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The Features of Theoretical Investigation of Rolling Process Pitch Stability

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As a result of the developed method for determination of average resultant of horizontal forces it is possible to specify the mechanism of metal balance maintenance in the rolls. The resultant of applied forces is not directed vertically but inclined aside strip motion at simple stable rolling process. Thus the balance in the deformation zone is maintained due to action of opposite force appearing as a result of "opposite" motion of metal. Hence, retracting forces are spent not only on overcoming pushing forces but also on balancing of applied forces. The arm increases at calculation of the moment of deformation in view of inclination of resultant of contact forces.

Keywords: STABILITY, LONGITUDINAL STRESS, RESEARCH, METHOD, ARM, MOMENT, FORCE, DISTRIBUTION DIAGRAM, ROLLING PROCESS, ANALYSIS

Results and Discussion

The method of rolling pitch stability estimation is suggested in [1-3]. It is based on the calculation of average resultant of horizontal contact forces Q_{av} in the deformation zone

$$Q_{av} = \frac{1}{\alpha_y} \int_0^{\alpha_y} Q_x d\varphi; \quad \text{(Eq. 1)}$$

$$Q_x = Rb \int_{\varphi}^{\alpha} q_x d\varphi; \quad \text{(Eq. 2)}$$

$$q_x = -p_x \sin\varphi + t_x \cos\varphi, \quad \text{(Eq. 3)}$$

where φ – current angle in the deformation zone; R – roll radius; b – plate strip width.

At positive value Q_{av} the process is stable without partial slip; if this force is equal to zero - rolling is carried out in limiting conditions; at its negative value the process is impossible. It is necessary to notice that the average resultant Q_{av} can be obtained at both analysis of theoretical distribution diagrams of contact stresses [2, 3] and experimental ones [4].

The task of present research is to specify the mechanism of metal balance maintenance in rolls, to estimate the role of neutral cross-section angle γ as a regulator of this balance and to analyze rolling torque components.

Distribution diagrams of contact stresses are initial data at definition of average resultant of horizontal forces. Therefore we consider the results of theoretical research related to calculation of pressure change $\frac{p_x}{2\kappa}$ (κ – pure shear resistance) and specific friction forces $\frac{t_x}{2\kappa}$ along the length of deformation zone showed in [5]. It is necessary to notice that solving Karman`s differential equation, the author used a friction model considering both slipping in the deformation zone and Coulombic bond between contact stresses. At rolling when R=300 mm, h_0=0.3 mm, α_y=0.017 rad and f=0.044, R- roll radius, h_0 - initial strip gage, α_y - angle of nip in steady conditions, f – friction coefficient) results of contact stress calculation are shown in **Figure 1 a, b**. Distribution of longitudinal contact stress and current resultant of horizontal forces in dimensionless forms are illustarted in **Figure 1 d, e**.

$$Q_x^* = \frac{1}{Rb}\frac{Q_x}{2\kappa} = \int_{\varphi}^{\alpha} \frac{q_x}{2\kappa} d\varphi, \quad \text{(Eq. 4)}$$

