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RELIABILITY ASSESSMENT USING REGRESSION ANALYSIS OF ELECTRIC LOCOMOTIVE ELECTRIC DRIVE CONTROL SYSTEMS IN VARIOUS OPERATING CONDITIONS OF THE REPUBLIC OF UZBEKISTAN

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Annotation. The paper analyzes the theory and practice of the operation of electric locomotive systems with TIM, as well as known methods of energy and resource saving during the transportation of passengers and goods in case of an emergency failure of the electric drive control system. Regression models for calculating the dependence on the performance of maintenance have been developed, which make it possible to quantify the dependence in the operation of the electric drive system of electric locomotives.

Key words: electric drive control, alternating current, electric locomotive, maintenance, repair, regression, failure.

Introduction. Effective management of the technological process of driving electric locomotives is impossible without timely receipt of complete and reliable information about the state of its control system. To obtain such information, indicators of the technical condition of power electrical circuits, control systems and their diagnostics are used. During the operation of the electrical equipment of electric locomotives, their failures inevitably occur.

In the system of electrical equipment of electric locomotives, the most vulnerable elements are controlled asynchronous electric drives that operate in sharply variable technological and climatic conditions of movement.

At present, JSC "O'zbekiston temir yo'llari" operates 49 AC electric locomotives of the following series "O'zbekiston", "O'zY", "UzEL" and "UzELR" manufactured by the Chinese company ZHUZHOU, the repair of which is carried out in the depot " O'zbekiston". The first batch of these electric locomotives was launched in 2003. The mileage of each electric locomotive averages over 1,500 million km.

The running-in period of these electric locomotives for electrical equipment was 320-370 thousand kilometers, the failure rate of which exceeded the average level by 2-3 times.

Main part. Analysis of recent research. The main causes of failures of asynchronous electric drives of electric locomotives are:

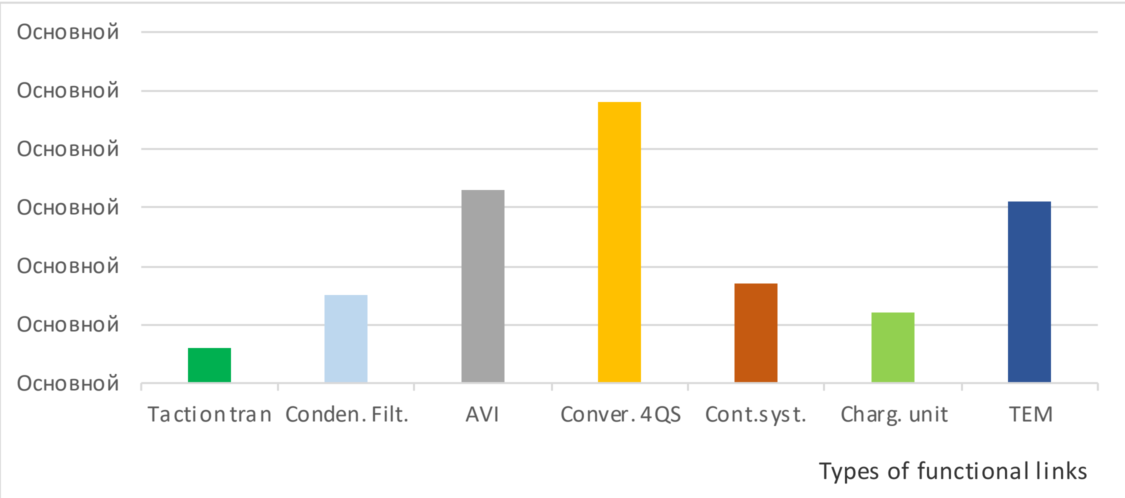
- low quality of current repair and maintenance and repair of the electric drive system;

- violation of the mode of control of electric locomotives by drivers;
- untimely delivery of spare parts (IGBT modules, microprocessor control systems, etc.).

