PAPER • **OPEN ACCESS**

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To cite this article: S M Kuznetsov and E V Volkova 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **560** 012175

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Calculation of residual technical resource and increase in reliability of electric machines

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Abstract. In this paper, we consider a probabilistic mathematical model for estimating the state of the traction motor of a trolleybus. The operation of electric motors in transport is inevitably associated with gradual wear and tear and the need for periodic repairs. For the effective construction of systems of preventive measures, control, testing, current and major repairs, the importance of the causes of the failure of electric motors is necessary.

1. Introduction

The operation of electric motors in transport is inevitably associated with gradual wear and tear and the need for periodic repairs. For the effective construction of systems of preventive measures, control, testing, current and major repairs, the importance of the causes of the failure of electric motors is necessary.

The growing share of electric motors that have exhausted their regulatory life of work contributes to the growth of failures. The need to predict the destruction of elements assessing the risk of exploitation in conditions of incomplete information about the quality and condition of the equipment is a constant factor [1].

In the process of operation of the trolleybus under the influence of external influences arising in the course of maintenance of traction, the electric motor (TEM) continuously deteriorates, its reliability decreases and the number of failures increases.

The required level of reliability of the TEM can be maintained only if it is systematically monitored and diagnosed for its technical condition and timely technical service (TS).

The reliability of mechanical and electrical equipment of vehicles was widespread in the automotive industry, aviation, railway transport, agricultural machinery. However, it follows from the patent information search that the reliability of the TEM of the trolleybus has been studied little and it is necessary to continue work in this direction.

At the same time, experience in operating trolleybuses shows that the costs of maintaining (restoring) reliability are 3 to 6 times higher than the costs of their creation. One of the significant factors affecting the technical condition of the trolleybus is the imperfection of the TS system currently in use.

For technical inspection and repair (maintenance and repair) of the trolleybus, up to 75% of all depot facilities are spent, and the costs for TS and R of the traction motor of the trolleybus are about 60% of the total cost of maintenance. Considering the fact that the actual rolling stock is worn out by

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more than 70%, the problems of ensuring the reliability of the EE in the process of operation and determining the actual technical condition and its prediction are top priorities.

2. Formulation of the problem

There are known mathematical methods for modeling the state of objects: graphical (using probabilistic papers and nomograms) and analytical (the maximum likelihood method, the method of moments, quantiles, tabular, Boolean algebras, probabilistic-statistical, modeling by the Markov process) [3, 4]. Modeling by the Markov process is one of the fundamental methods, which has drawbacks - the rigid exponentially of the distribution laws of a random variable and the fact that the elements of the system can only be in two states (workable and inoperative). Here mathematical methods for modeling the state of objects are known: graphical (using probabilistic papers and nomograms) and analytical (the maximum likelihood method, the method of moments, quantiles, tabular, Boolean algebras, probabilistic-statistical, modeling by the Markov process) [3, 4]. Modeling by the Markov process is one of the fundamental methods, which has drawbacks - the rigid exponentiality of the distribution laws of a random variable and the fact that the elements of the system can only be in two states (workable and inoperative).

In the case of modeling the TEM state of a trolleybus, the most probable statistical method is the one that was used as the basis for the model of the technical state of the traction motor of a trolleybus [2, 12-15].

Determination of numerical characteristics of statistical series.

For each case of failure, electric rolling stock (ERS) runs were recorded since the last repair. The obtained data on the failures of the trolleybus engine are reduced to ordered statistical series. Such series for TEM faults are given in Tab. 1. The grouping step was taken $\Delta L = 5 \cdot 10^3$ km.

For all statistical series, the following numerical characteristics characterizing a sample of a random variable were determined.

3. Theory

1. Mathematical expectation of mileages:

$$L_o = \frac{\sum_{i=1}^{k} L_i \cdot m_i}{\sum_{i=1}^{k} m_i}, \quad (1)$$

where L_i – mileage in i-th discharge, km; m_i number of failures in i - th discharge; k – number of discharges.

Table 1. Distribution of failures in the intervals of elements of trolleybuses

Denomination of the failed node	***The mileage intervals of the mobile unit ΔL, thous. km***			
	0-15	15-30	30-45	45-60
Collector, armature of the TEM	3	5	2	1
Windings of the TEM	1	2	2	1
Brush assembly of the TEM	1	2	2	1
Insulation Resistance	1	2	2	1

2. Dispersion of the scattering of ranges:

$$D = \sigma^2 = \frac{\sum_{i=1}^{k} (L_i - L_o)^2 \cdot m_i}{\sum_{i=1}^{k} m_i}. \quad (2)$$

