A technical solution for increasing the reliability of the phase-splitters of AC electric locomotives

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Abstract. Russian Railways OAO is developing a program of the expansion of the Eastern polygon until 2030, the modernization of the transport infrastructure of which is the most important task for the economic and political development of the country. In the near future it is planned to complete the drawing up of a detailed planning schedule of the main stages of construction and parameters of reconstruction of the infrastructure of the Baikal-Amur Mainline and the Trans-Siberian railway. This will not only help to expand access to the markets of the Asia-Pacific region, but will also provide an opportunity to draw more income through an international transit East – West route. The tasks of increasing the reliability of electric rolling stock are brought to the forefront. The implementation of these tasks will reduce the cost of operating and repairing technological equipment. The development of technical means compatible with power supply systems and taking into account the operating conditions of electrical equipment is an urgent task. Power supply of auxiliary machines on all domestic electric locomotives is carried out without the stabilization of the voltage value and balance. At the same time, in order to ensure the reliability of the electric drive motors themselves when operating in the entire range of supply voltage variation, their rated power is increased by 25-50%. Therefore, auxiliary machines on all domestic electric locomotives of alternating current have increased overall dimensions and weight, but the circuit design of the drive system is simple and is presented in the article.

1. Introduction
Over the next four years, the throughput capacity of the Eastern polygon should increase to 180 million tons, i.e. by about a quarter relative to 2020. The volume of export of coal products should grow by 30%. The planned volume of the industry transportation in the eastern direction from the Kuzbass regions by 2024 will amount to 68 million tons of cargo per year. This year it will amount to 53 million tons, and later it will be necessary to increase the volume by 5 million tons every year. In the course of the first stage of the Eastern polygon modernization, a total of about 670 km of tracks will be built, at the second stage (until 2024) – more than 1.3 thousand km, railway stations have been reconstructed, and projects for the modernization of traction power supply systems will be implemented [1-3].
The relevance of the presented work is proved by the production and testing of modern new-generation locomotives with an asynchronous traction drive. The main guideline for designers and developers is solutions that will ensure high traction and energy performance indicators of an electric locomotive.

The analysis of the state of the locomotive fleet indicates its significant wear and tear, requiring renewal. Due to a number of objective and subjective reasons, this fleet is improved at an extremely low rate. To solve this problem, it seems expedient to implement several directions. The first is government support using various instruments, one of which is subsidizing interest rates for the purchase of locomotives. The second is a decrease in the cost of locomotives. Conducted scientific research proves that today one of the areas that do not require significant investments is the increase of the level of reliability and safety of the existing fleet due to its modernization [5].

2. The main causes of voltage deviation in the system of auxiliary machines
An analysis of the reliability of traction equipment of AC electric locomotives based on reports and statistical materials from the Eastern Region's locomotive depots shows that auxiliary machines account for a significant proportion of failures. Damage to the electrical part of the electric motors in question accounts for up to 60% of the total number of faults. The emphasis on these faults is due to the high laboriousness of their repair and the high cost of replacement items when they are not repairable. The nature of the damage indicates that the electrical parts of the auxiliary machines are caused by poor electricity quality indicators [3-6].

Faults such as phase breakage, rotor winding melting-out, insulation breakdowns, low resistance of stator winding insulation, and electric motor winding burnout imply the development of radically new methods to improve the reliability of the electric motor.

This issue is often considered only with regard to the locomotive as a transportation object in detachment from the complex of tasks solved in the transportation process. Management of locomotive fleets, the organization of interaction with the repair complex of service companies that carry out maintenance and repair of traction rolling stock, the organization of train movement during the summer track work, taking into account the existing and planned future train schedule, made it possible to justify the proposed technical solution [7-11].

