ABSTRACT

dissertation for the degree of Doctor of Philosophy (PhD)
specialty 6D071800 – «Electric power engineering»

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DEVELOPMENT OF METHODS FOR REDUCING THE IMPACT OF POWER SUPPLY NETWORKS ON THE CHARACTERISTICS OF AN INTERCONNECTED ELECTRIC DRIVE OF HOT ROLLING MILLS

Relevance of the work.

A modern hot rolling mill is a complex multi-coupled multi-motor electromechanical system. The quality of the finished product of a hot rolling mill is determined mainly by the accuracy of the electric drives of the finishing group of the rolling mill, which contain elastic connections of various kinds in the mechanical part. However, due to the significant installed power of the equipment, there is objectively an electromagnetic relationship between the electric drives of the roughing and finishing groups through the power supply network. The electromagnetic interaction of electric drives of the roughing and finishing groups is associated with the use of standard design solutions for power supply systems of rolling mills, which provide for the operation of electrical equipment from two power transformers. With such a power supply scheme, shock loads of synchronous electric drives of the roughing group lead to significant differences in the quality of electricity of the power sources of individual elements of the finishing group of the rolling mill.

The influence of electromagnetic coupling through the supply network of electric drives of a hot rolling mill, in contrast to the influence of elastic connections in the mechanical part of the rolling mill, is practically not taken into account when developing control systems for electric drives of the finishing group, which also negatively affects the quality of the finished product of the rolling mill.

Therefore, the problem of quantitative assessment of the influence of the power supply network of the main drives of hot rolling mill stands on the quality of finished products, the quality of electricity in the power supply network of a rolling mill, the development of methods for reducing such influence on the characteristics of interconnected electric drives of hot rolling mills is an important and urgent task, the solution of which will have a comprehensive positive effect influence on various aspects of the functioning of electrical equipment of a hot rolling mill and the quality of products.

The purpose of the dissertation work is to develop methods for limiting the influence of power supply networks on the characteristics of the interconnected electric drive of hot rolling mills.

The object of study in the work is the power supply network and the interconnected electric drive of a continuous wide-band hot rolling mill.

The idea of the study is to study the main electric drives of a rolling mill electromagnetically connected through the power supply network, to establish the nature and numerical characteristics of the influence of the power supply network on

the operation of the main electric drives of hot rolling mills, to develop methods for reducing the influence of the power supply network on the operation of interconnected electric drives of hot rolling mills by developing methods and devices control of forced excitation of the main electric drives of hot rolling mills.

Tasks to be solved to achieve the goal:

– analyze the influence of power supply networks of hot rolling mills on the operation of interconnected electric drives of a hot rolling mill under shock load conditions;

– carry out experimental studies of the quality of voltage on the busbars of the substation that supplies the interconnected main electric drives of the hot rolling mill

– analyze the influence of rolling technological parameters (steel grade, billet temperature) on the characteristics of shock loads of electric drives of the roughing group;

– develop a mathematical model of the electromechanical system of the main electric drives of a hot rolling mill, taking into account the influence of the elasticity of the metal strip in the interstand space;

– carry out experimental studies of a hot rolling mill using a mathematical model;

– develop methods to compensate for the influence of synchronous electric drives of the roughing group on the stability of the electric drive of the finishing group;

– to develop the structure of the control system for the electric drive of the finishing stand of hot rolling mills, which allows minimizing the influence of voltage dips in the power supply network.

Scientific novelty:

– the theory of interconnected electric drives of rolling production was further developed in terms of substantiating the significant influence of the electromagnetic interconnection between the main electric drives of hot rolling mills through the power supply network;

– for the first time it was established that the minimum value of the voltage drop of the supply network and the minimum value of the relative elongation of the metal in the interstand gap when applying a shock load is achieved with an exact coincidence of the moments of application of the shock load and the supply of forced excitation of the synchronous motor of the roughing group of the rolling mill, which makes it possible to ensure an increase in the quality of the finished product products;

– for the first time it was established that the dependence of the relative elongation of the metal in the interstand gap on the excitation boost value of the synchronous motor of the roughing group of a rolling mill when an impact load is applied is extreme and has a pronounced minimum, which makes it possible to determine the optimal settings of the synchronous motor boost control system.

