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Development of Power Saving Modes of Tension on Cold Rolling Continuous Mills

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Abstract

Due to the results of modeling the influence of technology parameters (h_0, ε_Σ, f, ε u R_{work}) on the power of cold rolling with tension a new principle of distribution of relative specific tension in interstand gap of continuous rolling mill providing an increase of process energy efficiency is suggested and the dependence for its implementation is obtained.According to the developed dependence the relative specific tension should increase from the first interstand gap to the last one. The suggested principle of tension distribution on continuous cold rolling mills will reduce the specific consumption of electric energy by 2-8 %.

Key words: *cold rolling, strip, continuous mill, tension, energy efficiency*

Cold rolling is one of the most energy-intensive processes of plastic deformation. Statistical data [1] suggest that the specific consumption of electrical energy for cold rolling strips of 0.5-1.0 mm thick made of carbon steel is 40-100 kW • h / ton. In the production of tin of single rolling and thin tin of double rolling specific energy consumption increases, respectively, to 150-200 and 200-250 kW • h/ton or more. In the cold rolling of thin and very thin strips of electrical and high-strength steels specific consumption of electric energy is 1.5-2.5 times higher than in cold rolling of the same mix of low carbon steels. Large consumption of electricity in cold rolling leads to higher prices for its products and lower competitiveness of. Therefore, finding ways to reduce energy consumption in the production of cold-rolled steel in a continuous increase in the price of energy is very important. This purpose is the subject of this article. To achieve this goal using an unconventional, but very efficient way to reduce the specific consumption of electric energy in cold rolling , the essence of which is to develop energy-saving modes of current tensions at the mills. Since the majority of flat cold-rolled production is produced on continuous rolling mills, it is obvious that the development of energy-efficient modes of tension is most useful on these mills.

The tension is one of the main characteristics of the technology on non- continuous cold rolling mills. It is known from the theory and practice of plate rolling that tension reduces the contact stresses and rolling force, reduces flatlessness of rolled production, increases process stability and tightability of the work stands [1, 2]. It is also known that with a decrease in the thickness of the rolled bands and the extent of their prior work hardening the technological efficiency of the process of cold rolling increases with tension [2 , 3]. At the present time there are no evidence-based guidelines for the definition of the level and distribution nature of relative tensions in the continuous cold rolling mills. In addition, there are no data on the energy efficiency of tension modes. Therefore, when developing modes of tension the specialists are usually guided by experience and intuition. Table 1 shows the modes tension applied to the continuous cold rolling mills strips of carbon steels.

Table 1 The modes of tension applied in practice in the rolling of cold-rolled strips of carbon steel grades for continuous mills [1]

No.	The part of strip tension	Relative interstand tensions on the continuous mills $q/\sigma_{\text{т}}$			
		4-stand	5-stand of general purpose	5-stand tin-rolling	6-stand tin-rolling
1	Between mills 1 and 2	0.20–0.40	0.20–0.35	0.25–0.35	0.30–0.45
2	Between mills 2 and 3	0.15–0.35	0.20–0.30	0.20–0.30	0.25–0.35
3	Between mills 3 and 4	0.15–0.30	0.15–0.25	0.20–0.25	0.20–0.30
4	Between mills 4 and 5	–	0.10–0.20	0.15–0.25	0.20–0.25
5	Between mills 5 and 6	–	–	–	0.15–0.25

According to these data, the greatest relative tension (0.2-0.45 σ_t, where σ_t is the yield stress of the strip in the corresponding interstand interval) takes place in the first stands of continuous rolling mills, which decrease monotonically from the first to the last stand. Such a character of the distribution of specific tension adopted on the basis of the conditions of prevention of strip continuity in cold rolling, as this increases the probability of reducing the thickness and an increase in the total relative deformation of the strip [2]. Breakage of cold rolling strip depends on many factors, the most important of which are: accuracy of geometrical dimensions, quality and flatness of the longitudinal edges of hot rolling; the stability of the parameters of surface quality and weight of hot-rolled coils, full of tension wrenches; stability and efficiency of the automatic adjustment systems of regulation of accuracy parameters and management of technological processes that are installed on a particular mill.