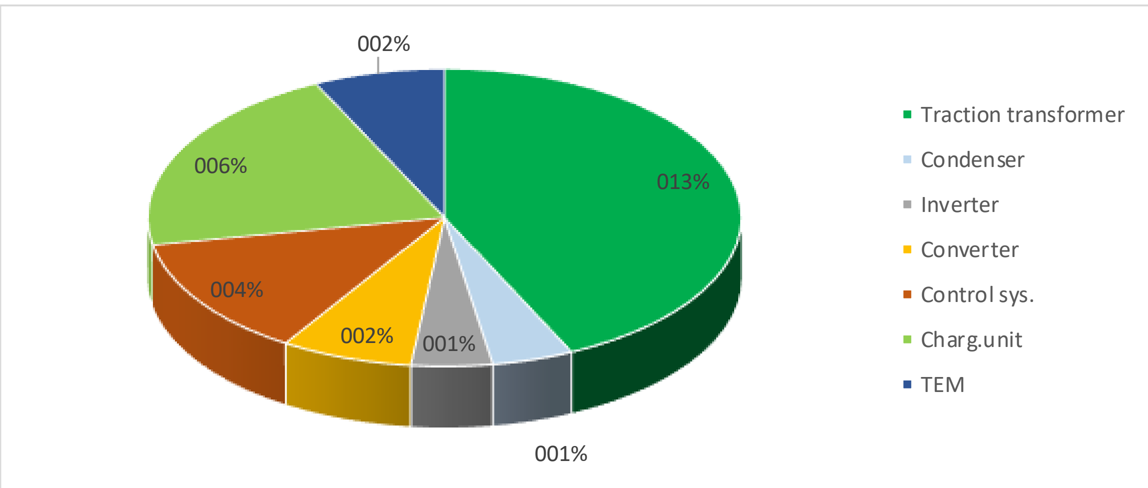
Data of failures and damages of functional links of asynchronous drive of electric locomotives.
Table 1.

Types of functional links of an asynchronous electric drive	Failures and damages, pcs.	The total number of operated functional links.
Traction transformer	6	49
Condenser filter	15	294
Autonomous voltage inverter	33	594
Converter 4QS	48	564
Control system	17	98
TEM	32	294

In Fig.1. a histogram and a diagram of specific failures of functional links (FL) of a controlled asynchronous electric drive are given.



a)



b)

Fig.1. Histogram and diagram of specific failures of functional links of control systems of electric locomotives of the series "O'zbekiston", "O'zY", "UzEL" and "UzELR" with asynchronous drive.

In case of failure of one of the functional units (FL) of the AC electric drive: a four-square converter 4QS, a capacitive filter, an autonomous voltage inverter (AVI), a control system, as well as a traction three-phase asynchronous motor (TAM), the operation mode of which is carried out by a microprocessor control system [1, 2.9].

With a partial metrological failure of each FL, the system retains its operability, but this error in many cases exceeds the permissible value. Diagnosis of complete failures of the FL is carried out using the built-in systems for diagnosing measuring instruments and the driver's controller.

In the existing system for diagnosing an asynchronous electric drive, a partial failure is not provided, therefore, an urgent task is to create a system for diagnosing partial failures, independent of the type of existing measuring instruments [1,2]. The proposed article discusses the stages of creating a regression model of the control device for the electric drive of electric locomotives.

Currently, maintenance and repair of AC electric locomotives in the depot "O'zbekiston" is a certain system of preventive and organizational impacts on the units and elements of the instruction in order to ensure their performance and assigned resource.

The operation of electric locomotives as recoverable objects is accompanied by two streams of events - the stream of failures of the elements of the FL and the stream of restoring their performance. In this case, the intensity of the restoration flow should be no less than the intensity of the failure flow. [3,4,7,8].

The essence of the established planned and preventive system for each stage of the maintenance and repair of AC electric locomotives is the performance of work in accordance with the structure of the cycle. At each stage of the maintenance and repair of the electric drive of electric locomotives, the work provided for by the standards and the list of operations is carried out.

An analysis of existing research in the field of TOR systems for the electric drive of AC electric locomotives in the conditions of the depot "O'zbekiston" made it possible to make a number of generalizations and definitions necessary to obtain new scientific and practical solutions [6]. To this end, we introduce a generalized characteristic of the state of tension of the operation of the electric drive of electric locomotives in the route - the ability and ability to perform multifaceted functions in each FL within the allowable deviations for its corresponding resource. The resource of the electric drive of an electric locomotive is a function of its generalized characteristic, i.e. abilities and multi-criteria capabilities to function in conditions of intensive development of the technical resource of electrical connections and electronic control units.

Formulation of the problem. Estimation of the greatest losses of resources of the control system during work processes during the period of passenger-freight intensive movements in case of emergency failure of the electric locomotive and the need to withdraw it from the established schedule. The resource capabilities of the installations of electric drives of electric locomotives involved in the process of movement depend on the variety, complexity and intensity of the traffic schedule, which requires the indispensable application of methods and tools for optimizing the frequency of the maintenance and repair system, taking into account the results of diagnosing [3,4].