– the structure of the control system for the electric drive of the finishing stand of hot rolling mills has been proposed, taking into account the parameters of the power supply network, which allows minimizing voltage dips in the power supply network.

Main provisions and research results submitted for defense:

− mathematical and simulation models of interconnected main electric drives of a hot rolling mill, taking into account both the electromagnetic connection of groups of electric drives through the power supply network and the elasticity of the metal strip in the interstand space;

− methods to minimize the influence of power supply networks on the characteristics of the interconnected electric drive of hot rolling mills under conditions of limited power;

− results of regression analysis of experimental studies, which make it possible to parameterize the control system for forcing the excitation of a synchronous electric motor of a roughing group when a shock load is applied.

Research methods. The scientific and practical results of the dissertation work were obtained on the basis of complex methods of searching and processing information, setting up and planning an experiment, statistical data processing, probability theory and simulation modeling using the basic scientific principles of the theory of electrical circuits and electrical engineering, the theory of electric drives, and the theory of automatic control widely used in studies of complex physical processes in electric drives of rolling production.

Experimental data were obtained directly at the wide-band hot rolling mill 1700 of sheet rolling shop №1 of JSC «ArcelorMittal Temirtau» (currently JSC «Qarmet») using the Resurs-UF2M electrical energy quality indicators measuring device certified in the territory of the Republic of Kazakhstan.

Mathematical modeling was performed in the Matlab/Simulink application package using the SimPower Systems library. Analysis and processing of experimental data was carried out in the Matlab Simulink application package and in Microsoft Excel. Regression analysis of the results of mathematical modeling was performed in the STATGRAHICS program.

Practical significance of the results obtained:

− the developed mathematical model of a system of electrically interconnected electric drives of the roughing and finishing groups of a rolling mill made it possible to establish numerical characteristics of the influence of shock loads of the roughing group on the quality indicators of the supply network voltage and the stability of the angular speed of the electric drives of the finishing group;

− the proposed method of compensating the influence of synchronous electric drives of the roughing group on the stability of the electric drive of the finishing group made it possible to increase the stability of the electric drive of the finishing group and improve the operating conditions of the hot rolling mill as a whole;

− regression equations were obtained for the dependences of the voltage drop of the supply network and the stability of the angular velocity on factors influencing, through the elasticity of the strip.

The results of the theoretical and experimental research carried out were introduced into the educational process of Non-profit Joint Stock Company «Karaganda Industrial University» (Temirtau) at the Department of «Energy» of the Faculty of Energy, Transport and Control Systems and are used in the preparation of bachelors students in educational programs: 6B07105 «Energy supply of industrial facilities» and 6B07106 «Engineering of automation systems»; masters students in

educational programs: 7M07112 «Electric power engineering» (scientific and pedagogical direction) and 7M07112 «Electric power engineering» (profile direction).

The results of scientific research and development will be used in the automatic control system for electric drives of the stands of the roughing and finishing groups of the hot rolling mill of the sheet rolling shop №1 of JSC «ArcelorMittal Temirtau»; in the technological complex «supply network - electric drives of the roughing and finishing groups» of the hot rolling mill of the sheet rolling shop №1 of JSC «ArcelorMittal Temirtau», which is confirmed by the minutes of the production meeting dated September 13, 2023.

The justification and reliability of scientific statements, results and conclusions is due to the use of proven methods and techniques for experiment planning, electric drive theory, simulation modeling using proven application packages Matlab/Simulink and STATGRAHICS.

The main scientific principles, research results and conclusions were confirmed based on a thorough analysis of the collected materials from analytical studies, results of simulation modeling and industrial experiments; published in the scientific literature included in the Scopus and CQASSHE databases, and are consistent with the results of other authors published previously.