Electric rolling stock operation experience made it possible to identify the following groups of factors, the impact of which is reflected on the reliability of phase-splitters of AC electric locomotives:

a) constructive ones, driven by the use of elements and items with low reliability; of schematic and design solutions, the shortcomings of which are not taken into account when designing a technical device; the use of constituent elements that do not meet environmental conditions;

b) production ones, due to a violation of the repair technological process; due to an insufficient control of the quality of installation and manufacture; due to non-compliance with technological requirements and regulations in the format of roundhouse servicing;

c) installation ones, due to non-compliance with the requirements of installation technology;

d) operational ones, conditioned by the operation mode of the phaser load; by the deviation of the current voltage value in the secondary winding of the electric locomotive's traction transformer; by implementing the launch of load electric motors in a direct way; by climatic factors.

The impact of climatic factors has a significant impact on the reliability of the electrical part of the phase-splitters, since dust and increased humidity have a direct negative impact on the dielectric properties of insulation. The elimination of humidity is possible due to the use of electric heaters, however, this technical solution will complicate the design of the electric locomotive. In addition, the effect of the ambient temperature, especially in the summer period, in combination with operational factors can lead to an excess of the maximum permissible insulation temperature of the electrical machine in question, according to its class.

Special attention should be paid to operational factors, the consideration of which predetermines the possibility of modernizing the system and increasing its reliability. Such factors include the following:
the quality of electricity on the windings of electrical machines;

- voltage unbalance;

- non-sinusoidal voltage in the secondary winding of the transformer.

The magnitude and duration of the voltage deviation directly determine the service life of electric motors and their efficiency. The main factor influencing the voltage deviation in the three-phase current circuit of the auxiliary machines of electric locomotives can be considered the voltage deviation on the current collector and the elements of the electrical circuit during the passage of the load current. For AC electric rolling stock, the influence of the voltage level is aggravated by the processes that occur in the power and auxiliary circuits. Therefore, the limits of voltage deviations in the secondary winding of the auxiliaries of the traction transformer, from which the asynchronous auxiliary machines are powered, turn out to be wider than on the current collector.

The analysis made it possible to identify the main causes of voltage deviation in the voltage system of auxiliary machines:

- a decrease in the electromotive force of the auxiliary winding of the transformer due to the active and reactive resistances of the primary winding when the transformer windings, supplying the reversible converter, are under load;
- voltage deviation in the circuits of the primary and auxiliary windings of the transformer from the current of the motors of auxiliary machines and balancing capacitors;
- change in the harmonic components of the non-sinusoidal alternating voltage on the current collector during the traction and speed control of the electric locomotive;
- the dependence of the effective value of the positive sequence voltage in the three-phase voltage system on the effective single-phase voltage on the auxiliary winding of the traction transformer due to the error in the operation of balancing devices.

3. A technical solution for increasing the reliability of the phase-splitters of AC electric locomotives

Long-term voltage deviation from the nominal value on the stator windings of three-phase asynchronous motors causes an increase in current, the magnitude of which leads to heating of the active parts of the electrical machine, deterioration of energy performance indicators and service life.

During the development of auxiliary drive systems for AC electric locomotives, options were considered for the use of automatic stabilization of the three-phase system symmetry. As part of the article, we consider the technical solutions of power-stabilizing devices for auxiliary machines, the use of which will optimize the operation modes of drive electric motors. However, the practical use of these devices in the auxiliary drive system will not only complicate the design, but will also cause difficulties when placing it in the locomotive section [12, 13].

In that respect, power supply of auxiliary machines on all domestic electric locomotives is carried out without stabilization and voltage balance [14, 15]. At the same time, to ensure the reliability of the drive motors themselves when working in the entire range of voltage changes, their nominal power is driven up to 50%, which preconditioned the increased size and mass of auxiliary machines. This disadvantage is compensated to some extent by the simplicity of the circuit design.

The first step in the development of the system was to review the passport data of the auxiliary machines to assess the parameters of the transient processes of the start-up and to substantiate the proposed control algorithm [16-19]. As part of the study, the electric locomotive of the VL80R series was considered.

Particular attention is paid to certain operating regimes. Thus, when passing a neutral section, the locomotive crew must disable the auxiliary machines in the following sequence: MV blower motors; MK engine compressor; phase-splitters; GV main switch.

After passing the neutral section, it is necessary to start all the auxiliary machines in the order, opposite to the shutdown.