Presentation of the main research material. To assess the linear regression dependence of the material of experimental studies, consider the data from the seven features indicated in Table No. 1. Corresponding to different types of FL. Data analysis shows that the most effective features are the capacitor filter, AVI, 4QS converter and the system of the existing control and diagnostics. Based on these data, we will compose a general linear equation [5]:

$$\hat{x}_{1,2,3,4,5} = b_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_5x_5$$

Random variables x_i will be normalized in the form:

$$t_j = \frac{x_j - \overline{x_j}}{s_j}, \qquad \text{Where} \quad j=\overline{1,5} \qquad (2)$$

As a result, we get the regression equation on a standard scale:

$$t_{1,2,3,4,5} = \beta_2 t_2 + \beta_3 t_3 + \beta_4 t_4 + \beta_5 t_5, \qquad (3)$$

Where $\beta_j = b_j \frac{s_j}{s_1}$ $\qquad j = \overline{2,5}$ $\qquad$ (4)

$b_j = \beta_j \frac{s_1}{s_j}$ $\qquad j = \overline{2,5}$ $\qquad$ (5)

We bring (3) to the form:

$$b_1 = \bar{x}_1 - b_2\bar{x}_2 + b_3\bar{x}_3 + b_4\overline{x_4} + b_5\overline{x_5} \qquad (6)$$

For further calculations, we will compose a correlation matrix using Ecxel [8]:

$$\begin{bmatrix} 1 & 0.56 & 0.48 & 0.58 & 0.25 \\ 0.56 & 1 & 0.46 & 0.14 & 0.10 \\ 0.48 & 0.46 & 1 & 0.15 & 0.04 \\ 0.58 & 0.14 & 0.15 & 1 & 0.30 \\ 0.25 & 0.10 & 0.04 & 0.30 & 1 \end{bmatrix} \qquad (7)$$

For the correlation coefficients $r_1 = \overline{2}; \overline{5}$, we determine the observed values of the criterion [5]:

$$|t_{набл}| = \frac{r_{1j}\sqrt{n-2}}{\sqrt{1-r_{1j}^2}} \qquad (8)$$

Taking into account (7), we obtain for each, respectively, the results of observations $|t_{набл}|$:

r_{1j}	0.56	0.48	0.58	0.25
$\lvert t_{набл} \rvert$	3.50	2.82	3.87	1.39

(9)

The tabular value of t - Student's test at the level $\alpha = 0{,}05$ of significance and the number of degrees of freedom n-2=30-2=28 is considered equal to 2.05. Hence the correlation coefficients $r_{12} = 0.56$; $r_{13} = 0.48$; $r_{14} = 0.58$ are significant at the $\alpha = 0{,}05$ level. And the correlation coefficients $r_{05} = 0.25$ are significant at the level of 0.20.

The regression equation on a standardized scale considering (3), (4), (5) can be represented as:

$$t_{1,2,3,4,5} = 0{,}41t_2 + 0.25t_3 + 0.52t_4 + 0.07t_5 \qquad (10)$$

$$\frac{\hat{x}_{1,2,3,4,5}-\bar{x}_1}{S_1}=\frac{0,41(x_1-\bar{x}_2)}{S_2}+0.25\frac{x_3-\bar{x}_3}{S_3}+0.52\frac{x_4-\bar{x}_4}{S_4}+0.07\frac{x_5-\bar{x}_5}{S_5} \quad (11)$$

Multiple determination coefficient:

$$R^2_{1,2,3,4,5}=\beta_2 r_{12}+\beta_3 r_{13}+\beta_4 r_{14}+\beta_5 r_{15} \quad (12)$$

Turned out to be $R^2_{1,2,3,4,5}=0,67$. This means that 67% of the fluctuation of the effective indicator (labor costs for maintenance and repair) is explained by the variation of the linear combination of failures in the operation of electric drive control systems, for given values of the regression coefficients $\beta_j, j=\overline{2,5}$. It is known [5] that the value (1-$R^2_{1,2,3,4,5}$)=1-0.67=0.33 determines the proportion of the effective attribute associated with the change in unaccounted factors. It must be indicated that the contribution of each factor x_j, при $j=\overline{2,5}$ taken into account in the total value of the attribute x_1 is determined as a product of $\beta_j r_{1j}$ expressed as a percentage.

