**Development of a Mathematical Model for Physical Processes Occurring in Auxiliary Asynchronous Electric Motors of Mainline Electric Locomotives**

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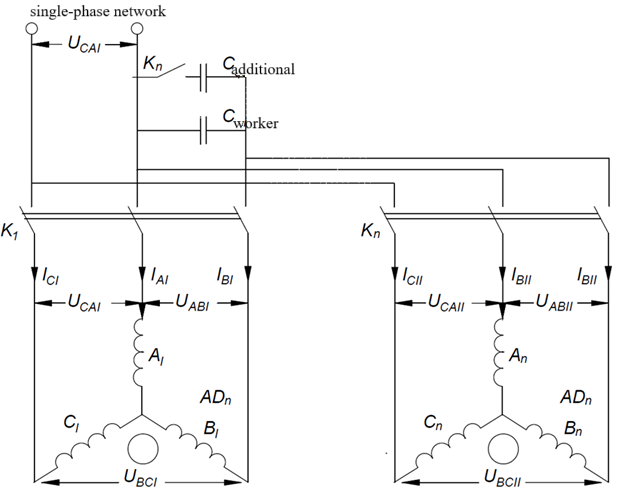
**Abstract.** There is a list of works that were carried out to increase the reliability of operation and additionally improve the level of maintenance of auxiliary asynchronous electric motors of mainline electric locomotives operated by JSC "Uzbekistan Railways". These studies focus on designing motors based on actual operating conditions. From this perspective, this research presents the results of long-term scientific investigations aimed at improving the operating conditions of auxiliary asynchronous electric motors. Specifically, the operational reliability of the asynchronous electric motor has increased through the modernization of its squirrel-cage rotor bars and rings. The important tasks of these motors are the cooling of traction electric motors of electric locomotives and other electric traction devices during the work, the collection of air in the brake system. The improvement was achieved by modifying the current-carrying structure of the auxiliary asynchronous electric motor rotor.

**Keywords.** Rotor, asynchronous motor, copper, aluminum, electric locomotive, slot, magnetic field, electromagnetic torque, rotor current, stator current, bar

**INTRODUCTION**

The technical state of asynchronous electric motors applying to auxiliary systems of VL60, VL80, and 3ES5K types mainline electric locomotives under management of JSC Uzbekistan Railways was considered [1, 2, 3, 4, 5]. Before investigating the operation of squirrel-cage rotors in auxiliary asynchronous electric motors of these locomotives, it is necessary to develop a system of equations that corresponds to the physical laws governing the motor's behavior in the absence of any damage [6, 7, 8, 9, 10].

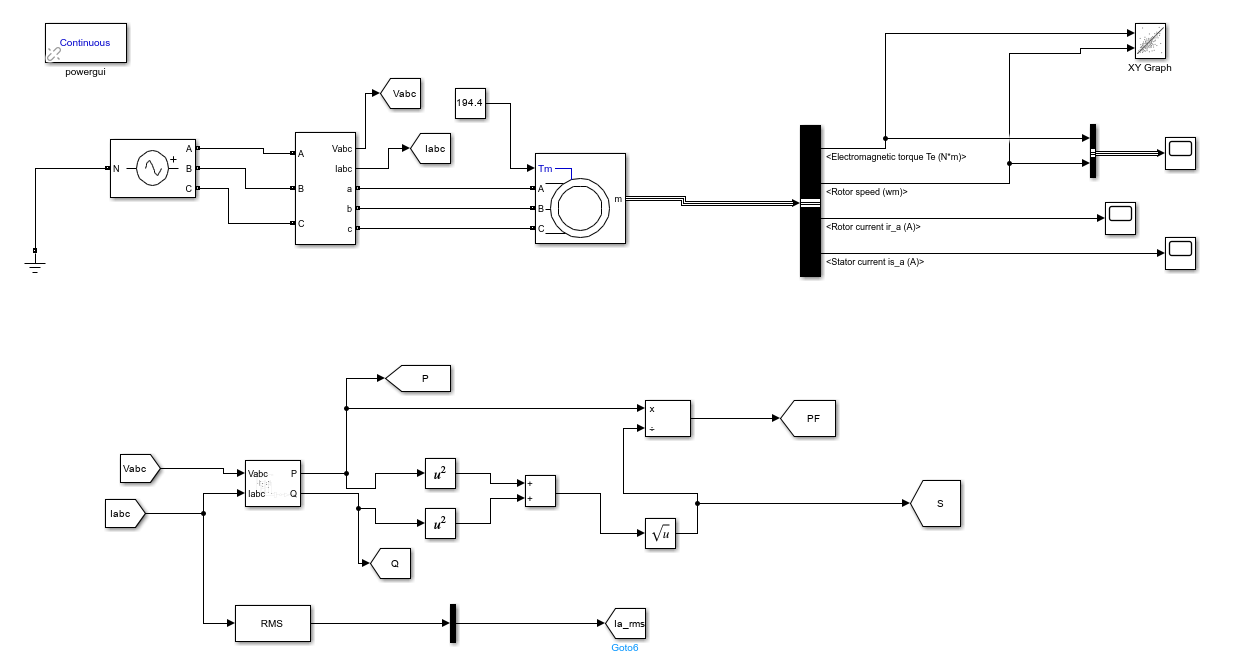
The physical equations are derived based on the schematic connection of existing auxiliary asynchronous electric motors in electric locomotives, as shown in Figure 1.



