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Analysis of Strip Asymmetrical Cold Rolling Parameters

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Results of theoretical investigation of rolling process parameters when using one-roll drive are presented. Effect of reduction, roughness of rolls and rolling rate on the friction coefficient, forward slip and average normal contact stress at symmetric and asymmetrical rolling (with one power-driven roll) is shown. The possibility to use one-roll drive on the sections of unsteady-state processes for improvement of strip quality and reduction of metal waste is shown.

Keywords: ROLLING, ROLLING-DRAWING, STRIP, LONGITUDINAL UNEVEN GAUGE, POWER-DRIVEN ROLLS, IDLE ROLLS, SURFACE ROUGHNESS, FORWARD SLIP, REDUCTION

Introduction

It is necessary to work out and apply technologies ensuring reduction of longitudinal uneven gauge of strips in the sections of unsteady-state processes (leading end; welding seam; trailing end at the exit from the strip mill) in order to improve technical-and-economic indices of cold strip mill operation.

Results and Discussion

The major drawback of thin strip cold rolling process is a significant effect of roll speed on the contact shearing stresses, rolling force and power, and, consequently, thickness of rolled strip. Especially this effect is revealed in unsteady-state processes at reduction of velocity of roll periphery to $v < 5$ m/s. Raise of power parameters at $v < 5$ m/s is caused by increase of friction coefficient and contact shearing stresses.

It is possible to compensate the effect of contact friction in unsteady-state processes on the strip thickness in various ways, including:

- application of additional reduction of thickened strip sections in two or all mill stands;
- using effective technological lubricant on the local sections of the strip;
- using asymmetrical process at roll speed reduction when thickened strip sections rolling.

The first method in view of reduction of longitudinal uneven gauge is effective but simultaneously with application of additional reduction friction coefficient, rolling force and power, modulus of strip rigidity and cross-section uneven gauge grow. The second method provides elimination of insignificant longitudinal uneven gauge but leads to some strip surface contamination.

Strip gage change methods which enable to lower the rolling force in unsteady-state processes without deterioration of strip surface are the most rational. Asymmetrical processes of rolling are referred to such methods. For example, rolling of thickened strip sections in unsteady-state processes in the stands with high-speed asymmetry of strip deformation enables to reduce effect of contact shearing stresses and, hence, normal contact stresses, rolling force and strip gage [1, 2].

So, at asymmetrical rolling of thin strips in single-roll driven stand the rolling force in some cases is 10-50 % less than when rolling with two rolls driven [1]. When aluminum strip rolling in single-roll driven stand in the contact with idle roll the friction coefficient drops $f_x \approx 0.062$ and critical cross-section angle (γ_x) grows to $\gamma_x / \alpha = 0.4\text{-}0.55$ [2] similar to metal drawing through a roller die (α -contact angle; γ_x - angle of critical cross-section from idle roll). On the contact with power-driven roll at reduction of cross-sectional area $\varepsilon > 0.2$ friction coefficient is $f_П \approx 0.11$ and ratio $\gamma_П / \alpha = 0.1\text{-}0.2$ (technological lubricant – emulsol T). The ratio γ_x / α from the idle roll increases due to forced transportation of the strip by power-driven roll that creates longitudinal tensile stresses in metal layers from the idle roll. At symmetric rolling of aluminum strips in power-driven rolls with diameter D = 100 mm the friction coefficient is f = 0.063-0.079 at ε = 0.2-0.3 [3] which is much less than on a power-driven roll and a little more than on the idle roll.

Thus, when rolling in the single-roll stand the average friction coefficient is 1.07-1.35 times more than at symmetric rolling in two power-driven rolls. This promotes raise of average direct stresses in the deformation zone. On the other hand, when rolling with single driven roll there is high-speed asymmetry due to difference of friction coefficient and kinematic parameters of deformation [7] and for $\varepsilon > 0.2$ the speed ratio is $v_П/v_x$ = 1.06-1.11 which stipulates longitudinal tensile stresses in the deformation zone sufficient for reduction of normal contact stresses ($v_П$ and v_x - speeds of strip layers from power-driven and idle rolls, respectively).