3. Mean square deviation of ranges or scattering:

$$\sigma = \sqrt{D} = \sqrt{\frac{\sum_{i=1}^{k} (L_i - L_o)^2 \cdot m_i}{\sum_{i=1}^{k} m_i}}. \quad (3)$$

4. The coefficient of variation:

$$V = \frac{\sigma}{L_o}. \quad (4)$$

Table 2. Results of calculations of numerical characteristics of the problems for the investigated elements of trolleybuses

Denomination of the failed node	***Numerical characteristics***			
	L_0	D	σ	V
Collector, armature of the TEM	31.875	221.484	14.882	0.467
Windings of the TEM	22.354	92.332	9.601	0.429
Brush assembly of the TEM	18.358	66.292	8.142	0.522
Insulation Resistance	19.813	80.335	8.963	0.471

For a justified solution of theoretical and practical problems of reliability, its current monitoring and forecasting for the TEM of a trolleybus, it is necessary to know the distribution laws of the initial random variables. However, an almost exact knowledge of these laws is possible only if there is sufficiently large statistical material on equipment failures [10, 13-15].

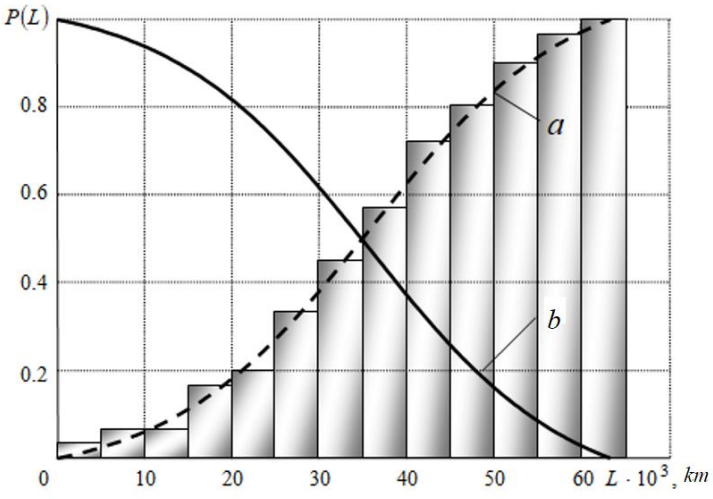

Figure 1. Probability a – failure $w(L)$; b – trouble proof operation $P(L)$ of the collector traction motor trolleybus ZiU.

Obtaining as a result of the experiment a statistical material about a random variable in the form of a sufficiently large number n of values of independent quantities x_i of the studied quantity X, called a statistical sample or a statistical series of the volume n, can determine the analytical form of the unknown probability density and the distribution function.

It is necessary to solve the problem of mathematical statistics [7, 8, 15-17], which consists in smoothing (aligning) statistical data by choosing comparatively simple analytic functions $\varphi(x)$ for estimation $f(x)$:

$$\varphi(x) \approx f(x). \tag{5}$$

To assess the likelihood of this approximate probability equality, the criteria for the agreement of the hypotheses under test are taken with respect to the type of functions $\varphi(x)$ and $f(x)$.

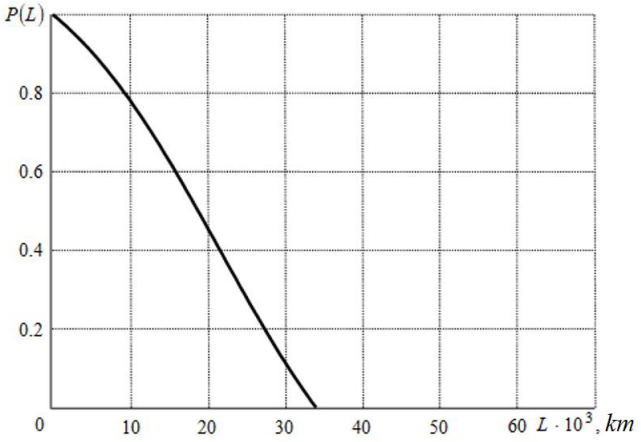

Figure 2. Probability trouble proof operation $P(L)$: brushes of TEM.

As the basic criterions, criterion χ^2 of Pirson and the criterion of Kolmogorov were adopted [9].

The criterion of consent of N.A. Kolmogorov is distinguished by simplicity and determined by the relation:

$$\gamma_1 = P\left\{\Delta = D_n \cdot \sqrt{n} \geq \lambda\right\}. \tag{6}$$

The application of the Kolmogorov criterion is limited by the requirement of preliminary (a priori) knowledge of the parameters for $F(x)$. Meanwhile, in practice the problem of statistical estimation of unknown parameters is most often posed.

