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EVALUATION OF POWER LOSSES DURING STOCHASTIC CHANGES IN THE CURRENT OF THE MAIN DRIVES OF COLD ROLLING MILLS

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This paper presents the analysis of the adverse impact of the current oscillations on electric power losses in the manufacture of flat rolled products. The results of mathematical processing of experimental data for the study of the influence of transient processes in the cold rolling mill electromechanical systems on the rate of power losses during rolling are discussed. The negative effect caused by power losses has been evaluated and focus areas to reduce the operational costs have been identified. In addition, technical measures aimed at minimizing oscillation processes during rolling have been proposed.

Kew words: cold rolling mill, electromechanical system, current oscillations, electric power losses, energy efficiency of the rolling process

INTRODUCTION

Generally, electromechanical systems (EMS) – electric drive systems which include a power converter, an electric motor, a mechanical transmission and an actuator - are among the most efficient tools to control industrial plant process variables which are directly linked to the quality and quantity of manufactured products.

When automatic electric drives are operated in real manufacturing environment of flat product mills, forced stochastic oscillations of the current occur due to nonstationary and unstable nature of the process variables. Deviation of the current is influenced by various control actions in complex drive systems, oscillations of multimass systems, take-up of backlashes in mechanical transmissions, etc. High surges of the armature current of main drives have an adverse effect on the rolling process energy efficiency, since they cause additional losses of electric power and reduce reliability and efficiency of electrical equipment, which results in lower quality and higher production cost of manufactured products.

Chatter in the rolling mill stands has a considerable influence on the transient current behavior in the electric drives of the stands. It is the chatter that hinders the increase in production of flat products at continuous cold rolling mills. To go away from resonance vibrations rolling speed has to be reduced, which causes dynamic deviations of the current.

As stated in papers [1, 2], one of the possible ways of eliminating the adverse effect of the current deviations is to improve performance of the control system for automatic main electric drives of roll stands and to optimize drive regulator adjustment on the criteria of quality of transient processes and energy saving in steady and transient states.

This paper focuses on the study of the influence of transient processes in the electromechanical systems of cold rolling mills on power and electric power losses during rolling.

The current tendency towards improvement of the continuous cold rolling mill control performance calls for the use of control systems that would match the controlled objects in terms of their complexity. In this regard, the use of EMS automated control systems (EMS ACS) with standard control modes for systems with non-rigid mechanics, for highly dynamic electric drives with nonstationary loading is low efficient [3]. For example, when a standard speed PI controller is used in the subordinate control system for the electric drive of one of the rolls of the wide-strip rolling mill, there occur high-speed dynamic armature current deviations reaching 80 – 100 % of the average value (Figure 1). That is, the existing automated control systems for electric drives of rolling mills are not able to eliminate such negative phenomena if standard control modes are used.

Higher requirements to the performance of the control process for continuous rolling mills under conditions of parametrical instability of such mills bring about the need to take into account more subtle phenomena of the mill operation, which, in its turn, leads to emergence of additional complexity factors and, therefore, calls for the use of higher-order control systems and more complex procedures for their design. Inertia-free and dynamic state controllers designed with the use of modal control technique [4, 5] have shown good results in solving such tasks. However, changing conditions of nonstationary dynamic loading during rolling may cause significant deviations of the EMS internal

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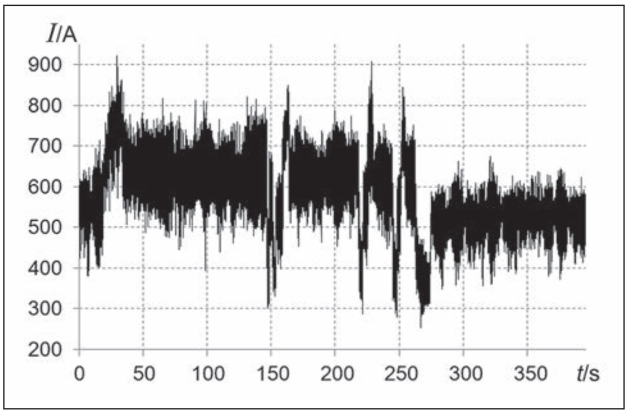

Figure 1 Graph representing the armature current variations for the motor of the work roll of the wide-strip rolling mill

parameters from the calculated values taken for design of state controllers and lead to substantial decline in the efficiency of the entire process automation system. In the light of the above, in addition to conventional quality indices (accuracy, fast response, resistance to interference, etc.) of great importance becomes achievement of low parametric sensitivity of the EMS being developed, i.e. maintaining their operability, as well as key performance indicators in case of variations in the parameters of the controlled object.