The problems associated with breakage of the strip on many modern factories are solved quite successfully and cold rolling on continuous cold rolling mills is performed with large relative specific tensions. This allows to decide technological challenges in a new way and to use more reliable criteria for the development of modes of tensions at cold rolling mill in order to increase the efficiency of the latter.

The results of previously performed theoretical studies [4] have shown that cold rolling with tension is more energy profitable process than cold rolling without tension. Energy efficiency of cold rolling tension was evaluated by the ratio of capacityW_{sn}/W_s at $V_{1n} = V_1$ [4]

$$\frac{W_{sn}}{W_s} = \left\{ \frac{p_{avsn}}{p_{avs}} \frac{\psi_{sn}}{\psi_s} \left(\frac{\ell_{sn}}{\ell s} \right)^2 + \frac{Rh_0}{2p_{avs}\psi_c \ell_c^2} \left[q_0 \varepsilon + S_{csn} (1-\varepsilon)(q_1 - q_0) \right] \right\} \frac{(1+S_s)}{(1+S_{sn})}, \qquad (1)$$

where W_{sn}, p_{avsn}, ψsn, l_{sn}, s_{sn}, W_s, p_{avs}, ψ_s, l_s, s is the total power on the roll drums, average contact normal stress, coefficient characterizing the position of the point of application of the resultant contact forces (the coefficient of the moment arm), the length of the deformation zone and ahead of the curve in rolling with tension and without tension, calculated taking into account the influence of the elastic deformation of the rolls and the strip; R, h_0, ε are the radius of the work rolls, the thickness of the strip at the entrance to the deformation and private strip relative reduction; q_0, q_1 are back and front absolute specific tension. V_{1n}, V_1 are the speed of the strip exiting the deformation zone at rolling with or without tension.

$$\frac{q_0}{\sigma_{F0}} = \beta k_q \left(\frac{1+f}{1+5\sqrt{\frac{h_0}{R}}} + \frac{1+\varepsilon\varepsilon_\Sigma}{1+\varepsilon} \right)$$

В основу вывода зависимости (1) положено уравнение энергетического баланса мощностей при прокатке [5].

The energy balance equation of rolling power [5] is the basis of the dependence calculation (1).

Research results [4] carried out by using the expression (1) showed that the power required for the cold rolling process with tension W_{sn}, other things being equal, is always less than the rolling power without tension W_s. It was found that the energy efficiency ($W_{sn}/W_s<1$) of cold rolling process with tension increases with the thickness reduction (h_0) and the particular relative reduction of the rolled strip at each stand (ε), as well as with the increase of total flow (ε_Σ), friction ratio f, and the working rolls radius (R) [3]. For that reason the use of high specific tension is energetically more efficient under conditions, when the elastic flows of rolls and strip have a significant negative impact on the process parameters of cold strip rolling, which is encountered in the rolling of previously cold-worked thin strips with a high flow limit in large diameter rolls.

Not only the level but also the ratio of relative specific tensions has a significant impact on the energy efficiency of the cold rolling process with tension. It was found that, other things being equal, rolling with the prevailing back relative tension ($q_0/\beta\sigma_{F0}>q_1/\beta\sigma_{F1}$, where σ_{F0}, σ_{F1} – the flow limit of strip material at the input and output of the deformation zone) is characterized by a lower level of power consumption than rolling with the prevailing front relative tension. For that reason cold rolling with the prevailing back tension is always an energetically more efficient process. The result of mass data analysis and generalization on the impact of technology parameters (h_0, ε_Σ, f, ε и R_{work}) the level of power consumption in the cold rolling with tension was the dependence for the determination of the level and property reticulation of relative back tension in each interstand space of continuous mill, providing the maximum process energy efficiency, when applied to the ends of the strip pulling force maximum energy efficiency of the process, when the tensile stress is applied to the ends of the strip

, (2)

where β - Lode coefficient (β = 1.15); k_q - coefficient taking into account the influence of the features of the cold-rolling practice at a particular mill on the back relative tension level (determined experimentally).

