DEVELOPMENT OF MATHEMATICAL MODELS FOR MINING ELECTROMECHANICAL SYSTEMS AND METHODS FOR THEIR NUMERICAL SOLUTION

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Abstract. This article investigates the development of mathematical models for mining electromechanical systems and methods for their numerical solution. The operational processes of electrically driven machinery used in the mining industry are characterized by the interaction between electrical and mechanical quantities. Mathematical modeling plays a crucial role in deeply analyzing these processes, determining the system's dynamic characteristics, and evaluating operating modes.

Keywords: mining electromechanical system, mathematical model, electric drive, differential equations, numerical solution, dynamic process, computer modeling.

Increasing production efficiency, ensuring the rational use of energy resources, and guaranteeing the reliability of technological processes are among the key scientific and technical challenges in the mining industry today. The efficient operation of mining machinery—including excavators, drilling rigs, conveyors, and mine hoisting mechanisms—depends directly on the condition of their electromechanical systems.

Electromechanical systems perform the functions of converting electrical energy into mechanical energy, controlling motion, and handling technological loads. The operation of such systems is influenced by factors such as electric motor parameters, mechanical load torque, inertia, friction, supply voltage, and the characteristics of the control system.

In mining environments, variable mechanical loads, start-stop cycles, and transient overloads give rise to complex dynamic processes within electromechanical

systems. Studying these processes solely through experimental methods can be time-consuming and costly; therefore, the use of mathematical modeling techniques is of great importance.

Through mathematical modeling, the system's fundamental physical processes are described using mathematical equations. The resulting model enables the calculation of changes in electric current, electromagnetic torque, rotational speed, and load-induced variations.

However, mathematical models of electromechanical systems often consist of a system of coupled differential equations. Solving such equations analytically is not always feasible. Therefore, the selection and application of numerical solution methods for these equations is of particular scientific and practical importance.

The aim of the study is to develop a mathematical model of a mining electromechanical system, express it as a system of differential equations, and analyze the applicability of numerical methods for solving these equations.

The main objectives of the study are as follows:

- identifying the components and key parameters of the mining electromechanical system;
- formulating mathematical equations that describe the electrical and mechanical processes;
- representing the mathematical model in terms of state variables;
- examining numerical methods for solving differential equations;
- evaluating numerical methods based on criteria such as accuracy, stability, and computational efficiency.

Mathematical modeling is the process of representing the key characteristics of a real-world object using mathematical relationships, equations, and algorithms. Modeling mining electromechanical systems involves the use of electric circuit theory,

the theory of electrical machines, the laws of mechanics, and methods of differential equations.

In general terms, the electromechanical system of mining machinery can be divided into the following components:

1. Electric energy source and power supply system.
2. Electric motor.
3. Mechanical transmissions and motion-transmitting elements.
4. Working mechanism.
5. External mechanical load.
6. Control and monitoring system.

These elements operate in an interconnected manner. The electromagnetic torque generated by the electric motor produces mechanical motion, while changes in the mechanical load affect the motor's rotational speed and electric current values.

When mathematically modeling the electromechanical system, the following are adopted as its key parameters:

- power supply voltage;
- active resistance and inductance of the motor winding;
- electromagnetic torque coefficient;
- back electromotive force (back-EMF) coefficient;
- referred moment of inertia of the mechanical system;
- friction coefficient;
- external load torque.

When developing the initial mathematical model, certain complex characteristics of the system can be simplified. For instance, the magnetic flux is assumed to be constant, and the electric motor is treated as a separately excited direct-current (DC) motor. This assumption enables the study of the fundamental relationships between electrical and mechanical processes.

Such a simplified model is convenient for developing a general methodology that can subsequently be adapted for induction motors, variable-frequency drives, and other types of electric drives used in mining machinery.

In the electric drive of a mining machine, the process of converting electrical energy into mechanical energy depends on the parameters of the electric motor.

The mechanical component of the mining machine consists of the motor shaft, the transmission system, and the working mechanism.

The objective of numerically solving the mathematical model of the electromechanical system is to calculate how parameters such as current and angular velocity change over time.

During the numerical solution process, the time interval is divided into small steps. At each step, the state of the system is determined based on the previous state and the governing differential equations.

The choice of a numerical method for the mathematical modeling of mining electromechanical systems depends on factors such as accuracy, computational speed, and stability. Therefore, it is necessary to compare different methods using a unified mathematical model and identical initial conditions.

The following criteria can be used in the comparative evaluation of numerical solution results:

- accuracy of calculated current and angular velocity;
- duration of calculation time;
- sensitivity to time step change;
- numerical stability of the solution;
- compliance of the obtained results with physical laws.

Mathematical modeling of mining electromechanical systems creates a number of opportunities for improving production processes.

First of all, it is possible to evaluate the change of current and electromagnetic torque by studying the starting and stopping processes of the electric drive. It helps to analyze the loads on electrical equipment and mechanical elements.

Secondly, it is possible to determine the effect of external load changes on the system dynamics. For example, how the engine speed changes when the amount of material entering the conveyor or the resistance torque of the working mechanism changes is studied through a mathematical model.

Third, mathematical modeling allows comparison of different management modes. For this, changes in control laws and power supply parameters are included in the model.

Fourthly, by employing numerical methods, it is possible to simulate various operating modes on a computer and screen promising solutions prior to the experimental stage.

Fifthly, by incorporating data on energy consumption, losses within the motor and converter, and actual operating cycles into the model, one can conduct studies to evaluate energy efficiency.

At the same time, to ensure that the results derived from the mathematical model accurately reflect the characteristics of the actual equipment, it is necessary to refine model parameters using experimental data and validate computational results against real-world measurements.

Developing mathematical models of mining electromechanical systems and solving them numerically is crucial for studying the dynamic characteristics of mining machinery, analyzing operating modes, and optimizing technological processes. Thus, the combined use of mathematical modeling and numerical solution methods enables in-depth research into mining electromechanical systems, the determination of their dynamic characteristics, and the pursuit of ways to enhance their technical efficiency.

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