Besides, change of backward slip and forward slip zone length on the contact arc changes the values of average contact tangents, and therefore, normal contact stresses. It occurs due to different values of tangential contact stresses in specified zones. So, according to data [4], at l_d / h_{av} = 3.0-6.6 in the backward slip zone the average shearing stresses are 1.86-3.0 times more than in the forward slip. Obviously, it is caused by the fact that metal flows against the movement of roll surface on the contact in backward slip zone whereas in forward slip zone - in the line of roll surface movement where slip resistance is less. Known theoretical formulas do not consider these features of friction in the deformation zone. Hence, reduction of backward creep zone length (increase γ/α), to some degree, promotes lowering of average normal contact stresses.

Joint effect of considered above three factors defines the difference of average normal contact stresses (forces) at rolling with one power-driven roll and with two power-driven rolls. Depending on strain conditions the rolling force with one power-driven roll can be less than when using two-roll stand drive.

Efficiency of metal deformation in the single-roll stand can be estimated under theoretical model presented in [2]. When using iterative process the model enables to count geometrical, kinematic and power parameters of rolling. The calculation algorithm is presented further.

First of all, average friction coefficient f in the deformation zone is computed using a model for symmetric process of rolling [3, 5]. We accept:

$$f_{ПX} = 0,5(f_{ПР} + f_X); \quad c_X = \frac{f_{ПР}}{f_X};$$

$$f_{ПР} = f_X \cdot c_X;$$

$$f_X = \frac{2 f_{ПX}}{(1 + c_X)}; \quad f_{ПX} \approx 1,25 f, \quad \text{(Eq. 1)}$$

where $f_{ПX}$, $f_{ПР}$, f_X - friction coefficients: average in the deformation zone, from power-driven and idle rolls, respectively; f - friction coefficient in symmetric process. Average factor C_x at $\varepsilon \gtrsim 0.1$ does not depend on reduction of cross-sectional area ε and is C_x = (0.111-0.124)/(0.063-0.07)≈1.75 as a first approximation according to experimental data [2]. Average friction coefficient $f_{ПX}$ is a little more in the asymmetrical process than in the symmetric one, obviously, due to increase of backward creep zone on the power-driven roll and increase of slip velocity on the contact.

Angles of critical cross-section in the asymmetrical rolling process are defined from a horizontal (longitudinal) force equilibrium condition taking into account effect of internal longitudinal tensile stresses in the deformation zone and effect of friction forces in bearings of working and back-up rolls [2]:

- for driven roll (B = 1)

$$- P_П \cdot \sin\varphi_П - P_X \cdot \sin\varphi_X + T_{П1} \cdot cos\frac{(\alpha_П + \gamma_П)}{2} - T_{П2} \cdot \frac{cos\gamma_П}{2} - P_X \frac{f_T \cdot r_Ш}{R_П} - \sigma_П \cdot H = 0; \quad \text{(Eq. 2)}$$

- for idle roll (B = 1)

$$- P_П \cdot \sin\varphi_X + T_{X1} \cdot \cos\frac{(\alpha_X + \gamma_X)}{2} - T_{X2} \cdot \frac{\cos\gamma_X}{2} - P_X \cdot f_{OT} \frac{r_{OШ}}{R_O} \cdot (\frac{R_X}{R_O}) + \sigma_X \cdot h = 0, \quad \text{(Eq. 3)}$$

where P_i - rolling force; T_{i1} and T_{i2} - friction forces in backward creep and forward slip zones, respectively; α_i - contact angles; φ_i - angle matching to point of force application on roll contact arcs; γ_i - angles of critical cross-section in the deformation zone; f_i - factors of external friction on the contact surfaces of deformation zone; f_T and f_{OT} - friction coefficients in necks of work and backup rolls, respectively; $r_{Ш}$ and $r_{OШ}$ - radiuses of necks of work and backup rolls, respectively; $R_П$ - radius of driven work roll; R_0 - backup roll radius; H and h – strip gage before rolling; σ_i - internal longitudinal tensile stress; B - plate strip width; i - index for driven roll "П", for idle roll "X".