EXPERIMENTAL PART

To calculate the power loss as a result of oscillation processes during the armature current ripples, it is necessary to determine a statistical root-mean-square deviation from the average current characterizing the performance of electric drives of roll stands. Then power loss variations will be:

$$\Delta W(t) = R(I(t) - I_S)^2 \tag{1}$$

where R – resistance of the work roll electric drive armature circuit / Ω; I – discrete sample of the current consumed for useful work / A; I_S – root-mean-square deviation of the current / A; t – time of discrete sampling / s.

Functions of *ibaAnalyser* environment were used to carry out statistical analysis of the performance of electric drives of the work rolls. During rolling of automotive grade steel coils at the 5-stand mill 1700 at the steel plant of PAO Severstal, a discrete sample of the armature currents of the electric drives of the top and bottom rolls of stands No. 1 – 5 was taken and analyzed.

Specifications and process characteristics of the equipment:

- electric motor of the work roll drive: double armature motor, series 2P2-19/60-4UKhL3.2x2 000 kWh, 930 V, 175/400 rpm, 2x2 300 A, CDF = 100 % total armature circuit resistance R_Σ = 2x0,02415 Ω;
- thyristor converter package: KPptK –1,000/1,250-2x6 900/2x3-450-2/1, 1 250 V, 6 900 A;
- a batch of 9 automotive grade steel coils: width – 1,315 m, thickness – 1 mm, weight – 16 – 24 t, average coiling time – 441 s;
- discreteness of the whole sample: 3 600 s with an interval of 0.01 s.

RESULTS AND DISCUSSION

Average level of the armature current oscillations in the main drives of the roll stands is 200 – 330 A at constant rolling speed. This is illustrated by Figure 2 showing the parts of oscillographs of the currents in the electric drives of the work rolls in stand No. 1 during rolling at the operational speed. During acceleration of the rolls to the operational speed, surges of the motor armature currents may reach 1 000 A.

Statistical values of the armature currents for all rolls of the stands are given in Table 1.

Formula (1) was used to calculate power losses in the elements of the power part of the electric drives.

The calculated curves for power losses are given in Figure 3 for illustrative purposes. These curves were built based on the Figure 2 data obtained directly from the rolling mill. Root-mean-square deviations of the current I_S were taken from Table 1. As can be seen from the graphs in Figure 3, the power loss rate in the steady-state process is 0,8 – 1,7 % of the average power consumption.

It is found that during acceleration and deceleration of rolls, with consideration of dynamic deviation of the current, power losses may reach 1,6 – 2,9 % of the average power consumption.

The results of calculation of the average power losses during rolling of nine coils and electric power losses during production of one ton of automotive grade steel with regard to the stochastic nature of the armature cur-

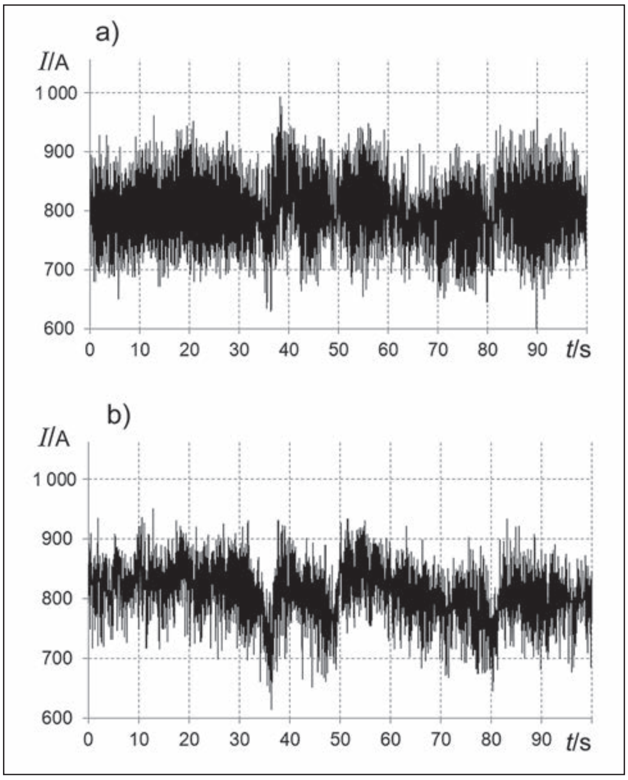

Figure 2 Oscillographs of the armature current in the electric drives of the top (a) and bottom (b) work rolls in stand No. 1

