ABSTRACT

Dissertation for the degree of Doctor of Philosophy (PhD)
in the educational program 8D07103 – «Electric Power Engineering»

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DEVELOPMENT AND RESEARCH OF AN ADJUSTABLE DOUBLE-MOTOR ASYNCHRONOUS ELECTRIC DRIVE OF THE MAIN BELT CONVEYOR

Relevance. One of the key sectors of the Republic of Kazakhstan's economy is the mining industry. Kazakhstan ranks third in the world in terms of explored copper reserves and first in zinc reserves.

Ore extraction and processing are integral parts of the mining industry. The transportation of ore to the surface from underground mines, as well as between remote units of the ore processing plant, is carried out via a material handling system. The main type of transport used in such systems at mining enterprises is the main belt conveyor, which often requires transportation over long distances and, in some cases, at an incline of 15–20 degrees. To drive a heavily loaded main belt conveyor, electric drives with a power rating of 500 kW or higher are required. According to GOST 31558-2012: «Conveyors with drive units of 250 kW and above must be equipped with auxiliary drive blocks that ensure a belt speed of no more than 0.5 m/s.» This level of power is achieved by using two motors of equal capacity driving the main drum. Synchronous operation of the motors is essential in such systems and is achieved through an automatic regulator. Poor synchronization leads to increased energy consumption.

When operating a main conveyor with a dual-motor drive, it is crucial to synchronize the motors driving the conveyor drum. Uneven load distribution leads to overloading of one motor, reducing its service life and, consequently, shortening the maintenance interval of the drive system.

Synchronous motor operation in a dual-drive system is achieved through optimal tuning of the automatic regulator. Incorrect tuning leads to belt oscillations, causing premature wear of the conveyor belt and a decline in system efficiency. Energy losses during start-up of the dual-motor drive can be reduced by adjusting the automatic regulator’s parameters in response to the incoming material flow.

The goal of the dissertation is to extend the service life of the conveyor belt and the mechanical parts of the electric drive, as well as to improve the energy efficiency of the drive by means of optimal control of the dual-motor electric drive of the main belt conveyor.

The object of research is the regulated dual-motor asynchronous electric drive of the main belt conveyor.

The scientific problem lies in:

– the distribution of load between the drives;

– the need to study the dynamic characteristics of the dual-motor asynchronous electric drive-in start-up modes.

The idea of the work is to develop an adaptive control system for the dual-motor asynchronous electric drive of a main belt conveyor that considers variable material flow during transport.

Research objectives:

– analysis of existing technical implementations of dual-motor asynchronous belt conveyor drives;

– analysis of disturbances affecting the drive in steady-state and start-up modes, considering variable load flow;

– development of a mathematical model of the dual-motor asynchronous belt conveyor drive and evaluation of its adequacy through comparison of theoretical and experimental data;

– formulation of optimality criteria for steady-state and start-up modes, considering variable load flow;

– synthesis of the adaptation loop for the control system of the regulated belt conveyor drive;

– synthesis of the automatic control system (ACS) for the interconnected dual-motor conveyor drive;

– development of the hardware part of the control system for the dual-motor conveyor drive;

– evaluation of the proposed adaptive automatic regulation system's effectiveness through industrial testing.

Scientific novelty:

– analytical dependencies of optimal control criteria for a dual-motor regulated asynchronous electric drive, accounting for the belt's elasticity, length, and variable material flow;

– synthesis of an adaptive automatic control system for the dual-motor regulated asynchronous drive, which extends the belt's service life in both start-up and steady-state modes;

– dynamic characteristics of disturbing factors in the belt conveyor under variable load conditions.

Main scientific statements and results submitted for the defense of the dissertation:

– Mathematical and simulation models of the electromechanical system of the main belt conveyor with a dual-motor regulated asynchronous electric drive, which consider the stiffness, length of the conveyor belt, and variable material flow during the conveyor's operation;

– The structure of the adaptive control system for the dual-motor electric drive of the main belt conveyor, includes feedback on the electromagnetic torque of the lead motor and an adaptive regulator with variable coefficients depending on changes in the material flow.

Research methods:

A review of works by domestic and foreign researchers in the field of energy efficiency of asynchronous electric drives. Study of global experience in developing control systems for dual motor interconnected asynchronous belt conveyor drives,

supported by scientific publications, patents, and authorship certificates for inventions. Scientific foundations used include the theory of automatic control, fundamentals of electrical engineering, electric machines, and the theory of electric drives widely applied in the design of dual-motor asynchronous belt conveyor drives.

Experimental data were obtained by recording oscillograms of currents, electromagnetic torques, and rotational speeds of the dual-motor asynchronous electric drive of the main belt conveyor located at the industrial site of JSC «Zhairem Mining and Processing Plant.»

The simulation model of the dual-motor frequency-regulated asynchronous electric drive of the main belt conveyor was developed using the Matlab/Simulink software package. The adequacy of the resulting model was evaluated using the Fisher criterion. The synthesis of the control system regulator and the development of the adaptive torque regulator were also performed using Matlab/Simulink.