Since the back relative specific tension (q_0/σ_{F0}) in each stand is numerically equal to the front relative specific tension ($q_1/\beta\sigma_{F1}$) in the previous stand, it is obvious that the dependence (2) allows us to calculate the tension mode for any stand and the whole continuous mill of cold rolling.

According to our data the k_q coefficient values are in the range from 0.1 to 0.25 (k_q = 0.1–0.25). The analysis of dependence (2) shows that the back relative tension level should increase with the thickness (h_0) and the reduction of cross-sectional area (ε) of the strip decreasing as well as the total reduction of cross-sectional area (ε_Σ), the working rolls radius (R) and the friction ratio (f) increasing to improve the energy efficiency of the cold rolling process with tension. It means that the interstand relative tensions level (q/σ_F) in the line of cold rolling continuous mill should increase from the first to the last interstand space to reduce the specific consumption of electric energy.

The comparative calculations of energy-power and temperature and high-velocity parameters for the existing and calculated according to the dependence (2) tension modes on cold rolling continuous mills at 1400 and 1700 «Arselor Mittal Timirtau» (Temirtau, Kazakhstan) and at 1680 JSC "Zaporizhstal" (Zaporizhia, Ukraine) were performed to obtain quantitative data on the implementation benefits of proposed design principle of tensions modes. The calculation is based on a well proven technique [6], taking into account the cooperative effect of the strip material hardening, rolls and strip elastic flows, friction ratio, tension and temperature and high-velocity deformation conditions at cold rolling. The drafting schedule as well as the delivery speed and relative specific strip tensions q_r/σ_F (where q_r - absolute specific tension on the reel) remained unchanged at the output of the mill during comparative calculations. The comparative calculations determined: the strip temperature t_{1S} and speed V_1 at the output of each stand, friction ratio *f*, the length of the elastic-plastic deformation zone l_w, the average contact normal voltage p_{avw}, forward flow S_w, force P_w, mill torque M_w at each stand, the drive motor power N_m of each stand, and technically possible hour productivity of the mill A (subscript "w" means that the variable is calculated with the influence of rolls and strip elastic flow). Knowing the total power consumption of all mill stands motors ΣN_m, the specific consumption of electric energy during cold rolling a ($a = N_m/A$) was calculated under the existing a_{ex} and proposed a_{prop} tensions modes, as well as the relative decrease of the electric energy specific consumption Δa when implementing the proposed tensions mode

($\Delta a = \dfrac{a_{prop} - a_{ex}}{a_{ex}}$, %).

The calculation results are presented in Table 2, 3

Table 2[*] The existing (numerator) and proposed (denominator) flow modes on cold rolling continuous mills 1400, 1700 and 1680

1. The sheet metal rolling 0.18x855 mm from the semifinished rolled stock 2.4x855 mm on the six-mills stand at 1400

[steel 08kp; $\sigma_F = 260+34.6(100\varepsilon)^{0.6}$; R = 300 mm; $t_{0S} = 40$ C; $t_c = 40$ C; $q_r/\sigma_F = 0.071$; $k_q = 0.175$]

№ q-ty	h_0, mm	ε	ε_Σ	q_0/σ_{F0}	t_{0R}, °C	f	t_{1S}, °C	l_w, mm	p_{avw}, N/mm^2	V_1, m/s	S_w, %	P_w, MN	M_w, kN·m	N_m, kW
1	2.40	0.140	0.140	0.089 0.089	40	0,087	55 55	12.69 12.72	486 491	2.86	3.78 3.63	5.27 5.34	-17.36 -13.40	-92 -54

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[*] $t_{0П}$, $t_{0В}$, $t_{охл}$ – соответственно температура исходного подката, среднемассовая температура рабочих валков и температура охлаждающей жидкости

[*] t_{0S}, t_{0R}, t_c – respectively, the initial semifinished rolled stock temperature, avarage working rolls temperature and coolant temperature