Having solved and transformed equations (1) it (2) we will obtain (taking into account an external tension):

$$\gamma_П = \frac{\alpha_П}{2}[1 - \frac{\varphi_П}{f_{ПР}}(1 + n_B \cdot a) - n_B \cdot a\frac{f_T}{f_{ПР}} \cdot \frac{r_Ш}{R_X}] - \frac{\sigma_П \cdot H}{2 f_{ПР} \cdot p_П \cdot R_П} + \frac{\sigma_1 h(1 - \frac{\sigma_0 H}{\sigma_1 h})}{4 f_{ПХ} \cdot p_{CP.H} \cdot R}; \quad \text{(Eq. 4)}$$

$$\gamma_X = \frac{\alpha_X}{2}[1 - \frac{\varphi_X}{f_X} - \frac{f_{OT}}{f_X} \cdot \frac{r_{OШ}}{R_O}(\frac{R_X}{R_O})] + \frac{\sigma_X \cdot h}{2 f_X \cdot p_X R_X} + \frac{\sigma_1 h(1 - \frac{\sigma_O H}{\sigma_1 h})}{4 f_{ПХ} \cdot p_{cp.H} \cdot R};$$

$$\varphi_П = \psi_П \cdot \alpha_П = 0,9 \cdot \psi \cdot \alpha_П; \quad \varphi_X = \psi \cdot \alpha_X; \quad a = \frac{\alpha_X}{\alpha_П} = \sqrt{\frac{\Delta h_X \cdot R_П}{\Delta h_П \cdot R_X}}, \quad \text{(Eq. 5)}$$

where σ_0 and σ_1 - stress of back and fast-head tension, respectively; $f_{ПХ}$ - average friction coefficient in the deformation zone; $P_{cp.H.}$ - average normal contact stress in the deformation zone; R - average radius of work rolls; ψ - factor of resultant force position at symmetric rolling [3]; $\psi_П$ and ψ_X - factors of resultant force position at asymmetrical rolling; $\Delta h_П$ and Δh_X - reduction values from driven and idle rolls (for two rolls); n_B, $n_П$, n_X - asymmetry factors equal

$$n_B = \frac{p_X R_X}{p_П \cdot R_П};$$

$$n_П = \frac{\sigma_П}{p_П};$$

$$n_X = \frac{\sigma_X}{p_X} \quad \text{(Eq. 6)}$$

Coefficients of deformation asymmetry effect $n_П$ and n_X are defined from equation (2):

$$n_X = 2 f_X(\sqrt{S_X} - \sqrt{S})\sqrt{\frac{R_X}{h}};$$

$$n_П = 2 f_{ПР}(\sqrt{S} - \sqrt{S_П})\sqrt{R_П \cdot \frac{h}{H^2}}, \quad \text{(Eq. 7)}$$

where S – forward slip at symmetric process of rolling; S_X and $S_П$ - values of forward slip from idle and driven rolls, respectively.

Forward slip values S_X and $S_П$ are defined from equation (8):

$$S_X = S + 0,5(\frac{v_П}{v_X} - 1);$$

$$S_П = S - 0,5(1 - \frac{v_X}{v_П}), \quad \text{(Eq. 8)}$$

where $V_П$ and V_X - velocities of strip layers from driven and idle rolls, respectively.

Ratio $\frac{V_П}{V_X}$ is pre-defined from [2]:

$$\frac{V'_П}{V'_X} = 1 + 0.285\varepsilon, \quad \text{(Eq. 9)}$$

where ε - reduction of cross-sectional area.

Average direct stresses on the rolls are computed by formulas [2]:

$$p_{П} = \frac{p_{cp}}{(1+n_{П})};$$

$$p_X = \frac{p_{cp}}{(1+n_X)};$$

$$p_{CP.H} = 0,5(p_H + p_X); \quad m = \frac{p_X}{p_П},$$

$$p_{cp} = \sigma_{ф}(1 + C_H \cdot f_П \cdot l_C / h_{cp}),$$

(Eq. 10)

where $P_{cp.}$ - average normal contact stress in symmetric process; $P_{cp.H}$ - average normal contact stress at asymmetrical rolling; $\sigma_ф$ - metal resistance to deformation; $f_П$ - friction parameter; h_{cp} - average strip gage in the deformation zone; C_H - factor depending on friction coefficient [2, 3].