**FIGURE 1.** Connection diagram of auxiliary electrical machines

**EXPERIMENTAL PART**

It is necessary to investigate the electrodynamic loads that occur in the rotors of asynchronous electric motors when they are made of various materials. As a result of our aforementioned studies, we concluded that to modernize the rotor of the auxiliary asynchronous electric motor of the ANE-225-4 type, the aluminum windings in it should be replaced with copper material. Therefore, it is necessary to consider the physical processes of rotor winding changes in this type of electric motor using the modern MatLab Simulink software. To begin with, the structural format of an asynchronous electric motor has to be attained at MatLab Simulink software. For this purpose, a block diagram of the Matlab Simulink program for an asynchronous motor was developed, consisting of the AC (alternating current) electric motor block, a three-phase power supply, a block for the phase distribution of voltage and current supplied to the stator windings, a block for the phase distribution of rotor windings based on stator current and voltage, and a resulting display block showing the electromagnetic torque, rotor speed, stator current, and rotor current of the electric motor (Figure 2).



**FIGURE 2.** Simulation model of the system for determining electrodynamic loads on the stators and rotors of auxiliary asynchronous electric motors in the Matlab Simulink software environment

Here, Continuous powergui represents a constant power source; A, B, C denote three-phase supply; and are the values of voltage and current in the motor's stator windings across three phases; =194.4 N∙m is the electromechanical torque; Electromagnetic torque Te (N·m) refers to the electromagnetic torque; rotor speed (wm) indicates the rotor speed; rotor current ir\_a (A) represents the rotor current in phase A; stator current is\_a (A) denotes the stator current in phase A; XY Graph displays the values of the electromagnetic torque.

The results obtained from the software took the following form:

* Statorcurrent in the starting condition in an asynchronous electric motor with an aluminum rotor. Type *A*;
* Stator current at an asynchronous electric motor starting (with copper rotor). Type *B*;
* Rotor current in the start-up condition of an asynchronous electric motor having an aluminium rotor. Type *V*;
* Starting rotor current of an asynchronous electric motor having a copper rotor. Type *D*;

**TABLE 1.** Research Indicators

|  |  |  |
| --- | --- | --- |
| General view | Fiber type | Characteristic |
|  | *А* | The engine starting current is 4-6 times greater;  Starting current is 600-660 A;  Start-up time is 1-1,3 s; |
|  | *В* | The engine starting current is 5-6 times greater;  Starting current is 1500-1550 A;  Start-up time is 0,4-0,5 s; |
|  | *C* | The engine starting current is 3-5 times greater;  Starting current is 580-630 A;  Start-up time is 1-1,4 s; |
|  | *D* | The engine starting current is 4-6 times greater;  Starting current is 1560-1600 A;  Start-up time is 1-1,2 s; |

The operating conditions of the auxiliary asynchronous electric motor ANE-225 in VL60 and VL80 electric locomotives are characterized by numerous malfunctions, most of which manifest in the melting of the aluminum alloy in the rotor winding, indicating significant losses in the rotor during operation [11, 12, 13, 14, 15, 16]. The following advantages can be achieved from the work carried out.

1. Instantaneous parameters of processes occurring in asynchronous electric motors were investigated.

2. A mathematical model of physical processes occurring in asynchronous electric motors based on Kirchhoff's second law and the laws of electromagnetic induction for stators and rotors has been developed, enabling a comprehensive study of the processes occurring in the motor based on this model.

3. Using the equations of voltage drops and magnetic flux acting instantaneously on transient processes in the stator and rotor windings, a simulation model of an asynchronous electric motor was developed using modern MatLab Simulink software.

4. Using the developed simulation model, diagrams were obtained characterizing the electrodynamic torque, electromechanical torque, and stator current when the rotor windings of an asynchronous electric motor are made of aluminum and copper.

**RESULTS AND DISCUSSION**

In constructing this system, equations for voltage drops and magnetic flux acting instantaneously on the stator windings and aluminum rods in the rotor of the asynchronous motor are presented.

Writing the differential equilibrium equations of voltages in phase coordinates provides several advantages.