2	2.06	0.400	0.484	0.342 0.324	44	0,073	110 108	18.67 18.54	654 637	4.77	5.28 6.29	10.44 10.10	162.39 139.70	2723 2345
3	1.24	0.414	0.698	0.238 0.343	48	0,049	160 151	15.66 15.25	794 698	8.14	5.45 5,07	10.63 9.09	118.33 108.55	3493 3189
4	0.73	0.400	0.819	0.223 0.360	52	0,048	197 183	12.89 12.36	902 773	13.56	7.55 6.61	9.94 8.17	74.23 71.35	3777 3574
5	0.44	0.330	0.878	0.266 0.375	56	0,058	215 197	10.98 10.13	1069 889	20.24	7.20 7.09	10.04 7.70	49.84 42.24	4097 3398
6	0.29	0.380	0.925	0.209 0.378	65	0,041	235 216	11.04 10.32	1266 1104	32.64	8.77 7.54	11.95 9.74	44.71 45.96	6272 6138

2. The strip rolling 0.5x1015 mm from the semifinished rolled stock 2.5x1015 mm on the fine-mills Stand at 1700

[steel 08kp; $\sigma_F = 300+34.6(100\varepsilon)^{0.6}$; R = 300 mm; $t_{0S} = 40$ C; $t_c = 40$ C; $q_r/\sigma_F = 0.059$; $k_q = 0.175$]

№ q-ty	h_0, mm	ε	ε_Σ	q_0/σ_{F0}	$t_{0R,}$ °C	f	t_{1S}, °C	l_w, mm	p_{avw}, N/mm^2	V_1, m/s	S_w, %	P_w, MN	M_w, kN·m	N_m, kW
1	2.50	0.260	0.260	0.038 0.038	64	0.111	83 84	17.17 17.23	674 684	2.82	6.35 6.16	11.75 11.96	51.07 60.03	648 737
2	1.85	0.292	0.476	0.365 0.334	62	0.072	119 119	16.09 15.88	709 682	3.70	3.14 4.30	11.59 11.00	167.37 125.38	2547 1933
3	1.31	0.313	0.640	0.176 0.345	60	0.070	156 154	15.03 14.41	905 766	5.38	5.44 5.17	13.80 11.21	124.55 113.04	2847 2551

4	0.90	0.278	0.740	0.179 0.358	54	0.068	182 177	12.94 12.17	978 815	7.46	5.16 4.94	12.84 10.07	84.38 76.01	2812 2477
5	0.65	0.230	0.800	0.183 0.370	51	0.092	209 203	12.41 11.82	1242 1114	9.69	4.52 4.06	15.66 13.36	77.41 88.60	3569 3864

3. The strip rolling 0.8x1000 mm from the semifinished rolled stock 2.5x1000 мм 5x1015 mm on the four-mills stand at 1680

[steel 08kp; σ_F = 260+34.6(100ε)$^{0.6}$; R_{work} = 250 mm; t_{0S} = 40 C; t_c = 40 C q_r/σ_F = 0.062; k_q = 0.200]

№ q-ty	h_0, mm	ε	ε_Σ	q_0/σ_{F0}	t_{0R}, °C	f	t_{1S}, °C	l_w, mm	p_{avw}, N/mm^2	V_1, m/s	S_w, %	P_w, MN	M_w, kN·m	N_m, kW
1	2.70	0.388	0.388	0.159 0.159	75	0.115	98 98	18.88 18.82	637 626	3.15	9.40 9.73	12.02 11.78	109.50 100.27	1438 1324
2	1.65	0.260	0.547	0.355 0.390	65	0.056	122 122	12.55 12.43	580 551	4.25	2.43 2.49	7.28 6.85	74.63 70.12	1456 1367
3	1.22	0.262	0.666	0.351 0.403	60	0.055	144 142	11.34 11.18	623 582	5.76	3.00 2.89	7.07 6.50	61.85 59.39	1622 1551
4	0.90	0.111	0.703	0.363 0.423	55	0.081	150 147	8.54 8.41	715 681	6.48	0.74 0.55	6.11 5.73	60.86 67.64	1741 1907

