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Theoretical Solution of Rolling-Drawing Process in Idle Rolls

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Abstract

Theoretical solution providing accomplishing of rolling-drawing process under rolling in idle rolls is discussed. The process of rolling-drawing can be applied during cold rolling of strips.

Keywords: *energy consumption in rolling, rolling-drawing process, idle rolls*

Energy saving is essential to reduce the cost price of cold-rolled products. This result can be achieved by means of application of special stand designs with working rolls of small diameter (these rolls should also have support in a horizontal plane) [1]. The paired working rolls of various diameters (velocities) or of various roughness under reduction of average roughness value are applied in a number of mills with the purpose of decrease in energy-power parameters. It is recommended to apply one working roll with a regular shape instead of notched working roll in the first stand of continuous mill [2]. In paper [3], it is recommended to use drawing in idle rolls instead of drawing in monolithic ones. The authors [4] advance implementation of idle roll stands in continuous rod mill train. It is known the process of rolling-drawing with strip drawing through the rolls having different peripheral velocities [5]. The process of rolling-drawing provides significant decrease in deformation force of metal in rolls. All the suggestions specified enable to reduce energy-power parameters of rolling and to improve technical and economic parameters of rolling mill operation.

The theoretical solution that allows implementation of rolling-drawing process during rolling in idle rolls is presented below.

In the paper, the equations for calculation of metal deformation power and average normal contact stress are obtained on the basis of equality of internal and external resistance powers [6]. For strip rolling without widening (strip width B = 1) these equations are as follows (for one roll):

$$N = 0{,}5\sigma_y \cdot v_r \cdot \frac{\Delta h}{H} \cdot h_{av}\left(1 + 0{,}86 \cdot f_p \cdot l_a / h_{av}\right); \quad \text{(Eq. 1)}$$

$$p_{av} = \beta \cdot \frac{h_{av}}{H}\left(1 + 0{,}86 \cdot f_p \cdot l_a / h_{av}\right), \quad \text{(Eq. 2)}$$

where v_r – the peripheral velocity of rolls; H – the initial thickness of strip; h_{av} – the average thickness of strip; Δh – the reduction in thickness; l_a – the contact arc length; f_p – the friction parameter; σ_y – the yield stress of metal; β – Lode coefficient for rolling.

On the other hand, power of metal flow resistance in a horizontal plane is determined by equation (for one roll) (B= 1):

$$N_r = \sigma_B \cdot v_h \cdot h / 2\,, \quad \text{(Eq. 3)}$$

where σ_B – the stress of metal flow resistance in the deformation zone; v_h - the speed of strip at the exit from the rolls, h – the strip thickness after rolling.

It is obvious that stress of strip drawing through idle rolls should be equal to pressure σ_B.

Speed of strip is equal to:

$$v_S = v_r\left(1 + S\right), \quad \text{(Eq. 4)}$$

where S – the strip forward flow that considers the value of front tension and friction in roll necks and in the area of roll contact in four-high mill stand. Considering, that the ratio of critical section angle (γ) to contact angle (α) equals $\gamma/\alpha \geq 0.55$-0.6 during the process of rolling-drawing, the numerical coefficient C = 0.86 in formulae (1) and (2) will be equal to C = 1.0-1.12 (average 1.06) according to paper [6]. Having solved Equations (1), (3) and (4) concerning pressure σ_B in view of change mentioned above, after transformations we will obtain (β = 1 – for drawing):

$$\frac{\sigma_B}{\sigma_y} = \frac{1}{(1+S)} \cdot \frac{\Delta h}{H} \cdot \frac{h_{av}}{h} \cdot \left(1 + 1{,}06 \cdot f_p \cdot l_a / h_{av}\right), \quad \text{(Eq. 5)}$$

where f_p – the friction parameter during rolling-drawing.

Forward creep S will be determined by Golovin-Drezden's formula [7] provided that ratio γ/α = 0.55-0.6:

$$S = R\gamma^2/h; \quad S \approx 0.33\Delta h/h\,, \quad \text{(Eq. 6)}$$

The average normal contact stress will be determined from equilibrium condition of horizontal force components affecting deformation zone [7, 8] (B = 1):

$$P \cdot \sin\varphi_0 - T_1 \cdot \cos\varphi_1 + T_2 \cdot \cos\varphi_2 = \sigma, \quad \text{(Eq. 7)}$$

where P – the deformation force; T_1 and T_2 – the frictional forces in zones of backward creep and forward creep, respectively; φ_i – the application angles of equivalent forces.