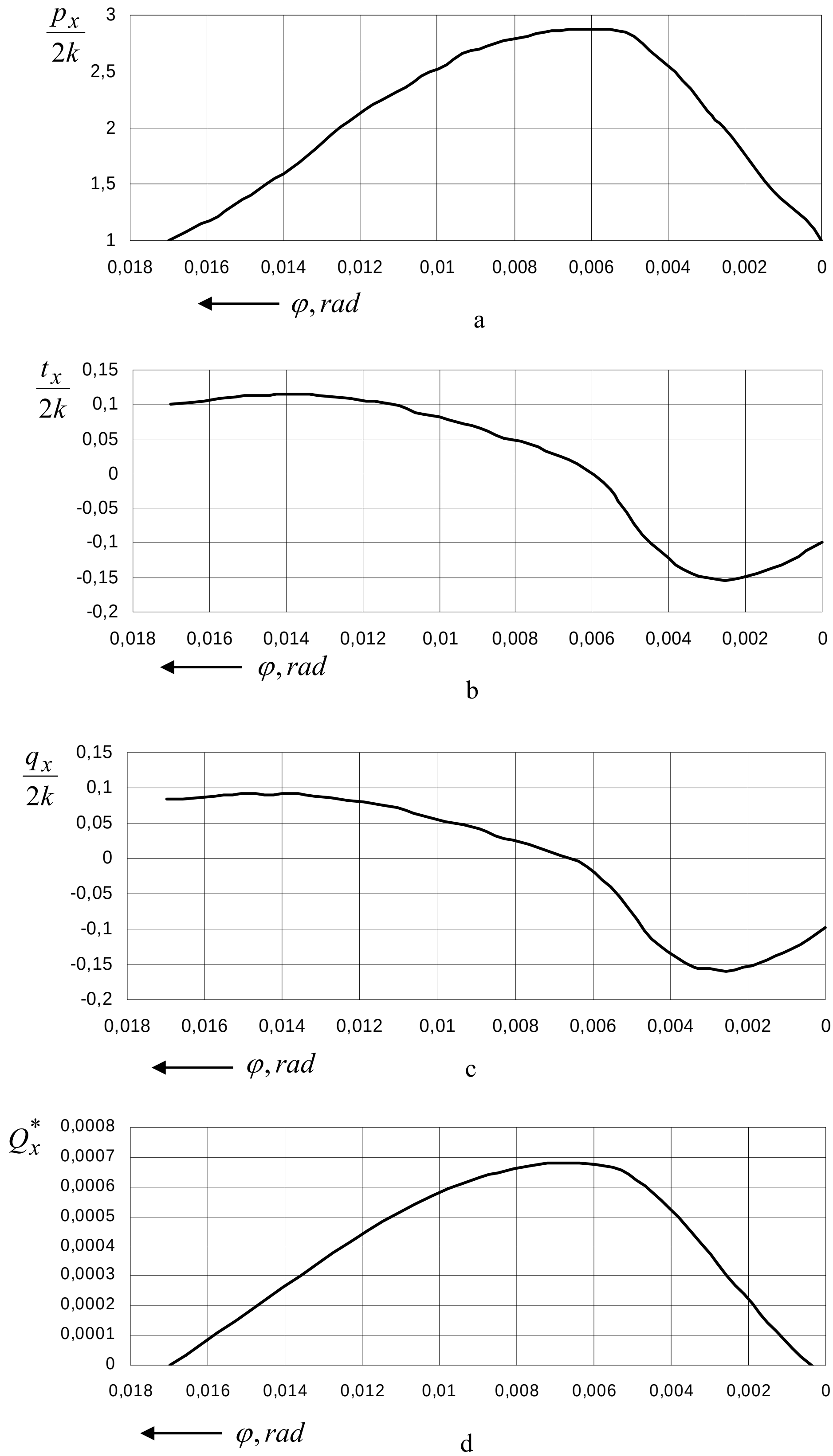

Figure 1. Distribution diagrams of contact stress, longitudinal external stress and current resultant of horizontal external forces

It is obvious that force Q_x^* on boundary lines of contact zone is equal to zero. It follows that the rates v_0 and v_1 (v_0, v_1 – metal rates at the entry into deformation zone and at the exit, respectively) are invariable in time, i.e. the deformation process is stationary.

We notice that force Q_x^* changes under the certain law along the length of deformation zone, so it is possible to find its mean value which in this case is $Q_{av}^* = 0.00039$, i.e. the average resultant of horizontal forces is directed towards the rolling process.

It is obvious that if the rolling process is stationary, all forces acting in the deformation zone should be balanced.

To find out which forces counterbalance Q_{av}^* we analyze the distribution of longitudinal normal stresses occurring in ductile metal $\frac{\sigma_x}{2\kappa}$. Considering the plasticity equation, it is easy to construct the diagram of stress change (**Figure 2a**) to find the current internal force $Q_{x\ in}^*$ in the deformation zone (**Figure 2b**) and obtain its mean value $Q_{av\ in}^*$.