1. All quantities in the system of equations have their own physical meaning and actual values (more precisely, this applies only to the variables of the stator windings, since the rotor's short-circuited winding naturally does not have three separate phases).

2. This formulation of the equations allows for consideration of all types of asymmetry in the parameters of the windings and supply voltages.

3. It enables the calculation of electromagnetic and electromechanical processes in static and dynamic operating modes when supplied with output voltage from networks and sources with non-sinusoidal waveforms.

The voltage equilibrium equations for the stator and rotor phases are written in different forms. Under this model, the enhancement of Kirchhoff second law and the law of electromagnetic induction, through which instantaneous electromagnetic phase quantities of each rotor rod is modelled, is explained in the following equation [4, 5]:

For the stator

(1)

For the rotor

(2)

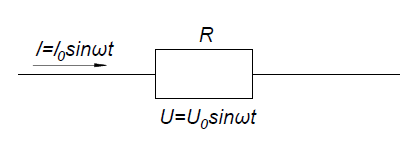
Here, represent the instantaneous values of voltage at the phase terminals;

is the A (a) phase current;

is the magnetic flux linkage in phase A (a);

is the active resistance in the stator phase A (in the rotor phase a);

We will examine how the expression representing the instantaneous values of voltage at the phase terminals changes in an AC circuit with respect to active resistance (Figure 3).



**FIGURE 3.** Instantaneous value parameters in a section of an asynchronous electric motor circuit

Thus, based on expressions (1) and (2), the voltage applied to the terminals of the auxiliary asynchronous electric motor can be expressed as follows:

(3)

(4)

**CONCLUSIONS**

The conducted research has enabled us to make the following recommendations:

a) Modernization of the technological process for manufacturing aluminum windings of a short-circuited rotor and development of a methodology for implementing new types of repairs under the conditions of   
JSC "Uztemiryulmashtamir."

b) To reduce the active resistance of the aluminum windings in the rotor slots by modernizing the design of the auxiliary asynchronous electric motor, it is recommended to reduce thermal and electrical losses at the actual voltage by replacing them with copper windings.

**FUTURE SCOPE**

The given research work will allow conducting both theoretical and experimental investigations to analyze the technical state and malfunctions of auxiliary asynchronous electric motors installed in mainline electric locomotives and to figure out the way to enhance the rotors. In addition:

1. As per the review of the technical state and faults of auxiliary asynchronous electric motors used in mainline electric locomotives owned by JSC "Uzbekistan Railways, 376 pieces out of 1077 in total, that is, 35 percent, of the auxiliary asynchronous electric motors used in the number of mainline electric locomotives had the greatest number of faults in the rotor windings identified. This necessitates improving their reliable operation methods during use through scientifically based developments.

2. The system's operation was simulated by creating a simulation model to determine the electrodynamic parameters of auxiliary asynchronous electric motors using Matlab Simulink software. In this case, the stator current of the asynchronous motor with a copper rotor increased by 41%, and the rotor current by 36% compared to an aluminum rotor. The simulation model allows testing the system's efficiency and accuracy, enabling comparison with experimental study results.

3. In the future, modernizing the rotors of auxiliary asynchronous electric motors in VL60, VL80, and Yermak 3ES5K electric locomotives available in the republic will create opportunities for developing new types of repairs and localizing production.

4. By modernizing the rotors of auxiliary asynchronous electric motors and mastering new types of repairs and localizing production, it is possible to reduce the costs of repairing the electrical components of mainline electric locomotives belonging to JSC "Uzbekistan Railways" by more than 7 times.

5. As it was stated in the analysis of a technical condition and malfunctions of asynchronous electric motors used as auxiliary electric motors in mainline electric locomotives on the railway of Uzbekistan, it was found out that the majority of different malfunctions happens in the rotor windings. This research improves the methods for their reliable operation during use.

6. The system's operation was simulated by creating a simulation model to determine the electrodynamic parameters of auxiliary asynchronous electric motors using electronic computing software. The system's efficiency and accuracy were tested using the simulation model and compared with experimental study results. According to the comparison results, after modernization, the efficiency of auxiliary asynchronous electric motors in electric locomotives increased by 6.8%.

Due to the absence of technology for repairing rotor units of auxiliary asynchronous motors under the conditions of JSC "Uzbekistan Railways," it is necessary to study malfunctions and develop measures to reduce defects [17, 18, 19, 20]. From this perspective, this dissertation provides scientific substantiation for processes such as increasing the performance level of auxiliary asynchronous electric motors in mainline electric locomotives of JSC "Uzbekistan Railways," developing a methodology for mastering new types of rotor unit repairs, and improving methods for their reliable operation.

