The Study of Influence of Technology Factors and Equipment Design Parameters on Energy Consumption taking into Account Stochasticity of the Cold Rolling Process

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Abstract. Capabilities of simulation of the cold rolling process taking into account unsteadiness and stochasticity of its parameters are demonstrated. The analysis of the results of simulation of rolling power parameters with the decrease of the work roll diameter is carried out. An example of search for the most power efficient technology using a dynamic model is provided.

1. Introduction

Implementation of energy efficient technologies of thin steel strips rolling is of high importance for the increase of competitive ability of existing production facilities, and for the reduction of resource intensity and energy intensity of steel production. A significant aspect is the accelerated performance and implementation of inventions along with high reliability of the results, which requires improvement of methods of the technology parameters mathematical simulation considering equipment design parameters.

A method based on a deterministic description of the cold rolling process without taking into account process unsteadiness and stochasticity is widely used in practice of flat rolled products manufacturing [1 – 6].

Further, the overall development of the sheet steel rolling technology together with the stability of the process technology requires consideration of correlation of dynamic processes taking place in the driving line of the rolling stand, the roll set, and the deformation zone.

2. Model description

As shown in the paper [7], the following elements of the continuous rolling mill system shall be considered: plastic-deformation zones, hydraulic screw downs (HSD), and electromechanical systems (EMS) of stands, including automated electrical drives, mechanical transmissions, and work stands themselves (Figure 1). The following designations are accepted on Figure 1: u_i is the voltage at the motor's armature; ω_{ri} is the angular velocity of rotation of the work roll; M_{ri} is the torque required for the rolling process; v_{i-1}, v_i are the strip speeds at the exit from the $(i\text{-}1)^{\text{th}}$ and the ith stands; h_{i-1}, h_i are the strip thicknesses at the exit from the $(i\text{-}1)^{\text{th}}$ and the ith stands; N_{i-1}, N_i are the strip tension forces; P_i is the rolling force in a stand; g_i is the gap between work rolls; σ_{di-1}, σ_{di} are the strip deformation resistances in the $(i\text{-}1)^{\text{th}}$ and the ith stands; S_i is the lead factor.

The input coordinates of the electromechanical system are the voltages applied to armatures of electric motors of work stands, and the torque required for the rolling process; the output coordinate is the angular velocity of rotation of work rolls. In order to take into account influence of transient
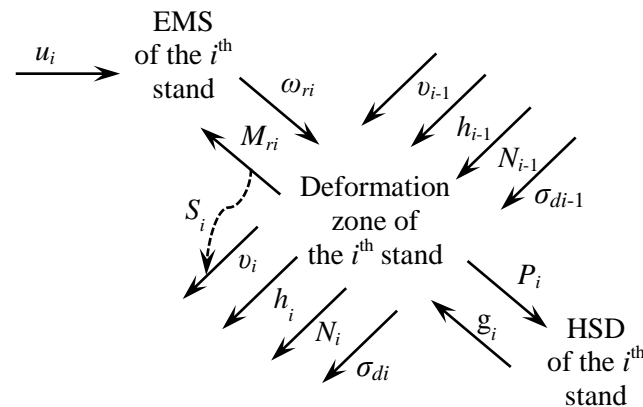

Figure 1. A Diagram of the Model of the Cold Rolling
Process in the ith Stand of the Continuous Mill.

phenomena taking place in electric motors on the nature of dynamic loading in the electromechanical system of the stand, a description of a DC motor with independent excitation is introduced.

The deformation zone in the system of interaction of the strip with the work stand contains six input coordinates and six output coordinates. A mathematical description of the deformation zone of the ith work stand is based on the diagram where a strip is regarded as a thin elastoplastic body, and rolls are regarded as massive elastic bodies. Its detailed characteristic is provided in papers [8 – 10]. The impact upon the motor voltage is transferred to the entrance of the deformation zone through the speed of the rolls with the torque feedback.

All coordinates specified on Figure 1 are set considering the dynamics of the cold rolling process and stochasticity of its parameters. Parameters of the strip state like thickness, yield strength, factors of strengthening because of variations of heat chemical compositions are random values, which distribution is determined by the statistical simulation modelling.

When controlling strip thickness according to the Golovin-Sims method [11] the correlation between the deformation zone and the hydraulic screw down is performed through the rolling force and the roll gap. The gap is an input variable allowing to take into account external disturbances, e.g. the roll body whipping or controlling actions. A mathematical model of the hydraulic screw down coordinates control is described by the equations presented in the paper [7].

3. Results and analysis

The study of influence of technology parameters and design parameters of the revamped four-stand cold rolling mill of PAO Severstal on energy consumption was performed based on the developed dynamic model.

Design parameters of the roll set of the four-stand mill were changed by the renovation as follows: the diameter of work rolls was reduced by 20 mm, the diameter of back-up rolls was reduced by 50 mm, the length of the work roll body was increased by 420 mm, and the length of the back-up roll body was increased by 150 mm.

According to some studies [11 – 13], reduction of the work roll body diameter decreases capital expenditures and power consumption, however, reduction of the back-up roll diameter along with the increase of roll bodies has an adverse effect on rigidity of the roll system, and consequently, the accuracy of rolled strip with respect to off gauge and non-flatness is reduced. When studying design

parameters, a minimal diameter of work rolls of the renovated mill equal to 420 mm was taken as a basic case, and the diameter of work rolls equal to 350 mm with the possibility to increase the diameter of back-up rolls to save dimensions of the housing window was taken as an alternative case. This solution can provide the increase of rigidity of the roll set and the decrease of the vertical deflection of work rolls. A further decrease of the work roll diameter would require changes of the neck diameter of work rolls and back-up rolls that means that it would not allow using the existing bearings and chocks of the rolls, and would result in significant growth of the shear stress from transmitted torques.