Practical significance:

– technical implementation of the adaptive automatic control system (ACS), considering the constraints of the unmodifiable part of the dual-motor belt conveyor drive;

– evaluation of the effectiveness of the adaptation loop in start-up and steady-state modes.

Experience in implementation of the results.

The results of theoretical studies were confirmed by industrial trials conducted on the main belt conveyor at JSC «Zhairem Mining and Processing Plant.» The industrial testing report is included in the dissertation (Appendix A).

Validity and reliability of scientific statements, conclusions, and recommendations.

Theoretical studies were conducted in the laboratories of the Department of «Automation of Production Processes» at Abylkas Saginov Karaganda Technical University and the Department of «Electric Drive and Automation of Industrial Installations» at Ural Federal University named after the first President of Russia B.N. Yeltsin (Yekaterinburg).

The calculations and conclusions obtained during the theoretical studies were confirmed by the results of industrial trials conducted at the production site of JSC «Zhairem Mining and Processing Plant.»

The conclusions of the dissertation are consistent with the scientific principles formulated by leading experts in the field of energy-efficient automated electric drives, which confirms their validity and reliability.

Author's personal contribution:

The creation of a simulation model of the dual-motor frequency-regulated asynchronous electric drive for the main belt conveyor, the development of the adaptive torque regulator, as well as all the results of theoretical studies and experiments, were carried out independently by the author or with his direct participation.

Testing of the developed control system was conducted under real industrial conditions. In co-authored publications, the author is responsible for the experimental research results, data analysis, preparation, formatting, submission, and follow-up of the materials.

Thesis Validation (Approbation).

The main results of the dissertation are presented in 7 publications, including:

– 1 article in a journal indexed in the Scopus scientific database:

1. Optimizing the operation of a double-motor asynchronous frequency-controlled electric drive of the main belt conveyor in startup mode // International Journal on Energy Conversion (IRECON). – 2023. – Vol. 11, №5. – P. 170-182 (Scopus percentile – 53 in the category «Energy Engineering and Power Technology»).

– 3 articles in journals recommended by the Committee for Quality Assurance in the Sphere of Science and Higher Education of the Ministry of Science and Higher Education of the Republic of Kazakhstan:

1. Analyzing the main belt conveyor dual-motor asynchronous electric drive operating modes // Trudy Karagandinskogo Tekhnicheskogo Universiteta. – 2022. – №3. – P. 327-333.

2. Metody teoreticheskikh issledovaniy elektroprivoda lentochnogo konveyera: podkhody, modelirovanie i otsenka // Trudy Karagandinskogo Tekhnicheskogo Universiteta. – 2025. – №1. – P. 414-420.

3. Modeling of an induction motor driven by a frequency converter // Vestnik Toraygyrov Universiteta. Energeticheskaya seriya. – 2025. – №1. – P. 201-215.

– 3 articles in proceedings of international scientific conferences:

1. Simulation of an electric conveyor drive using Simulink Matlab // 2024 IEEE 22nd World Symposium on Applied Machine Intelligence and Informatics, SAMI 2024 - Proceedings, 2024. – P. 513-518 (included in the Scopus database).

2. Machine learning modeling and simulation of asynchronous electric drive // 2024 IEEE 6th International Symposium on Logistics and Industrial Informatics, LINDI 2024 - Proceedings, 2024. – P. 95-102 (included in the Scopus database).

3. Optimizatsiya raboty dvukhdvigatelnogo asinkhronnogo chastotno-reguliruemogo elektroprivoda magistral'nogo lentochnogo konveyera // Trudy Mezhdunarodnoy nauchno-prakticheskoy konferentsii «XVI Saginovskie chteniya. Integratsiya obrazovaniya, nauki i proizvodstva» (Part 2. – P. 57-59).

– 1 utility model patent of the Republic of Kazakhstan obtained: «Control system for a dual-motor frequency-regulated electric drive of a belt conveyor», Utility Model Patent of the Republic of Kazakhstan №9314 dated 28.06.2024 (Appendix B).

Structure and Volume of the Dissertation:

The dissertation consists of an introduction, four chapters, a conclusion, and appendices. The manuscript contains 85 pages of typewritten text, 40 figures, 11 tables, 2 appendices, and a list of 101 references.

Contents of the Dissertation:

The introduction outlines the current state of the research problem and substantiates its relevance. It defines the aim and objectives of the dissertation, highlights the scientific novelty, the key statements and research results submitted for defense, and emphasizes the practical significance of the findings.

The First Chapter presents the current state of the problem and provides an analysis of existing literature sources. This analysis helped to identify the distinctive features of the dual-motor asynchronous belt conveyor drive’s operation and the key

technological parameters that significantly influence its energy efficiency and durability.

The chapter also considers the specifics of the dual-motor asynchronous electric drive of the main belt conveyor in start-up, operational, and emergency modes. It describes the methods of theoretical and experimental research and formulates the requirements for their application.

The analysis confirmed that improving energy efficiency and extending the service life of main belt conveyors is a relevant and pressing issue.