Table 3 The total capacity ΣN_m of drive motors and the specific energy consumption a_{ex} of the existing (the numerator) and proposed (denominator) rolling modes

Mode of continuous rolling	Parameter

	A, t/h	ΣN_m, kW	a_{ex}, kW·h/t	Δa_{ex}, %
Mode 1. The sheet metal rolling 0.18x855 mm from the semifinished rolled stock 2.4x855 mm on the six-mills star 1400	112	20270 18590	180.98 165.98	8.29
Mode 2. The strip rolling 0.5x1015 mm from the semifinished rolled stock 2.5x1015 mm on the fine-mills stand 1700	139	12424 11562	89.40 83.18	6.93
Mode 3. The strip rolling 0.8x1000 mm from the semifinished rolled stock 2.5x1000 мм 5x1015 mm on the four-mills stand 1680	101	6257 6148	61.95 60.87	1.73

Table 2 shows that the proposed tensions modes imply a sizeable (1.1-1.5 times), and on the last three mill stands at 1700 and on the last mill stand at 1400 almost a doubling increase of interstand relative specific tensions (q/σ_F), and their maximum come up to 0,35-0,42. As a result, the contact normal rolling voltage and forces of tension respectively decreased by 2-17%, 2-23%, and the specific consumption of electric energy by 1.73-8.29% (Table 2). In this case cold rolling process stability did not substantially deteriorate, as evidenced by the high forward flow values for all mill stands at 1400, 1700 and 1680.

The data in Table 2 and 3 show that the greatest reduction of the electric energy specific consumption is fixed on the six-mills stand at 1400 during the rolling of 0.18 mm thickness sheet metal, i.e. during the cold rolling of a thinner strip (R/h_0 = 1667) with a large total relative reduction of cross-sectional area (ε_Σ = 0,925). It confirms the validity of the theoretical conclusions about the inlet feasibility of thin strips rolling with large relative specific tensions to improve energy efficiency of the process. The reduction of electric energy specific consumption during the cold rolling of sheet metal thin strips by improving the tension modes can reach 7-10% or more, which is essential. The increase in relative specific tensions and tensions modes optimization provide the reduction of specific energy consumption by about 2-6% during the cold rolling of thicker (0.3-0.8 mm) strips. The ability to reduce the specific energy consumption by applying the modes with higher specific tensions is confirmed experimentally on the stand at 2030 "NMC" (Novolipetskyi Metallurgical Complex). For example, the reduction of specific energy consumption by 5.7% was recorded by increasing the level of relative specific tensions with 0.2-0.24σ_F N/mm^2 up to 0.27-0.30σ_F during the rolling of the 2.5 mm → 0.57 mm x 1252 strip of steel 08ps.

From the above it follows that the the electrical energy specific consumption can be reduced by an average of 2-15 kW·h/t only due to the improvement of tension modes on continuous mills, mainly by the increase of the relative specific tensions level during the continuous cold rolling of sheet metal and thick strips up to 0.5-0.8 mm. Implementation of the engineering solution will allow to reduce the cost value of flat cold-rolled mill products not less than by 1.5-15 UAH/t.

Conclusions

1. Earlier [4] we found that cold rolling with tension is an energetically more efficient process than rolling without tension. Hence, the energy efficiency of applied tensions modes should be considered in the development of deformation modes on continuous mills.

2. The new principle of relative specific tensions on cold rolling continuous mills distribution, providing the energy efficiency increase of the process and the mathematical model for its implementation have been introduced. In accordance with this principle, the relative specific tensions of on cold rolling continuous mills should be increased from the first to the last interstand space.

3. The calculations results of the power parameters on continuous mills at 1400, 1700 and 1680 have shown that the specific consumption of electric energy during cold rolling reduces by 2-8%, or 2-15 kW • h/t only by the implementation of the tensions modes, calculated in accordance with the new principle of distribution. In addition, it was found that the energy efficiency of the cold rolling process increases with the total reduction of cross-sectional area increase and the thickness of rolled strip decrease.

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