All the main conclusions presented in the dissertation are justified and based on recognized methodological research approaches, on the analysis and evaluation of numerous scientific sources of literature, which confirms the scientific reliability and validity of the study.

Approbation of work. The main materials and results of the dissertation work were reported and discussed:

− at the scientific and technical council of the Non-profit Joint Stock Company «Karaganda Technical University named after Abylkas Saginov»;

− on the scientific and technical council of the department «Automation of Production Processes» of the Non-profit Joint Stock Company «Karaganda Technical University named after Abylkas Saginov»;

The main scientific results of the dissertation work are presented in 20 publications, including:

– in publications included in the information base of Scorus companies – 2 articles:

1) Druzhinin V.M., Kalinin A.A., Sivyakova G.A. Rolling stand electric drive model regarding influence of power supply network parameters. Indonesian Journal of Electrical Engineering and Computer Science, 2023, – Vol.29, №3. – pp. 1213–1223. ISSN: 2502-4752, DOI: 10.11591/ijeecs.v29.i3.pp. 1213-1223 (Percentile – 46 Scopus)

2) V. Druzhinin, G. Sivyakova, A. Kalinin, V. Tytiuk, A. Nikolenko, V. Kuznetsov, M. Kuzmenko Preventing the development of emergency modes of interlocked electric drives of a rolling mill under the impact loads.Diagnostyka, 2023, – Vol. 24, №1:2023105 – pp. 1 – 13. e–ISSN 2449–5220 https://doi.org/10.29354/diag/157089. (Percentile – 37 Scopus)

in publications recommended by CCSES MES RK - 3 articles «Proceedings of the University» (Karaganda);

– 12 articles in the materials of international scientific and practical conferences «Improving the quality of education, modern innovations in science and production» (KuzSTU, Ekibastuz), «Integration of science, education and production - the basis for the implementation of the Nation's Plan» (Saginov Readings)», (KarTU, Karaganda) and 1 article – 15th International Conference on Industrial Manufacturing and Metallurgy, IOP Conference Series: Materials Science and Engineering, which is included in the Scopus database;

– 2 articles in the proceedings of the Republican scientific journal «Bulletin of the Karaganda State Industrial University» (KSIU, Temirtau);

– received 1 certificate of state registration of rights to copyright objects «Simulation model of the electric drive of the finishing stand of a hot rolling mill (computer program)» Breido I.V., Druzhinin V.M., Kalinin A.A. IS 4003 №2744 dated August 24, 2018;

– 1 patent of the Republic of Kazakhstan was received for the utility model «Method of controlling the electric drive of the finishing group of hot rolling mill stands» Druzhinin V.M., Kalinin A.A., Sivyakova G.A., Druzhinin K.V. Patent of the Republic of Kazakhstan for utility model №6957 dated March 18, 2022.

The personal contribution of the dissertation author is to solve research problems, develop and substantiate provisions that constitute the scientific novelty and practical significance of the work, conduct experimental studies of the quality of voltage on the busbars of a 10 kV supply substation; developing a model of the electromechanical system of the mill, taking into account the existing power supply system, in justifying the possibility of reducing the influence of shock loads by influencing the excitation windings of power electric drives, in studying the dependence of mill performance indicators on the magnitude of shock loads when controlling the excitation of Synchronous Motors and DC Motors, in conducting analysis and processing of experimental data.

Scope and structure of work. The dissertation work consists of an introduction, four chapters, a conclusion, a list of references, including 95 titles and 5 appendices. The total volume of the work is 115 pages, including 7 tables and 47 figures.

The content of the work. The introduction describes the state of the problem and substantiates the relevance of the work. The purpose and objectives of the dissertation are formulated, the scientific novelty, scientific provisions and research results submitted for defense, and the practical significance of the research results are determined.

Brief content.

The first chapter outlines the state of the issue and reviews the literature. The review made it possible to establish the features of hot rolling production on continuous wide-band hot rolling mills, as well as the main technological parameters that have a significant impact on the quality of the products.