We present Equation (7) using stresses and accepting the strip width as B = 1, Amonton Friction Law, $\sin\varphi_0 \approx \alpha/2$, $\cos\varphi_1 \approx \cos\varphi_2 = 1$. After transformation we obtain:

$$p_{av}\frac{R\alpha^2}{2} - fp_{av}R(\alpha-\gamma) + fp_{av}\cdot R_\gamma = \sigma_B h/2$$

or

$$\frac{P_{av}}{\sigma_y} = \frac{\sigma_B/\sigma_y}{\frac{\Delta h}{h}\left[1+\frac{2f}{\alpha}\left(\frac{2\gamma}{\alpha}-1\right)\right]}\,, \quad \text{(Eq. 8)}$$

where f – the friction coefficient; α – the contact angle; γ – the actual angle of critical section in view of frictional losses in roll unit.

The angle of critical section is within the limits of γ/α = 0.55-0.6 under rolling in two-high stand without a drive. We use the friction parameter f_p (E.Zibel Friction Law) and friction coefficient f (Amonton Law) in the above-considered formulae. It follows from paper [8] that the ratio between them is determined by equation:

$$\frac{f_p}{f} = \frac{p_{av}}{\sigma_y}\,, \quad \text{(Eq. 9)}$$

which can be determined by experimental data of p_{av} and σ_y, and friction parameter on the basis of known value of friction coefficient f. Since there is no experimental data of ratio f_p/f, it is possible to take $f_p \approx f$ as the first approximation for calculation.

Figure 1 gives the computed values of σ_B/σ_y and p_{av}/σ_y by formulae (5) and (8), and also by equations of paper [3], which are as follows:

$$\begin{cases} \dfrac{\sigma_B}{\sigma_y} = \left(\ln + \dfrac{\alpha}{2}\right)\left[1 + \dfrac{f}{2}(2m-1)\right]; \\ \dfrac{p_{av}}{\sigma_y} = \left(\ln\lambda + \dfrac{\alpha}{2}\right)/(\lambda - 1); \\ m = 0{,}5\left(1 + \dfrac{f_n}{f}\cdot\dfrac{r_n}{R}\right), \end{cases} \quad \text{(Eq. 10)}$$

where λ - the reduction coefficient; m – the coefficient considering friction effect in roll necks; R, r_n – the radii of roll and neck, respectively; f_n – the friction coefficient in roll necks.

Function p_{av}/σ_y (β = 1.15) calculated by Equation (2) for rolling in driven rolls is also presented in Figure 1. It follows from Figure 1a that change pattern of parameter σ_B/σ_y is similar by functions (1) and (2), and their values are rather close to each other. Increase of σ_B/σ_y with increase of cross-sectional area reduction is determined by rising metal flow resistance from the roll side. At actual values σ_B/σ_y = 0.3-0.4 the respective values of reduction of cross-sectional area are $\varepsilon \leq 0.2$-0.3 according to condition of strip integrity.

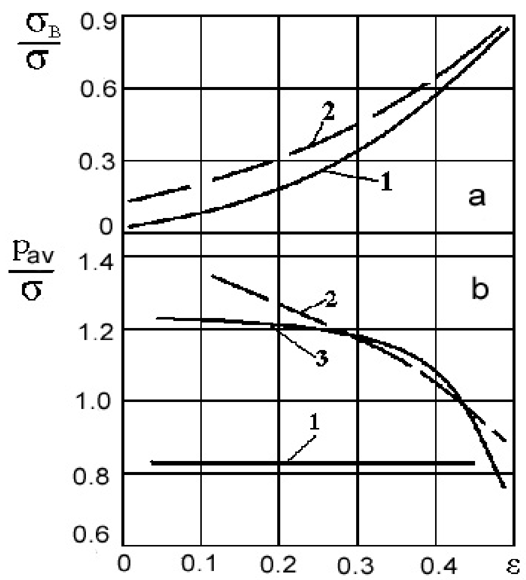
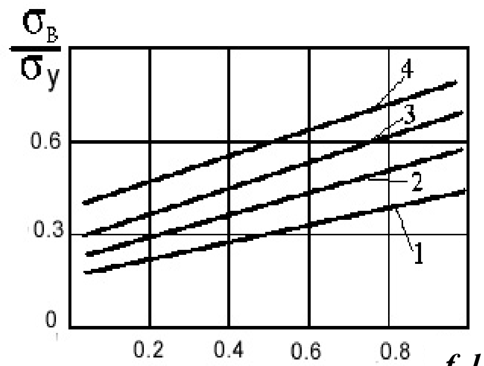