**REFERENCES**

1. Sh. Mamayev, S. Fayzibayev, A. Djanikulov, and O. Kasimov, Method of selection of mainline locomotives in the unloaded state according to the speed characteristics affecting the electromechanical vibrations of the WMB, AIP Conf. Proc. **2432**, 030001 (2022).
2. O. R. Khamidov, I. S. Kamalov, and O. T. Kasimov, Diagnosis of traction electric motors of modern rolling stock using artificial intelligence, AIP Conf. Proc. **2612**, 030045 (2023).
3. A. T. Djanikulov, S. I. Mamayev, and O. T. Kasimov, Modeling of rotational oscillations in a diesel locomotive wheel-motor block, J. Phys.: Conf. Ser. **1889**, 022017 (2021).
4. S. Jamilov, O. Ergashev, M. Abduvaxobov, S. Azimov, and S. Abdurasulov, Improving the temperature resistance of traction electric motors using a microprocessor control system for modern locomotives, E3S Web Conf. **401**, 03030 (2023).
5. O. E. Ergashev, M. E. Abduvakhabov, O. R. Khamidov, N. K. Tursunov, and O. T. Toirov, Increasing the durability of gear transmissions of asynchronous torsion electric motors, Web Sci. J. **3**(10), 1030–1036 (2022).
6. S. Jamilov, A. Yusufov, S. Samatov, S. Kudratov, and S. Abdurasulov, Research of factors affecting the heating and cooling of locomotive traction electric machines, ICTEA Int. Conf. Therm. Eng. **1**, 012010 (2024).
7. S. F. Jamilov, S. A. Samatov, A. M. Yusufov, S. M. Azimov, and S. X. Abdurasulov, Analysis of reliability indicators of locomotive traction motors, IOP Conf. Ser.: Mater. Sci. Eng. **XXX**, Article ID (2023).
8. O. Ergashev, O. Kasimov, S. Jamilov, S. Azimov, and Z. Keldibekov, Improvement of diagnostics of traction electrical motors of railway rolling stock, AIP Conf. Proc. **3045**, 050041 (2024).
9. S. Jamilov, Studying factors determining the service life of electric machines, Acta Tashkent Polytech. Univ. **13**(3), 25–29 (2023).
10. S. Jamilov, TSTU modern temperature sensors for the assessment of the permissible thermal state of electric traction machines of a locomotive tractor, Acta Tashkent Polytech. Univ. **13**(1), 41–44 (2023).
11. O. T. Kasimov, S. Fayzibayev, A. Djanikulov, and S. Mamayev, Numerical studies for estimation of temperature fields in bandage material during locomotive braking, AIP Conf. Proc. **2432**, 030025 (2022).
12. A. T. Djanikulov and U. I. Safarov, Correction of TED field weakening switching diagram for mainline diesel locomotives of the type, E3S Web Conf. **401**, 01071 (2023).
13. A. T. Djanikulov and U. I. Abdulatipov, Torsional oscillations of armature shaft of generator of main diesel locomotive in diesel start-up mode, E3S Web Conf. **401**, 01072 (2023).
14. S. Abdurasulov, N. Zayniddinov, A. Yusufov, and S. Jamilov, Analysis of stress-strain state of bogie frame of PE2U and PE2M industrial traction unit, E3S Web Conf. **401**, 04022 (2023).
15. O. Khamidov, A. Yusufov, S. Jamilov, and S. Kudratov, Remaining life of main frame and extension of service life of shunting locomotives on railways of Republic of Uzbekistan, E3S Web Conf. **365**, 05008 (2023).
16. A. Yusufov, O. Khamidov, N. Zayniddinov, and S. Abdurasulov, Prediction of the stress-strain state of the bogie frames of shunting locomotives using the finite element method, E3S Web Conf. **401**, 03041 (2023).
17. O. Khamidov and D. Udalova, Technical and economic efficiency of intelligent data analysis on the railways of the Republic of Uzbekistan, Transp. Res. Procedia **57**, 230–239 (2021).
18. S. Abdurasulov, N. Zayniddinov, O. Khamidov, A. Yusufov, and S. Jamilov, Stress-strain state analysis of cross beam of main frame of industrial electric locomotives PE2M and PE2U, AIP Conf. Proc. **3256**, 060011 (2025).
19. S. Jamilov, U. Safarov, N. Zhulenev, and K. Qosimov, Analysis of experimental studies of transient processes during the start-up of the protection of the diesel generator set, ICTEA Int. Conf. Therm. Eng. **1**, 012010 (2024).
20. Z. Mukhamedova, S. Fayzibayev, D. Mukhamedova, A. M. Batirbekova, K. Jurayeva, G. Ibragimova, and   
    Z. Ergasheva, Calculating the fatigue strength of load-bearing structures of special self-propelled rolling stock, Sci. Rep. **14**, 19205 (2024).