Values of reduction in thickness from each roll are computed by formulas [2]

$$\Delta h_X = \frac{\Delta h}{(1 + m^2 \text{v}_X/\text{v}_П)};$$

$$\Delta h_П = \Delta h - \Delta h_X \qquad \text{(Eq. 11)}$$

We substitute doubled values $\Delta h_П$ and Δh_X in formulas for calculation of contact arc length and roll radius taking into account elastic deformation of rolls and strip [3]. Roll radius is computed from computed values of contact arc lengths $l_{CП}$ and l_{CX}

$$R_П = \frac{l_C^2}{2\Delta h_П};$$

$$R_X = \frac{l_C^2}{2\Delta h_X} \qquad \text{(Eq. 12)}$$

Average roll radius and contact length are computed from equation (13)

$$R = \frac{2 \cdot R_П \cdot R_X}{R_П + R_X};$$

$$l_{CP.H} = \sqrt{R \cdot \Delta h} \qquad \text{(Eq. 13)}$$

Contact angles are

$$\alpha_П = \sqrt{\frac{2\Delta h_П}{R_П}};$$

$$\alpha_X = \sqrt{\frac{2\Delta h_X}{R_X}}, \qquad \text{(Eq. 14)}$$

and rolling force

$$P = p_{CP.H} \cdot l_{CP.H} \cdot B, \qquad \text{(Eq. 15)}$$

$P_{cp.H}$ - in MPa; $l_{cp.H}$ - in m; B - in m.

Stresses $\sigma_П$ and σ_X from equations (6) are

$$\sigma_П = n_П \cdot p_П;$$

$$\sigma_X = n_X \cdot p_X \qquad \text{(Eq. 16)}$$

The next step is calculation of critical cross-section angles by equations (4), (5) of forward slip and speed ratio [2]

$$S_П = \frac{R_П \cdot \gamma_П^2}{h};$$

$$S_X = \frac{R_X \cdot \gamma_X^2}{h}; \qquad \text{(Eq. 17)}$$

$$\frac{\text{v}_П}{\text{v}_X} = 1 + S_X - S_П \qquad \text{(Eq. 18)}$$

The calculation algorithm of geometrical, kinematic and power parameters in the single-roll stand is presented below.

1. Calculation of strip rolling parameters in symmetric process in the single-roll stand [3, 5].
2. Calculation of friction coefficients by equations (1).
3. Calculation of parameter $\frac{V_П}{V_X}$ by formula (9). Ratio $\frac{V_П}{V_X}$ is a varied parameter.
4. Calculation of forward slip values S_x and $S_П$ by equations (8).
5. Determination of factors n_x and $n_п$ by formulas (7).
6. Calculation of average normal contact stresses p_X, $p_П$, p_i and factor m by formulas (10).
7. Calculation of internal stresses σ_X, $\sigma_П$ by equations (16).
8. Calculation of geometrical parameters of deformation by equations (11) - (14).
9. Determination of critical cross-section angles γ_X and $\gamma_П$ by formulas (4), (5).
10. We define new values of forward slip $S`_x$

and $S`_{П}$ by formulas (17) and ratio $\frac{V_{П}}{V_X}$ by formula (18).

11.Iterative computation process of values S_x and $S_{П}$ by parameter $\frac{V_{П}}{V_X}$ prior to obtaining their values in the previous and subsequent calculations with accuracy $\Delta = \pm 0.003$.

12.The final calculation of all parameters in items 2-10.

Using presented above model, we defined the extent of high-speed asymmetry effect on power and kinematic parameters as compared to symmetric process of rolling.

Calculations are carried out for parameters: D = 500 mm, $D_{ОП}$ = 1300 mm, H = 1-3 mm, ε = 0.1-0.4, v = 1-20 m/s, R_a = 1-5 microns (D - roll diameter; R_a - roll surface roughness). Grease lubricant - emulsion, mineral oil. Design parameters are presented in **Figures 1-3** and **Table 1-2**.