The general features of the design of continuous wide-band hot rolling mills, features of the functioning of production equipment and power supply systems are

considered. The production of hot rolled products is considered using the example of the ArcelorMittal Temirtau Joint Stock Company, which is the largest enterprise in the mining and metallurgical sector of the Republic of Kazakhstan and is an integrated mining and metallurgical complex.

Based on the analysis of scientific and technical literature, factors have been identified that have the most significant impact on the quality of the finished product of wide-band hot rolling mills, among which researchers highlight the influence of power supply networks on the characteristics of the interconnected electric drive of hot rolling mills under shock loads occurring in the roughing group of a rolling mill.

The analysis performed showed that at the moment there are no methods for determining the patterns and numerical characteristics of the influence of the parameters and configuration of the power supply network on the operation of interconnected electric drives of a hot rolling mill.

Thus, the task of studying the patterns and numerical characteristics of the influence of the power supply network on the operation of a hot rolling mill, as well as the development of methods for limiting the influence of the power supply network on the operation of the interconnected electric drive of hot rolling mills is an urgent task to ensure highly efficient functioning of rolling production.

The goals and objectives of the study are formulated.

The second chapter discusses the features of the structure of the power supply system and the composition of the equipment and parameters of the electromechanical system of a wide strip hot rolling mill. Based on the analysis, the possibility of impact loads of synchronous electric drives of the roughing group of the mill on the operating conditions of the electric drives of the finishing group is shown. Since the drive motors of the successive rolling stands of the finishing group are connected to different power transformers of the two-transformer substation, it was hypothesized that the shock loads of a synchronous electric drive can disrupt the symmetry of the supply voltages in the finishing group and have a negative impact on the quality of the hot-rolled sheet. The necessity of developing a mathematical model of a rolling mill that takes into account the influence of the power supply network on the interconnected electric drive of hot rolling mills is substantiated.

In order to confirm the assumptions made, experimental studies of the voltage quality on the busbars of the supply substation and on the electric drives of the CWSM 1700 hot rolling stands of the JSC «ArcelorMittal Temirtau» enterprise were carried out. Based on the results of the experimental study, it was established that with the existing configuration of the power supply network, the shock loads of the synchronous electric drive of stand №1 of the roughing group of the rolling mill cause significant voltage dips, up to 10-12%, on the busbars of the supply transformer with a duration of 2-2,5 sec. Based on the observation and measurement methods used for the power supply system CWSM 1700 for hot rolling, conclusions were obtained confirming the significant influence of the main electric drives of hot rolling mill stands through the power supply network on the operation of the rolling mill as a whole.

To establish the absolute value of the shock loads of the electric drive of stand №1 of the roughing group, an analysis was carried out of the magnitude of its loads

from such rolling characteristics as the grade of rolled steel and the temperature of the workpiece, which changed at two levels: the first value is 1250°C - as close as possible to the maximum heating temperature of the slab 1270°C according to the technological instructions, and the second value 1150°C adopted on the basis of established production practice. It has been established that under current production conditions the rolling power varies in the range from 2500 to 4200 kW.

The third chapter is devoted to the development of a mathematical model of the electromechanical system of a hot rolling mill, which takes into account all the above-mentioned operating features, namely: shock loads on the shaft of the synchronous electric drive of the roughing group; the existence of an elastic connection through the strip of rolled metal between the DC electric drives of the finishing group; the existence of communication and mutual influence of interconnected electric drives of the rolling mill through the power supply system of the rolling mill, mathematical models of individual elements of the mathematical model were developed and tested. The adequacy of the developed mathematical models of individual electric drives is confirmed by the compliance of the modeling results with the technical characteristics of electric motors and the compliance of the obtained modeling results with general theoretical principles.

The structure and parameters of the elements of the mathematical model of the power supply system exactly correspond to the existing schematic diagram of the power supply system of the CWSM-1700.