Table 1 **Statistical performance data for the electric drive armature circuits**

Stand No.	Work roll	Motor armature current, A			
		Minimum	Maximum	Average value	Root-mean-square deviation
1	Top	0	1 404,95	798,166	259,050
	Bottom		1 445,60	812,882	264,067
2	Top		2 163,53	1 110,307	331,111
	Bottom		2 106,01	1 159,133	399,682
3	Top		2 477,78	1 434,906	463,637
	Bottom		2 541,75	1 414,569	457,541
4	Top		2,792.35	1 449,977	514,500
	Bottom		2 752,97	1 442,227	499,464
5	Top		1 364,18	736,689	288,610
	Bottom		1 374,50	747,555	277,858

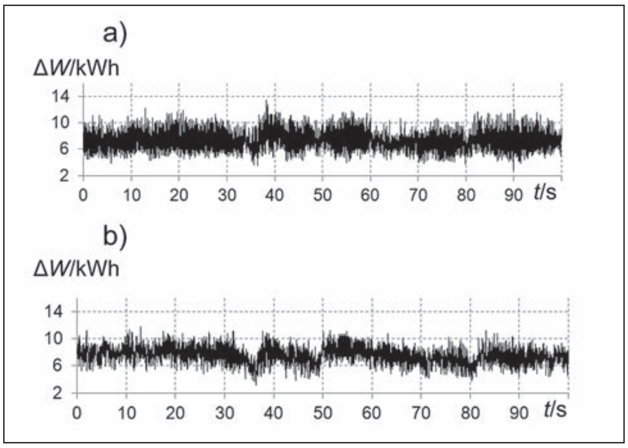

Figure 3 Graphs showing variations in power losses in the armatures of the motors of the top (a) and bottom (b) work rolls of stand No. 1

rent oscillations in the electromechanical systems of the continuous cold rolling mill are given in Table 2. Having analyzed these data, we can state that electric power losses without efficient suppression of the armature current ripples in the main drives of the roll stands average 1,5 kWh per ton of steel. Introducing high-speed ACS based on modern intelligent information technologies will make it possible to save 2,4 mln. kWh per year for the cold rolling mill design capacity of 1,6 mln. t. Taking into account electricity prices in Europe, saving in money terms is expected to be no less than 500 000 US dollars per year.

CONCLUSION

Statistical analysis and calculation of power and electric power losses with consideration for the current oscillations in the main drives of the continuous rolling mill stands was performed.

Costs related to power losses at the 5-stand mill 1700 at Cherepovets steel mill of PAO Severstal were estimated.

The developed method for calculation of electric power losses may help the rolling process specialists address challenges related to energy efficiency and stability of the rolling process.

Table 2 **Energy performance of the electric drive armature circuits**

Stand No.	Work roll	Power losses / kWh	Specific electric power losses / kWh/t
1	Top	13,6762	0,0666
	Bottom	14,2111	0,0692
2	Top	22,3432	0,1088
	Bottom	32,5558	0,1585
3	Top	43,8081	0,2133
	Bottom	42,6637	0,2078
4	Top	53,9473	0,2627
	Bottom	50,8402	0,2476
5	Top	16,9755	0,0827
	Bottom	15,7342	0,0766
Total:		306,7553	1,4939

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List of symbols, abbreviations and acronyms

R – resistance of the work roll electric drive armature circuit, Ω;
I – discrete sample of the current consumed for useful work, A;
I_S – root-mean-square deviation of the current, A;
t – time of discrete sampling, s;
ΔW – power loss, kWh;
EMS – electromechanical system;
ACS – automated control system.

Note: The person responsible for the translation of the paper into the English language is Natalia Skrobot, Cherepovets, Russia.