Design parameters S_i, γ_i / α_i, σ_X/p_H and p_i are presented in **Figure 1**. As follows from **Figure 1** and **Table 1** in all cases specified parameters are various at symmetric and asymmetrical processes. Friction coefficient at symmetric and asymmetrical rolling with increase of reduction of cross-sectional area is almost invariable due to joint effect of contact conditions of deformation and strip heating-up temperature.

However, reduction increase leads to increase of forward slip advancing defined for symmetric rolling by known dependences [2, 6], and for asymmetrical rolling - by formulas (8), (9) with the subsequent iteration by parameter $\frac{V_{П}}{V_X}$. It is seen in **Figure 1a** that forward slip values essentially grow linearly and at symmetric rolling for ε = 0.4 reach value S = 15.2 %.

At asymmetrical rolling with one idle roll the forward slip according to various high-speed conditions is different on the rolls. Forward slip S_X = 19.7 % on the idle roll due to its smaller speed at ε = 0.4 and forward slip $S_{П}$ = 11.1 % on the driven roll. Thus, parameter γ_i / α_i decreases from $\gamma_x / \alpha_x \approx 0.63$ to $\gamma_x / \alpha_x \approx 0.53$ with increase of reduction of cross-sectional area from idle roll, and from driven roll grows insignificantly (**Figure 1b**).

Table. 1. Calculation of parameters at symmetric rolling process (H = 2 mm, v = 1 m/s, Ra = 1 micron, at ε = 0.1-0.4)

h, mm	ε	f	$\sigma_{ф}$, N/mm^2	l_c, mm	p_{cp}, N/mm^2	P, MN
1.8	0.1	0.087	394.81	8.32	495.01	5.15
1.6	0.2	0.092	461.15	11.84	649.80	9.61
1.5	0.25	0.094	487.96	13.28	724.06	12.02
1.4	0.3	0.096	509.98	14.59	793.96	14.48
1.3	0.35	0.097	526.34	15.78	856.48	16.89
1.2	0.4	0.097	534.70	16.83	905.49	19.05

h, mm	ε	ψ	S	t, °C	U, s^{-1}	R_C, mm	α, rad	γ, rad
1.8	0.1	0.346	0.030	34.29	10.91	346	0.028	0.013
1.6	0.2	0.343	0.063	50.2	15.38	350	0.04	0.017
1.5	0.25	0.340	0.083	60.6	17.19	352	0.045	0.019
1.4	0.3	0.338	0.104	72.8	18.78	354	0.049	0.02
1.3	0.35	0.337	0.127	86.5	20.14	355	0.053	0.022
1.2	0.4	0.339	0.152	101.10	21.22	354	0.057	0.023