Using the developed mathematical model of a hot rolling mill, a regression model of the dependence of the maximum voltage drop on the transformer busbars on the rolling power was obtained, which makes it possible to simplify the assessment of the influence of rolling operating parameters on voltage quality indicators.

The developed mathematical model can be used to study operating modes and develop methods for controlling the synchronous electric drive of the stands of the roughing group of hot rolling mills in order to reduce the negative impact of power supply network parameters on the operation of power receivers.

The fourth chapter analyzes well-known theoretical methods aimed at reducing the influence of shock loads of synchronous electric drives of the roughing group on the operation of a hot rolling mill.

One of the best methods for reducing the influence of power supply networks on the characteristics of the interconnected electric drive of hot rolling mills, combining the simplicity of technical implementation and the quality of the results achieved, is to overexcite the synchronous electric drive of the roughing group for the period of billet rolling. Overexcitation of a synchronous motor leads to an increase in voltage in the load node and directly affects the main cause of the drop in the angular speed of electric drives of a numerical group, which reduces the impact and simultaneously affects all DC electric drives connected to the load node. In addition, this improves the operating conditions of other mechanisms and processes of the rolling mill.

To study the influence of excitation parameters of a synchronous electric drive of a roughing group on the performance of interconnected electric drives of a rolling mill, a two-factor computational experiment was developed and implemented using a rotary central compositional plan. The following variable factors were used in the

experiment: the voltage value of the excitation winding of a synchronous motor for the period of rolling the workpiece Uf and the duration of the pause between the start of excitation forcing and the start of rolling the workpiece Δt.

As a result of the experiments, it was established that the dependence of the relative elongation of the metal in the interstand space on the magnitude of the excitation boost of the synchronous motor of the roughing group stand of a rolling mill when an impact load is applied is extreme and has a pronounced minimum, which makes it possible to determine the optimal settings of the synchronous motor boost control system. In accordance with the chosen direction of research, the following values were recorded as experimental responses: the maximum value of the relative voltage drop in the power supply unit ΔU; the maximum and minimum value of the relative elongation of the metal strip in the interstand space εMAX and εMIN.

Analysis of the obtained regression models made it possible for the first time to establish that the dependence of the relative elongation of the metal in the interstand space on the magnitude of the excitation boost of the synchronous motor of the roughing group stand of a rolling mill when an impact load is applied is extreme and has a pronounced minimum, which makes it possible to determine the optimal settings of the synchronous motor boost control system.

Another effective method of reducing the influence of power supply networks on the characteristics of the interconnected electric drive of hot rolling mills is a method in which the voltage of the excitation circuit of an independent excitation DC electric motor is boosted at the moment the strip enters the rolls, which makes it possible to increase the speed of the considered control system for the electric drive of the finishing group stand of a rolling mill hot rolling. A patent of the Republic of Kazakhstan for a utility model «Method of controlling the electric drive of the finishing group of hot rolling mill stands» was received for the proposed device. Druzhinin V.M., Kalinin A.A., Sivyakova G.A., Druzhinin K.V. Patent of the Republic of Kazakhstan for utility model №6957 dated March 18, 2022.

The main results of the studies performed are as follows:

– an analysis was carried out of the influence of power supply networks of hot rolling mills on the operation of interconnected electric drives of a hot rolling mill under shock load conditions;

– experimental studies of the quality of voltage on the busbars of the substation supplying the interconnected main electric drives of the hot rolling mill were carried out;

- an analysis of the influence of rolling technological parameters (steel grade, billet temperature, etc.) on the characteristics of shock loads of electric drives of the roughing group was carried out;

– a mathematical model of the electromechanical system of the main electric drives of a hot rolling mill has been developed, taking into account the influence of the elasticity of the metal strip in the interstand space;

- experimental studies of a hot rolling mill were carried out using a mathematical model;

– methods have been developed to compensate for the influence of synchronous electric drives of the roughing group on the stability of the electric drive of the finishing group;

– the structure of the control system for the electric drive of the finishing stand of hot rolling mills has been developed, which allows minimizing the influence of voltage dips in the power supply network.