The rolling mode of the 08ps ("08пс" in Russian) steel strip with the width of 1,850 mm, and the thickness of 0.9 mm from a work piece with the thickness of 3.2 mm, offered by a supplier of the renovated Mill 2100 equipment, which setting parameters are given in Table 1, was chosen for the study.

Table 1. Process Parameters of the Cold Rolling Mode for the Strip with the Thickness of 0.9 mm, and with the Width of 1,850 mm on the Four-Stand Mill 2100 of PAO Severstal.

Stand No.	v_i (m/s)	h_{i-1} (mm)	h_i (mm)	ε_i (%)	N_{i-1} (kN)	N_i (kN)
1	8.27	3.2	1.995	37.66	20	75
2	12.2	1.995	1.35	32.33	75	95
3	17.6	1.35	0.937	30.59	95	100
4	18.3	0.937	0.9	3.95	100	35

ε_i is the individual relative strip reduction in the ith stand.

Calculated distributions of power parameters of the strip rolling process are provided in Table 2. According to the received data, the reduction of the work roll diameter results in the decrease of all power parameters and their variations. The reduction of the work roll diameter provides the decrease of the steel stress in the deformation zone because of the smaller length of the contact arc. When the work roll diameter is decreased from 420 mm to 350 mm, the rolling power is decreased by 10%. The comparison of distribution of the rolling process parameters suggests that the greater stability of power parameters of the rolling process is achieved with the decrease of the work roll diameter.

Table 2. Power Parameters of the Strip Rolling Process.
(Numerators are $D_p = 420$ mm, and Denominators are $D_p = 350$ mm).

Parameter	Stands			
	No. 1	No. 2	No. 3	No. 4
$\overline{P}$ (MN)	15.69 / 14.01	14.82 / 13.17	15.52 / 11.99	9.96 / 8.10
S_P (MN)	0.76 / 0.68	0.62 / 0.52	0.57 / 0.47	0.98 / 0.53
$\overline{N}$ (kW)	5,844 / 5,222	8,300 / 7,379	9,136 / 8,712	3,040 / 3,038
S_N (kW)	233 / 209	237 / 211	261 / 249	122 / 120

$\overline{P}$, $\overline{N}$ are average values of rolling forces and power; S_P, S_N are standard deviations of rolling forces and power.

The study of efficiency of strip rolling modes taking into account variations of the parameters starts with the procedure of simulation of yield strength and thickness values for each point of the work

piece out of the user-set points. The simulation process is implemented using the procedure of generation of the random number according to the normal distribution law with the standard deviation of 10% for the yield strength, and 2% for the strip thickness. Reductions and interstand tensions range with account for restrictions on power and kinematic parameters; the rolling speed is recalculated on the basis of the law of volume constancy per second. After calculation according to the model, arrays of values characterizing the strip state and the rolling process parameters, which are estimated according to selected indices, are formed.

The values of reduction and tension for two process modes of rolling of the strip with the dimensions of 0.4×1,850 mm made of 08ps ("08пс" in Russian) steel are given in Tables 3 and 4 as an example of the methodology stated. In Case 1, reduction and tension are suggested by the equipment supplier, and in Case 2, the process parameters are determined by the simulation modelling of the rolling process. In both cases, the work piece thickness was 1.9 mm, and the original yield strength was 265 MPa, the rolling speed was 25 m/s.

Table 3. Reduction Modes.

Case No.	Individual Relative Reductions in Stands (%)			
	No. 1	No. 2	No. 3	No. 4
1	37	38	36	15
2	39	35	40	11

Table 4. Modes of Specific Tensions Broken down by Interstand Spaces.

Case No.	Specific Tension (MPa)				
	Before Stand 1	Space 1	Space 2	Space 3	After Stand 4
1	70	180	200	220	42
2	70	160	220	235	42

The tables suggest that in Case 2 the reduction is redistributed between stands — relative reductions in stands 2 and 4 were reduced, and in stands 1 and 3, on the contrary, increased, together with the growth of specific tensions in the 2nd and 3rd spaces and the decrease in the 1st space. The comparison of values of total power of the rolling mill motors (Figure 2) demonstrates that power reduction amounted to 1.17 MW during rolling according to the developed mode that means that expenses for the process technology are reduced by 5%.
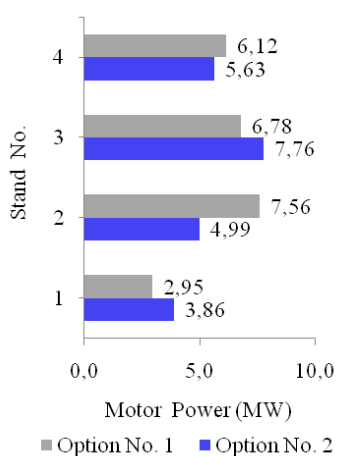

Figure 2. Comparison of Total Power of Rolling Mill Motors.

4. Conclusions

This paper presents rolling modes providing reduction of energy consumption due to correction of process parameters, and the results of the study of influence of the work roll diameter decrease on rolling force and power, received through the use of the dynamic model of the cold rolling process, which takes into account unsteadiness and stochasticity of its parameters.

The simulation results can be used for solving various tasks on optimization of design parameters of the rolling equipment and development of energy efficient production technologies of thin wide cold rolled strips.

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