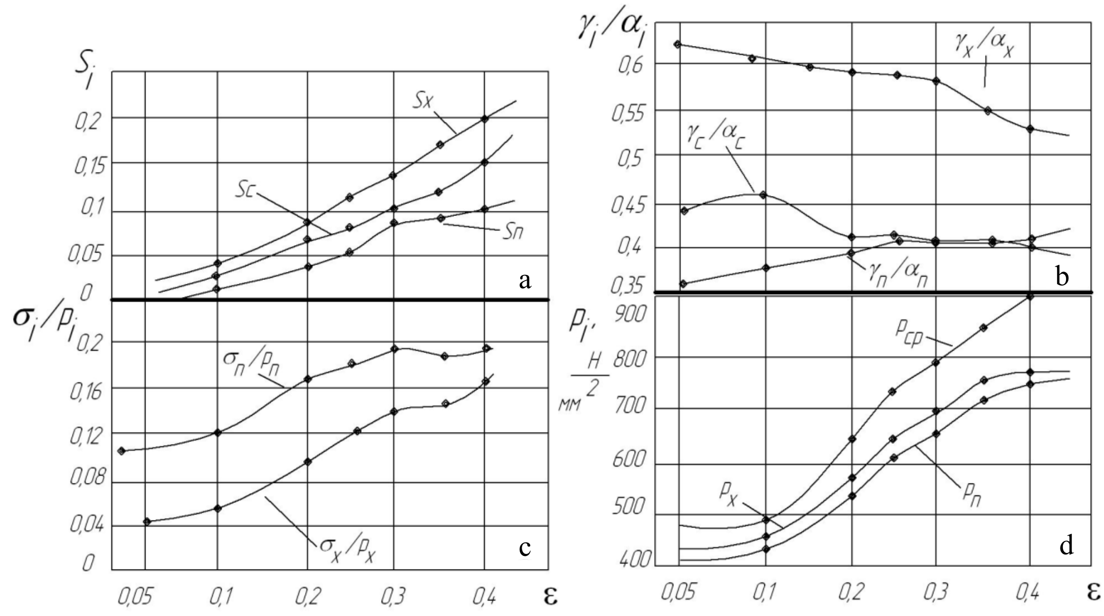

Figure 1. Effect of reduction of cross-sectional area on parameters of symmetric and asymmetrical process of rolling with one driven roll: H = 2 mm; v = 1 m/s; R_a = 1 micron

Table 2. Design variables of rolling asymmetrical process (H = 2 mm, v = 1 m/s, Ra = 1 micron, at ε = 0.1-0.4)

h, mm	ε	$f_{ПХ}$	f_X	$f_{ПР}$	$v_П/v_X$	$S_X/S_П$	$n_X/n_П$	$p_X/p_П$, N/mm^2	p_{av}, N/mm^2	m	$\sigma_X/\sigma_П$, N/mm^2
1.8	0.1	0.108	0.079	0.138	1.023	0.042	0.066	464	452	1.054	30.84
						0.019	0.124	440			54.64
1.6	0.2	0.115	0.084	0.147	1.047	0.087	0.107	587	571	1.059	62.62
						0.041	0.172	554			95.16
1.5	0.25	0.118	0.086	0.15	1.058	0.112	0.123	645	629	1.052	79.1
						0.055	0.181	613			110
1.4	0.3	0.12	0.087	0.152	1.071	0.14	0.141	695	682	1.044	98.3
						0.071	0.191	666			127
1.3	0.35	0.121	0.088	0.154	1.078	0.166	0.148	745	735	1.029	110
						0.091	0.182	724			131
1.2	0.4	0.121	0.088	0.154	1.095	0.2	0.172	772	766	1.017	132
						0.109	0.192	759			145

h, mm	ε	$\Delta h_X/\Delta h_П$, mm	$R_X/R_П$, mm	$l_X/l_П$, mm	$\alpha_X/\alpha_П$, rad	n_B	$\varphi_X/\varphi_П$, rad	$\gamma_X/\gamma_П$, rad	t, °C	U, c^{-1}
1.8	0.1	0.096	316	8.11	0.023	1.265	0.007	0.01	34.81	12.03
		0.104	379	8.54	0.026		0.008	0.014		
1.6	0.2	0.194	321	12.18	0.032	1.258	0.01	0.014	50.32	16.93
		0.206	381	11.5	0.036		0.011	0.019		
1.5	0.2	0.246	330	13.62	0.036	1.202	0.011	0.016	60.33	18.84
	5	0.254	377	12.95	0.039		0.012	0.021		
1.4	0.3	0.299	339	14.9	0.04	1.136	0.012	0.017	71.71	20.57
		0.301	370	14.3	0.042		0.013	0.023		
1.3	0.3	0.357	352	16	0.045	1.049	0.014	0.018	84.76	22.18
	5	0.343	359	15.55	0.044		0.013	0.025		
1.2	0.4	0.415	361	16.98	0.049	0.976	0.015	0.019	98.06	23.76
		0.385	347	16.69	0.046		0.014	0.026		

Asymmetrical process has a significant effect on tensile stresses (**Figure 1c**). Values σ_X/p_H are much less on the idle roll than $\sigma_П/p_P$ on the driven roll. This is caused by higher values of friction coefficient $f_П$ [2]. Thus parameter σ_i/p_i essentially increases that is caused by decrease of final strip gage and effect of contact friction. Due to smaller internal tensile stress σ_X the average normal contact stress from the idle roll is a little more than on the power-driven roll that is in agreement with empirical data [7].