Let's compile a modified table, based on the above correlation matrix, mutual influence, taking into account (9):

X_1	X_2	X_3	X_4	X_5
β_j	0.41	0.25	0.52	0.07
r_1	0.56	0.48	0.58	0.25
$\beta_j r_1$	0.23	0.12	0.30	0.02

From the latest data, it follows that 23% of the fluctuation of labor costs for TOR is associated with variability, i.e., the magnitude of failures in the operation of an asynchronous electric drive of an electric locomotive:

- 12% with variation of failures of autonomous voltage inverter;
- 30% - with a variation of failures in the operation of TAM;
- 2% - with a variation of 4QS failures.

The adjusted multiple correlation coefficient is [5]:

$$R^2_{1,2,3,4,5}=\sqrt{1-(1-R^2_{1,2,3,4,5})\frac{n-1}{n-k-1}}=0,82 \quad (13)$$

Substituting the initial data in (13) we get:

$$\hat{R}_{1,2,3,4,5}=\sqrt{1-(1-0.82^2)\frac{30-1}{30-4-1}}=0.79 \quad (14)$$

Next, we define the generalized resource of the system of a controlled asynchronous electric drive with TAD:

$$F_{\text{набл}}=\frac{R^2_{1,2,3,4,5}\cdot(n-k-1)}{(1-R^2_{1,2,3,4,5})k}=\frac{0,79^2\cdot(30-4-1)}{(1-0,79^2)\cdot 4}=6,36 \quad (15)$$

Let us now determine the role of the coefficients in the standardized regression equation (10). Let's say $x_2=\overline{x_2}+s_2$, $x_3=\bar{x}_3$; $x_4=\overline{x_4}$, $x_5=\bar{x}_5$.

Taking into account the initial data and substituting them into (10), we get:

$$\widehat{x_1} = \bar{x}_1 + \beta,\ s = \bar{x}_1 + 0.41 \cdot 25 = \bar{x} + 10.48 \qquad (16)$$

Analysis (16) shows that with an increase in the average number of failures in the operation of the electric drive system by $x_2 = 1.67$, the average value of labor costs for TOR-2 increases by 10.48, taking into account the fact that the values of other factors will be fixed at average levels.
Let us now consider the linear equation (11) of multiple regression and find out the role of the $b_j, j = \overline{2.5}$ coefficients in the equation.
In equation (11), we increase the values of the factor X_2 by $\Delta x_2 = 1$,and the values of the remaining factors, leaving them unchanged, we get:

$$\mathrm{x}_1 = \mathrm{x}_1(\mathrm{x}_2 + \Delta\mathrm{x}_2; \mathrm{x}_3; \mathrm{x}_4; \mathrm{x}_5) = 33.11 + 6.28(\mathrm{x}_2 + \Delta\mathrm{x}_2) = 4.32\mathrm{x}_3 + 12.31\mathrm{x}_4 + 1.74\mathrm{x}_5 \qquad (17)$$

The developed regression calculation models make it possible to quantify the dependence of the TOR volumes of failures in the operation of electric drive systems with TAJ and can be used to develop an optimal TOR system under the conditions of the current operation of electric locomotives.

Conclusions

The operation of modern electric locomotives such as "O'zbekiston", "O'z Y", "O'zEl" and "O'zELR" on the railway lines "O'zbekiston Temir Yo'llari" is very specific.
Work with the transportation of passengers and heavy cargo is carried out on various characteristics (length, longitudinal and transverse slopes, the radius of curves in plan and profile, the condition of the pavement of the track, routes, high dynamic loads on electric locomotives; these characteristics lead to a deterioration in their technical condition and significantly differ from the operating conditions prescribed by the manufacturer.
The analysis of regression and correlation indicators gives reason to believe that in complex and difficult operating conditions of electric locomotives in the system "O‘zbekiston temir yo‘llari", the indicators of change in the utilization coefficients of electric locomotives put into operation are characterized by three stages. At the first stage (1-1.2 years), there is a significant decrease in the utilization factor; at the second (2-5 years), the utilization factor stabilizes; at the third stage, it again decreases to the level when the operation of the electric locomotive takes a long time to perform major repairs.
Based on the above calculations, it can be said that the performance of electric locomotives is largely determined by the maintenance and repair system.
With a regulated service life of electric locomotives (20-30 years), the extension of their performance is largely determined by the use of modern monitoring and maintenance systems, including modified built-in devices and mathematical and algorithmic diagnostic methods, which is a priority task in this area.
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