta_D = \beta_N = 1$ leads to the case of flat deformation. When the metal deformation is three-dimensional, transverse metal flow should be taken into account also. Almost every article considering metal flow at the site of deformation deals also with the problem of widening. The best analysis of this problem is presented in ref.[2-4].

As it has been shown in ref.[5-9], the systems of equation (4)-(6) can be transformed to the form

$$\frac{\sigma_{res}}{\beta o_{RD}} = \frac{\delta_D\left(\frac{1}{\mu_D}-1\right)+2}{\frac{1}{\mu_D}-1}\ln\frac{1}{\mu_D} - 2, \quad (7)$$

$$\frac{\sigma_b}{\sigma_y} = \frac{4}{\left(1+\frac{k_L L}{\pi\rho_1}\sqrt{\frac{\sigma_y}{E}}\right)^2}, \quad (8)$$

$$\frac{\sigma_{NR}}{\beta\rho_{RD}} = \frac{1+k_1\delta_N}{k_1\frac{1}{\eta_N}}\left(\frac{1}{\eta_N} - 2\frac{1^A}{\eta_N}e^B + 1\right), \quad (9)$$

with $\eta = h_1/h_0$ as metal widening coefficients; δ, A and B as parameters defined as

$$\delta = 2f/\sigma,\ A = 0.5 + (1/\eta - 1)/\delta,\ B = (\Psi_0 - 2)/2\delta,$$

with $\Psi_0 = \sigma_D/\beta\sigma_D$ - the back upthrust coefficient and α- the angle between strip and roll surface.

Using the equations of force interaction between DS and NDS the analytical investigation is carried out for the conditions of process implementation depending on the friction force reserve and strip stability before NDS. The strip stress factors σ_{res}/σ_{RD}, σ_b/σ_Y, σ_{NR}/σ_{RD} were analysed as functions of the distribution of deformation between DS and NDS. The use of the values in per-unit allows to eliminate the influence of the metal temperature as independent variable.

The $(\mu_N - 1)/(\mu_\Sigma - 1)$ ratio is taken as a parameter of the distribution of deformation that characterizes the relation of the strip area in NDS to the total displaced area in the DS-NDS system.

The analysis is performed for special rolling conditions of a finishing rolling stand in the Institute for Iron Metallurgy with one non-drive stand, that corresponds to the conditions of case hardening steel rolling in continuous rod and strip stands. The initial slabs had square sections of side of 14, 20, and 26 mm.

The results of the analysis are presented in **figure 1**. The significance of each process restricting factors is shown in dependence on the conditions of its implementation. The $(\mu_N -1)/ (\mu_\Sigma -1)$ value is plotted on the abscissa and the total coefficient of metal widening in the DS-NDS system μ_Σ - on the ordinate. The curves 1-3 specify the strip bending stability in DS-NDS inter-stand spacing and the curves 4-6 the friction forces reserve at the site of DS deformation. The left part of the figure shows the implementing conditions for given original parameters. On the right side the implementing of rolling process inside the curves area is impossible. The curve intersection points (A, B, C) characterize the equivalence of the influence of the process limiting factors (strip bending stability and friction force reserve at the site of deformation in DS) on the conditions of its implementation. To the left from the points A, B, C the process is limited by the strip bending stability, and to the right by the friction force reserve. The value of each of these factors is defined by the minimal ordinate of the intersection of the σ_{res}/σ_{RD} and σ_b/σ_Y with the curve σ_{NR}/σ_{RD}. In these points the process limiting factors become equivalent and define the maximal possible share of NDS in the total deformation of the DS-NDS system. The area of possibility of implementation of rolling in the DS-NDS system is limited by the branches of the curve corresponding to different rolling conditions and the coordinate axes in the bottom left part of the figure.

When the total elongation coefficient in the DS-NDS system is low (μ_Σ= 1.1-1.3), the process is limited by the reserve of friction forces, since the strip bending stability is ensured. When μ_Σ is greater than 1.4, the strip bending stability becomes the process limiting factor.

The analysis of results has shown that a significant change of the process implementing factors occurs when Rf^2/h_1= 0.8-1.05, that is typical for the intermediate group of finishing rolling stands. The analytical results have been verified during experimental rolling on the "250" stand in the Institute for Iron Metallurgy.

The analytical investigation of the conditions of process implementation in dependence on friction force reserve and strip bending stability before NDS has shown that the maximal efficiency of the continuous rolling process using non-drive service stands is obtained in the intermediate group of the finishing rolling stand. It allows to outline the ways of process optimization with regard to the optimal system capacity and the maximal loading of a non-drive stand.

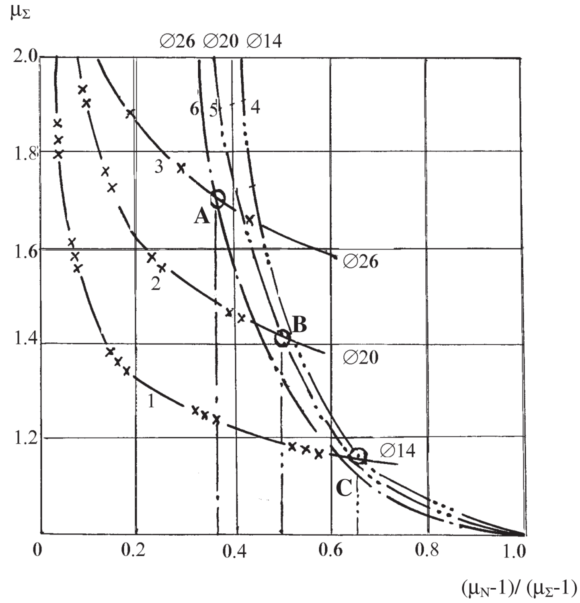

Figure 1: Strip bending stability (1-3) and friction forces reserve (4-6) curves

Slika 1: Krivulje upogibne stabilnosti valjanca (1-3) in rezerve torne sile (4-6)

Thus, when developing non-traditional technological processes based on the more complete utilization of the drawing friction force reserve at the deformation site of non-drive service stands and requiring the implementation of auxiliary non-drive metal deforming tools, the value of this reserve has to be estimated taking into account other factors limiting the rolling process. After obtaining the limits of the possibility of the rolling process implementation, the areas of its most effective practical application and the ways of its optimization can be determined.

3 CONCLUSIONS

As a result of the investigation the following conclusions are proposed:

1. A method for obtaining the conditions of implementation of a non-traditional rolling process is proposed, which is based on the more complete use of the drawing force reserve. The method consists of arranging non-drive service stands along the line of a continuous finishing stands unit. Using this method the boundaries of the implementation of rolling process, which depend on the friction force reserve and the strip bending stability before non-drive stand, are obtained analytically.
2. It is shown that for low values of the total elongation coefficient in the DS-NDS system (μ_Σ = 1.1-1.3) the process is limited by the friction force reserve, and for μ_Σ > 1.4 - by the strip bending stability.
3. Is it shown that the significance of the factors defining the conditions of the process implementation is changed when Rf^2/h_1= 0.8-1.05,

which is typical for the intermediate group of finishing rolling stands.

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