V. E. Grum-Grzhimaylo noticed that under this force action there is a "backward" metal flow [6]. If we put vertical lines on the strip surface (**Figure 3**, lines 1), they are bent in direction

$$Q_{x\ in} = \sigma_x h_x b = (p_x - 2\kappa)(h_1 + R\varphi^2)b = 2\kappa Rb\left(\frac{p_x}{2\kappa} - 1\right)\left(\frac{h_1}{R} + \varphi^2\right);$$

$$Q_{x\ in}^* = \frac{Q_{x\ in}}{2\kappa Rb} = \left(\frac{p_x}{2\kappa} - 1\right)\left(\frac{h_1}{R} + \varphi^2\right), \qquad \text{(Eq. 5)}$$

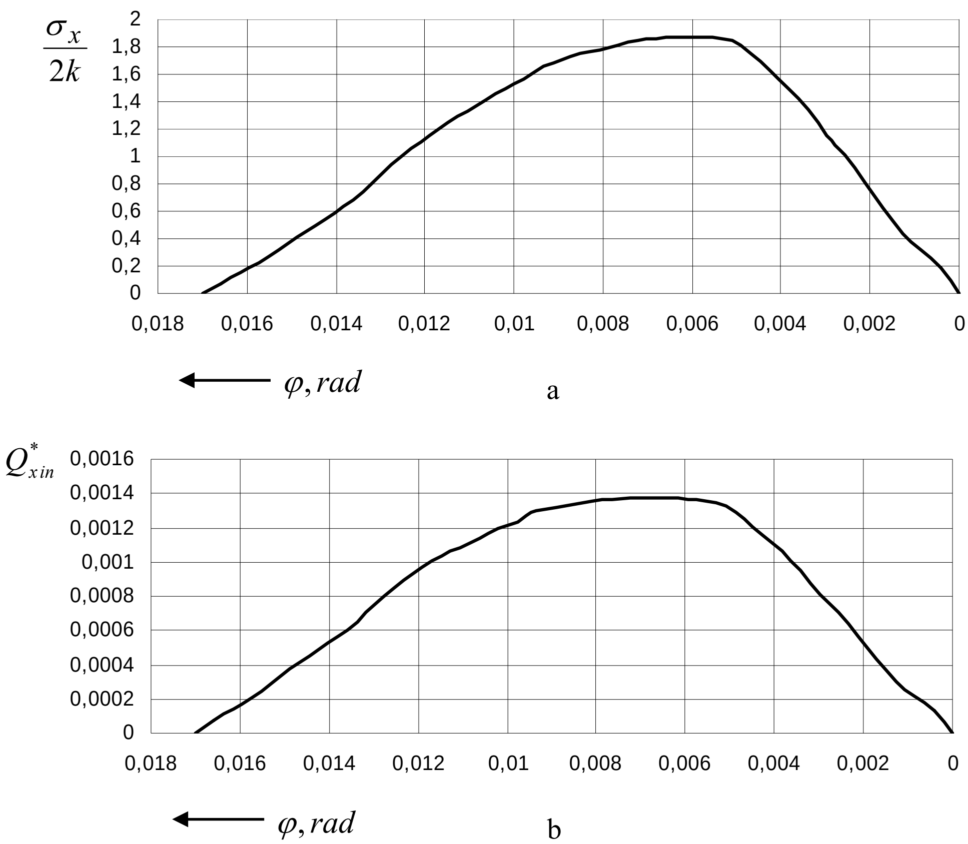

Figure 2. Distribution diagrams of internal stress and current resultant of horizontal internal forces

opposite to metal flow at the entry into deformation zone (**Figure 3**, curves 2).

Comparing the current value of horizontal contact Q_x^* and longitudinal internal $Q_{x\ in}^*$ forces we conclude that the following equality is always observed at steady rolling process

$$2Q_{av}^* = Q_{av\ in}^* \qquad \text{(Eq. 6)}$$

It follows that at given neutral cross-section angle the drawing forces are spent for not only overcoming pushing forces but also for internal force balance $Q_{av\ in}^*$. Besides, angle γ changes so that to provide equality (6). If this equality is disturbed, for example Q_{av}^* becomes more than $Q_{av\ in}^*$, than surplus force is acting in rolling direction. It should cause acceleration and increase of strip rate which will lead to growth of angle γ and, ultimately, to restoration of equality (6).