Figure 1. Effect of reduction of cross-sectional area on parameters σ_B/σ_y (a) and p_{av}/σ_y (b): 1 – by Equations (5), (8); 2 – by Equation (10); 3 - by Equation (2) (R = 25 mm; H = 2 mm; $f_p = f$ = 0.1; γ/α = 0.55)



$f_p\, l_a / h_{av}$

Figure 2. Parameter σ_B/σ_y as a function of conditions of contact friction in deformation zone of idle rolls at ε = Δh/H: 1 – 0,2; 2 – 0,3; 3 - 0,4; 4 - 0,5

Parameter $a = f_p l_a/h_{av}$ (Figure 2) has a considerable effect upon value σ_B/σ_y. Coefficient σ_B/σ_y is directly proportional to increase of parameter $a = f_p\, l_a/h_{av}$ at ε = 0.2 – 0.5. On the basis of maintenance of strip integrity during rolling-drawing process, it is possible to apply reduction of cross-sectional area within the limits of ε ≤ 0.4 and admissible value of parameter a is $a \approx 0.6$. In this case, the parameter σ_B/σ_y is rather close to practical values for cold strip rolling.

Change patterns of stressed condition coefficient $n_\sigma = p_{av} / \sigma_y$ obtained by Equations (2), (8) and (10) are shown in Figure 1b. According to Equation (8) (Figure 1b, curve 1) the coefficient n_σ does not depend on reductions of cross-sectional area, which is caused by small effect of friction coefficient in deformation zone. In this case, the average normal contact stress varies directly as metal flow stress with increasing reduction. This thesis is contradicted by a theoretical function n_σ = f (ε) by Equation (10), according to which the coefficient of stressed condition n_σ decreases substantially with increasing reduction (curve 2). As shown in Figure 1b, the coefficient of stressed condition n_σ (Equation (10) is more almost in all range of reductions than those obtained by Equation (2) for rolling in driven rolls (curve 3). Equation (2) considers the effect of friction coefficient (parameter) and contact angle (through the arc contact length l_a) on deformation conditions. As a result of increase in contact angle [contact angle increases from α ≈ 0.09 rad up to α ≈ 0.2 rad (f_p = 0.1)], the internal tensile stresses occur in deformation zone.The process of rolling-drawing can be used on strip cold rolling and skinrolling mills. For example, the process of rolling-drawing can be used for additional reduction of strip in thickening zones when passing the back end or welded seam on four-high stand cold-rolling mill. In this case, the process of rolling-drawing is carried out by temporary (unless the thickened zone leaves a stand) consecutive switching-off electric motors of stands No.1 and No.2.

The process of rolling-drawing enables to reduce energy-power parameters of rolling and to improve quality of strip surface. The research [9] demonstrate that the application of one idle roll in skinrolling mill 1700 reduces effect of dynamic elastic fluctuations of driven spindles on the condition of strip surface and reduces such a defect as "ribbing".

Conclusions

Mathematical relations for calculation of longitudinal stresses σ_B of metal flow resistance and average normal contact stresses under strip rolling – drawing are obtained on the basis of equality of powers of internal and external resistances and equilibrium condition of horizontal force components that affect the deformation zone.

It is shown that parameter σ_B/σ_y increases as the reduction of thickness and coefficient $a = f_p\, l_a/h_{av}$ increase. The ratio σ_B/σ_y is limited by plastic properties of strip metal during rolling-drawing and the value of admissible reduction is $\varepsilon = 0.4$ at $\sigma_B/\sigma_y = 0.3 - 0.4$.

The average normal contact stress does not depend on reduction value, depends slightly on friction coefficient and is considerably less than the average normal contact stress in the process of rolling in idle rolls.

The process of rolling-drawing can be applied in cold rolling of strips.

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Теоретическое решение процесса прокатки-волочения в неприводных валках

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Представлено теоретическое решение, показывающее возможность осуществления процесса прокатки-волочения при прокатке в неприводных валках. Процесс прокатки-волочения может найти применение при холодной прокатке полос.