In order to reduce the starting currents and provide the necessary characteristics, the load acceptance should be made sequentially. The simultaneous start of all the auxiliary machines powered
through the phase-splitter is not allowed. Between the start of each engine, the time exposure required to ensure the transition of the engine to a stable branch of mechanical performance must be observed. The disregard of the regulated time between the start of auxiliary machines by locomotive crews predetermines the integral number of failures of the electrical part of the electric cars under consideration. The technical solution proposed in the framework of the article will help to eliminate the human factor, ensuring the regulated sequence and the time between the start of load electric motors.

Implementation of the proposed technical solution is possible taking into account the use of a semiconductor frequency converter, the use of which will help to implement a "soft" start-up of blower motors at a reduced frequency.

The circuit, which monitors the amount of voltage in the secondary winding of the auxiliaries of the traction transformer, will predetermine the start of the proposed control system. It should be noted that the parallel work of the phase-splitter and the proposed semiconductor frequency converter not only makes it possible to solve the tasks set within the article, but also performs the reservation of the standard circuit, figure 1.

![Figure 1. Upgraded power circuit of VL80R electric locomotive auxiliary machines.](image)

After starting the electric locomotive or passing the neutral section, the control system must ensure the priority activation of the motor-compressor and the oil pump from the standard circuit with a phase-splitter, implement from the proposed frequency converter the alternate start of the blower motors at a reduced speed and the subsequent transition to the standard circuit.
The implementation of the sequential start at a reduced rotation frequency is carried out by the use of contactors KM1-KM4. The proposed circuit will be put into regular mode after the programmed time by timers of the microprocessor control system.

In order to justify the choice of the frequency converter, it is necessary to calculate its power to practically implement the proposed system.

The start of the proposed system is the start of the phase-splitter and the motor-compressor from the standard circuit of the VL80R electric locomotive. At this point in time, the KM1-KM4 contactors are switched and break the standard circuit into the proposed circuit design. Upon the expiration of time of the microcontroller setting, which takes into account the parameters of the transient process of starting the motor-compressor, the contact KM5 is closed to start MV1 at a reduced speed from the proposed semiconductor converter. Guided by the passport data of the asynchronous electric motor, and specifically the time of the starting transient process, after which the contact KM6 closes. Similarly, all blower motors are started for the operating modes under consideration, which is aimed at improving the reliability of the phase-splitter by eliminating the load machine starting currents. The above-considered algorithm of work is presented in Figure 2.

![Figure 2](image-url)

**Figure 2.** Algorithm of work of the proposed electric locomotive auxiliary machine control system of the electric locomotive.
After the start of the last blower motor, taking into account the transient process time, the KM1-KM4 contactors switch the cooling machines to the standard circuit of the electric locomotive, and the contactor QF1 disables the power of the system proposed in the article.

Modern rolling stock trends are improving reliability, minimizing energy consumption while maintaining the reliability of equipment, which will bring undoubted economic benefits and ease of operation of electric rolling stock.

A power supply circuit for auxiliary machines at a reduced frequency is proposed by installing a semiconductor frequency converter in the power circuit of VL80R electric locomotives for its parallel operation with a phase-splitter. The economic calculation showed that the return on investment is within the normative period and is 1.26 years.

\[ t \geq \text{7 sec} \]

4. Conclusion
The developed control system is aimed at eliminating the impact of the starting currents on the electric locomotive's power system as a whole. Installation of the proposed system due to the presented design features of the selected elements will not affect the complexity and loading level of the electric locomotive body. Using the proposed system with the presented control algorithm will reduce the number of failures of phase splitters associated with the melting-out and burnout of its elements and items.

The presented algorithm implements the sequential start of the electric locomotive blower motors, taking into account the time of the transient process of a given mode of each electric motor. As soon as the mechanical characteristic passes to the steady-state branch, the next load motor is started, which makes it possible to draw an objective conclusion about the absence of starting currents of the machines under consideration.

The proposed control system of the frequency converter is safe for the life of workers who maintain and repair it, and environmentally friendly.

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