Reduction values from rolls are various at observed total reduction but, at ε <0.3 particular reduction is less from idle roll and at ε> 0.3 vice versa. However, the difference in values of particular reduction does not exceed 7.5 % (**Table 2**). With increase of reduction of cross-sectional area the average normal contact stress in all cases grows, but at asymmetrical rolling the average normal contact stress p_{av} is less by 12-18 % than in symmetric process. The average normal contact stress is more by 1.5-6.7 % on the idle roll.

Similar regularities are saved at strip rolling in the rolls with roughness 5 microns R_a (**Figure 2**). However all parameters grow a little. So, forward slip increases by 19 % and average normal contact stress grows by ~25 % at ε = 0.4. Internal tensile stress σ_i/p_i and all other parameters at asymmetrical rolling also increase.

Velocity of roll periphery has a much more influence on all parameters of rolling process (**Figure 3**). The original cause of change of parameters is drop of friction coefficient at symmetric and asymmetrical processes [8] caused by better conditions of holding grease lubricant and heating-up of strip surface [2]. As a result of effect of specified factors at increase of roll velocity from v = 1 m/s to 20 m/s the friction coefficient at symmetric rolling drops from f = 0.096 to f = 0.041 (H = 1 mm; ε = 0.3; R_a = 1 microns). R_a friction coefficient grows significantly to f = 0.183 at v = 1 m/s (H =1 mm, ε = 0.3) at increase of roughness to 5 microns.

Drop of friction coefficient (decrease of roll roughness) with increase of roll velocity promotes decrease of all rolling parameters (**Figure 3**, **Table 2**). It occurs in both symmetric and asymmetrical processes. In all cases the average normal contact stress on the idle roll is more than on the driven one due to smaller internal tensile stress at ε = 0.3 (**Figure 3**). However, the average normal contact stress in asymmetrical deformation zone is always less by 10-25 % than in the symmetric deformation zone. Thus, in all cases application of single-roll drive ensures drop of average normal contact stress.

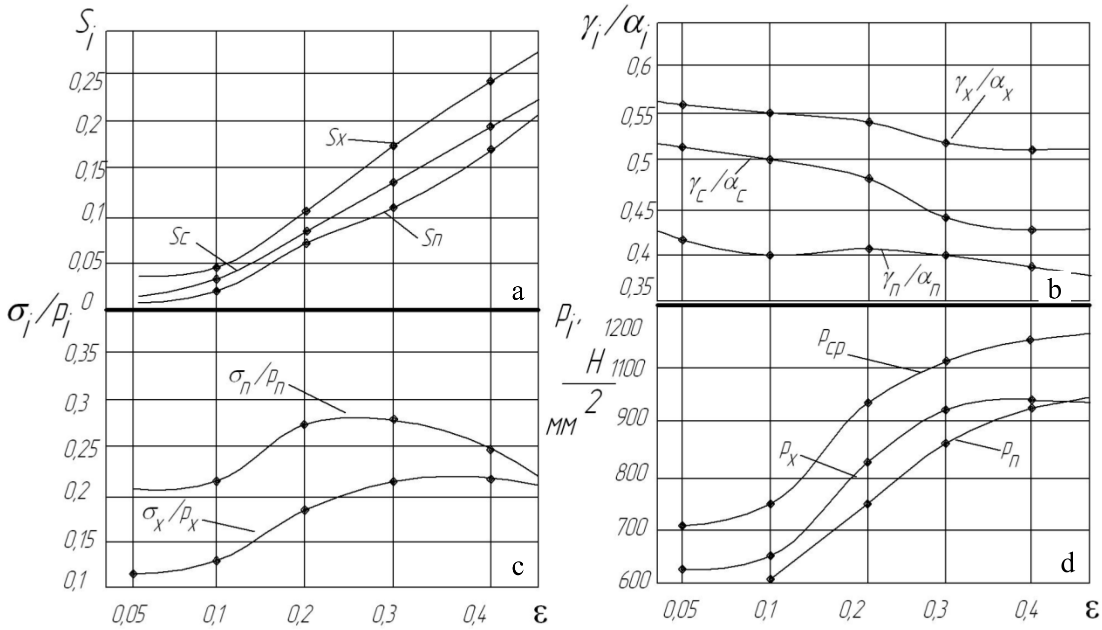

Figure 2. Effect of reduction of cross-sectional area on parameters of symmetric and asymmetrical process of rolling with single driven roll: H = 2 mm; v = 1 m/s; R_a = 5 microns