The goals and objectives of the research are clearly formulated.

In the Second Chapter, theoretical studies of belt conveyors with dual-motor asynchronous drives are conducted. The parameters are calculated, and a simulation model of the frequency-regulated asynchronous motor is developed using two approaches: based on a linearized system with scalar control, and based on a model with vector control and compensated cross-links. In the first case, the speed controller is synthesized using the root locus method with Vyshnegradsky's diagram. With an accepted assumption of reducing the order of the characteristic equation, the angular velocity overshoot error was 0.014%. In the second case, the controller is synthesized using the «modular optimum» approach.

For controlling a belt conveyor transporting ore, it is advisable to use vector control rather than scalar control. Vector control provides precise regulation of motor speed and torque, which is crucial when handling heavy materials. It enables smooth start and stop processes, reduces mechanical stress, and extends equipment life. The advantages of vector control include high precision, energy efficiency, and effective torque control, though it is more complex to configure. Scalar control is simpler and suitable for constant loads, but its main drawback is reduced accuracy and efficiency under varying conditions, which may lead to increased equipment wear.

A kinematic diagram of the main belt conveyor with a dual-motor asynchronous drive is developed, along with a simulation model of the mechanical part of the conveyor. The following results were obtained from experiments using this mechanical simulation model:

– Elastic dynamic oscillations occur in the conveyor belt during start-up;

– On an unloaded conveyor, the shortest oscillation period observed was 10 seconds, with the smallest initial amplitude being 12.91 kN·m (for a step input) and 10.79 kN·m (for a gradually increasing input), and the shortest damping time was 23 seconds;

– On a fully loaded conveyor, there was an 11% increase in the oscillation period, a 3.3% increase in initial amplitude (step input), a 1.4% increase (gradual input), and a 13% increase in damping time compared to the unloaded state;

– When starting the conveyor under identical load conditions but with different input intensities, the oscillation period remained unchanged;

– Different acceleration times had different effects on the conveyor belt during full-load start-up. The longer the start-up time, the less mechanical stress on the belt. The smoother the input signal, the lower the oscillation amplitude and the shorter the damping time.

In Chapter Three, theoretical studies are conducted on a dual-motor asynchronous regulated electric drive with elastic couplings. Based on the results obtained in Chapter Two, a simulation model of the dual-motor frequency-regulated asynchronous electric drive of the main belt conveyor is developed.

The adequacy of the resulting model is evaluated using the Fisher criterion: the modeling error does not exceed 5%. This level of accuracy is sufficient for studying the dynamic processes of the dual-motor frequency-regulated asynchronous electric drive of the conveyor.

An adaptive torque controller is developed for the dual-motor asynchronous electric drive of the main belt conveyor, considering variable load flow. The torque controller is synthesized using the modular optimum method.

To avoid load redistribution between the drive motors and reduce the overshoot of electromagnetic torque under variable load conditions, it is advisable to use an adaptive torque controller that linearly adjusts its parameters depending on the conveyor's load level.

Dynamic processes occurring in the belt conveyor during the start-up mode under various load conditions are studied. The results showed that it is advisable to apply different automatic controller settings for different conveyor load levels. Experiments confirmed that using an adaptive torque controller reduces the conveyor drive's energy consumption during start-up and increases the service life of the mechanical components.

In Chapter Four, a description is provided of the experimental studies of the dual-motor asynchronous electric drive of the main belt conveyor, considering variable load flow. The specifics of the experimental test bench, organized at an operating mining and processing plant, are described, and experimental studies are conducted on the dual-motor asynchronous drive in both start-up and steady-state modes.

During industrial trials, it was found that the motor torque during start-up did not exceed twice the nominal value. The mismatch between the torques of the driven and driving motors did not exceed 25% during the transient process and 5% during steady-state operation.

When starting the conveyor under maximum load, a 20–30% reduction in peak start-up torque (and thus inrush current) was observed. This reduces stress on power supply components and lowers the risk of motor overheating.

The results of testing the automatic control system of the interconnected dual-motor asynchronous electric drive of the main belt conveyor show that this system, based on its static and dynamic characteristics, can be recommended as a control system for such drives in conveyor applications.

Implementing the proposed automatic regulation system allows for improved energy efficiency of the dual-motor frequency-regulated asynchronous drive and extends the lifespan of the conveyor's mechanical components.

The main results of the research conducted are as follows:

– analysis of existing technical implementations of dual-motor asynchronous belt conveyor drives was carried out;

– analysis of disturbance factors in steady-state mode and start-up conditions under variable load flow was performed;

– a mathematical model of the dual-motor asynchronous belt conveyor drive was developed and its adequacy assessed through comparison with experimental data;

– optimality criteria for steady-state and start-up modes under variable load flow were defined;

– the adaptation loop of the control system for the regulated belt conveyor drive was synthesized;

– an automatic control system (ACS) for the interconnected dual-motor conveyor drive was synthesized;

– the hardware component of the control system for the dual-motor conveyor drive was developed;

– the efficiency of the proposed adaptive automatic control system was evaluated during industrial testing.