This criterion χ^2 of Pearson's consent is free from this shortcoming. As a measure of the discrepancy for this criterion, the value of:

$$\Delta = \chi^2 = \sum_{i=1}^{k} \frac{\left(\Delta n_i^* - \Delta n_i\right)^2}{\Delta n_i}, \tag{7}$$

where Δn_i^* – the experimental number of realizations of the statistical series, grouping i-th interval; Δn_i – the theoretical (expected) number of realizations under the assumption that the unknown probability density is described by the chosen function $f(x)$.

As a result of the implementation of the above interpolation methods using programs developed by the author and analysing the convergence of functions, a universal analytic function was chosen with the help of which it was possible to smooth out the experimental data and obtain the characteristics of failures $W(L)$ and toubleproof operation $P(L)$ for each type of electrical equipment of the trolleybus. In detail, the method of selecting a smoothing function for one node is shown in Fig. 1. The universal analytic function has a form:

$$\psi(L) = \frac{\xi_1 - \xi_2}{1 + e^{\frac{(L - L_0)}{\Delta L}}} + \xi_2 . \tag{8}$$

4. Experimental results

The results of calculations of the numerical characteristics of the ranges for the samples studied are presented in TableII, from which it is possible to determine an important characteristic of the failure of the electrical equipment of the trolleybus, when the maximum number of its failures will be observed.

The mathematical expectation of the run L_o characterizes the mileage of a unit of ERS when the number of equipment failures is maximized. Scattering σ and the coefficient of variation indicate a possible range from their expectation.

It was proposed to estimate the relative reliability characteristic of the traction motor as the main term of its reliability and to determine it through the indicator that characterizes the number of failures of the engine equipment per unit of run, that is, through the failure flow W_o'.

For determination the relative characteristics of the reliability of the TEM trolleybus, the following numerical characteristics were determined characterizing the sampling of a random amount of equipment failures:

1. Mathematical expectation of failures:

$$W_o = \frac{\sum_{i=1}^{k} L_i \cdot m_i}{\sum_{i=1}^{k} L_i}, \tag{9}$$

where L_i – mileage in i-th interval, km; m_i – number of failures in i-th interval; k – number of interval.

2. Dispersion failure scattering:

$$D = \sigma^2 = \frac{\sum_{i=1}^{k} (m_i - W_o)^2 \cdot L_i}{\sum_{i=1}^{k} L_i} . \tag{10}$$

Table 3. Results of calculation of the numerical fault characteristics for investigated selections of trolleybuses

Denomination of the failed node	**Numerical characteristics**				
	W_o	W_o'	D	σ	V
Collector, armature of the TEM	2.242	0.0344	1.656	1.287	0.574
Windings of the TEM	1.931	0.0292	1.321	1.149	0.595
Brush assembly of the TEM	1.626	0.0251	1.047	1.023	0.629
Insulation Resistance	1.626	0.0251	1.047	1.023	0.629

Table 4. Coefficients and numerical characteristics of smoothing functions of trolleybuses

Denomination of the failed node	**Coefficient and numerical characteristics**			
	$\xi_1, \xi_2, L_0, \Delta L$	$\pm\sigma$	k	χ^2
Collector, anchor TEM	-0.05189, 1.07877, 36.7195, 11.78097	0.01983, 0.02601, 0.60945, 0.71925	0.988	0.0016
Windings of the TEM	-0.21321, 1.32577, 20.8753, 13.5633	0.09377, 0.03989, 0.94237, 0.07574	0.923	0.0019
Brush assembly of the TEM	-0.20721, 1.39359, 22.05213, 11.63301	0.04562, 0.08456, 0.83119, 0.09298	0.991	0.0011
Insulation Resistance	-1099.6672, 0.6535002, -208.90467, 27.80998612	40.835642, 0.0711454, 4.3354815, 2.287988	0.988	0.0026

3. Mean square deviation of failures or scattering of failures:

$$\sigma = \sqrt{D} = \sqrt{\frac{\sum_{i=1}^{k} (m_i - W_o)^2 \cdot L_i}{\sum_{i=1}^{k} L_i}}. \quad (11)$$

4. The coefficient of variation:

$$V = \frac{\sigma}{L_o}. \quad (12)$$

5. The discussion of the results

From Table III it is possible to determine the expected maximum number of failures of the trolleybus TEM W_o equipment by the grouping interval. Knowing the magnitude of the run, it is not difficult to calculate the maximum number of failures per 1000 km of mileage.W_o'. The mathematical expectation of failures W_o' determines the maximum number of failures per 1000 km. Scattering σ and the coefficient of variation V indicate a possible spread of the failure parameter from their expectation.

6. Conclusions

As a result of the statistical analysis, the degree of damage to the elements of the electric motor is determined, which is an important parameter for assessing the reliability of the TEM of a trolleybus.

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