Thus, the adjusting role of angle γ consists in balance maintenance between horizontal contact external Q_{av}^* and longitudinal internal $Q_{av\ in}^*$ forces. Conducted investigation also shows that if there is a resultant of horizontal forces Q_{av}^* in the deformation zone, the total resultant force of external forces will be inclined from a vertical towards metal flow. We specify the value of total resultant force. For this purpose we determine the vertical component of contact forces

$$Q_v = \int_0^{\alpha} Rb\left(p_x \cos\varphi + t_x \sin\varphi\right)d\varphi, \qquad \text{(Eq. 7)}$$

or in dimensionless form

$$Q_v^* = \frac{Q_B}{2\kappa Rb} = \int_0^{\alpha}\left(\frac{p_x}{2\kappa}\cos\varphi + \frac{t_x}{2\kappa}\sin\varphi\right)d\varphi \qquad \text{(Eq. 8)}$$

The total resultant force is as follows

$$Q_{tot}^* = \sqrt{\left(Q_v^*\right)^2 + \left(Q_{av}^*\right)^2} \qquad \text{(Eq. 9)}$$

With diagrams of contact stress distribution it is easy to find a point of this force application in the deformation zone (**Figure 3**).

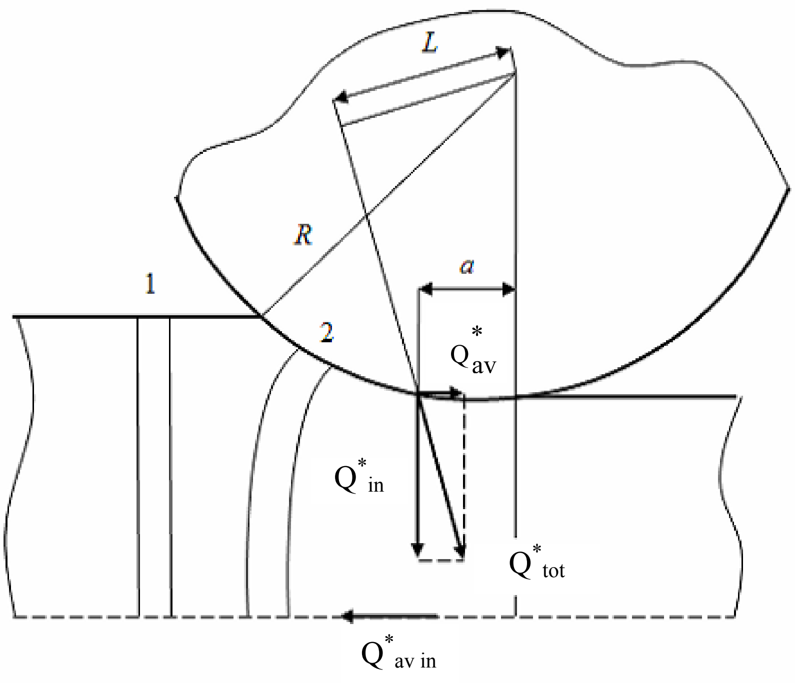

Figure 3. Deformation zone at steady rolling process

Then the rolling torque

$$T_{rol}^{*} = Q_{tot}^{*} L \qquad \text{(Eq.10)}$$

or as a first approximation

$$T_{rol}^{*} = P^{*} a + Q_{av}^{*} R \qquad \text{(Eq.11)}$$

where P^{*} - dimensionless force of rolling, $P^{*} = \frac{P}{2\kappa Rb}$; a - arm of force application P^{*}, $a = \psi \cdot l_d$.

As $R >> a$, the second summand can make a considerable part from the first one, and the torque defined by formula (11) will be considerably more than at calculation under the known formulas. Further, it is planned to carry out concrete numerical calculations of rolling torque for various cases of deformation.

Conclusions

At steady rolling process the inter-balanced horizontal resultants contact and internal forces act in the deformation zone. At change of external conditions of strip deformation the equality of these forces is provided at increase (decrease) of neutral cross-section angle.

The total resultant of contact forces in the deformation zone is not directed vertically but inclined towards metal flow which leads to arm increase at rolling torque calculation. Therefore, it is necessary to specify the calculation procedure of deformation moment.

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Особенности теоретического исследования продольной устойчивости процесса прокатки

Максименко О.П., Романюк Р.Я.

В результате разработанной методики определения средней результирующей горизонтальных сил можно уточнить механизм поддержания равновесия металла в валках. При простом устойчивом процессе прокатки результирующая внешних сил не направлена вертикально, а наклонена в сторону движения полосы. При этом равновесие в очаге деформации соблюдается за счёт действия противоположно направленной силы, возникающей в результате «попятного» движения металла. Следовательно, втягивающие силы затрачиваются не только на преодоление выталкивающих, но и на уравновешивания внешних сил. С учётом наклона равнодействующей контактных сил увеличивается плечо при расчёте момента деформации.