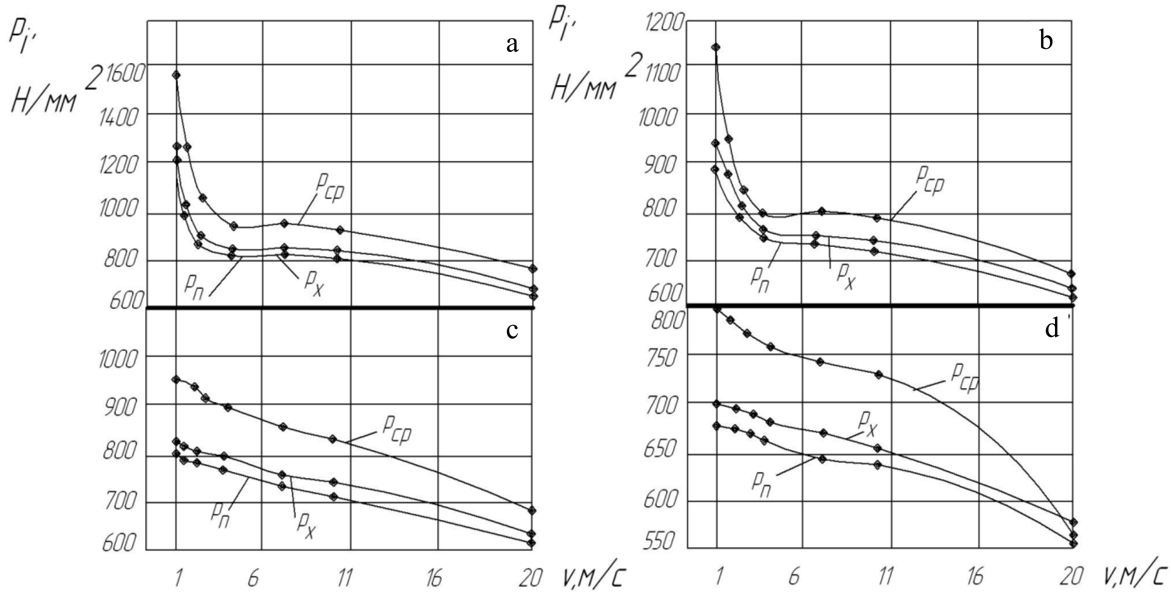

Figure 3. Effect of velocity of roll periphery on average normal contact stress at symmetric and asymmetrical rolling ε = 0.3: *a* - H = 1 mm and R_a = 5 microns; *b* - H = 2 mm and R_a = 5 microns; c - H = 1 mm and R_a = 1 microns; *d* - H = 2 mm and R_a = 1 microns

Conclusions

Results of calculations showed that it was possible to reduce average normal contact stresses in the deformation zone with one driven roll in 1.1-1.25 times. Using single-roll drive can be recommended to decrease strip gage in sections of unsteady-state processes on cold mills by switching off one of engines at individual drive mechanism as well as on temper mills for improvement of strip surface quality, at operation without one (top) spindle in case of drive through a pinion stand.

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Анализ параметров несимметричной холодной прокатки полос

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Приведены результаты теоретических исследований параметров процесса прокатки при использовании одновалкового привода. Показано влияние обжатия, шероховатости валков и скорости прокатки на коэффициент трения, опережение и среднее нормальное контактное напряжение при симметричной и несимметричной прокатке (с одним приводным валком). Показана возможность использования одновалкового привода на участках переходных процессов, для улучшения качества полос и снижения отходов металла в обрезь.