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ALGORITHM AND METHODOLOGY FOR EVALUATING RELIABILITY INDICATORS OF A LARGE GEAR WHEEL OF A TRACTION GEARBOX FOR AN ELECTRIC LOCOMOTIVE

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ABSTRACT

The article presents an algorithm and methodology for assessing the reliability of a large gear wheel of a traction gearbox for electric locomotive. Numerical studies were performed in the MATHCAD 15 programming environment, using approximation and spline interpolation methods.

During the operation of traction rolling stock, the parameters of parts change, as a result of their interaction or the effects of external factors and in the manufacture of technical inspection or repair their control. All technical parameters monitored must be within certain tolerances i.e. to have a minimum $\boldsymbol{X_{min}}$ and maximum $\boldsymbol{X_{max}}$ value. The value that can be between the parameters during operation: $\Delta = \boldsymbol{X_{max}} - \boldsymbol{X_{min}}$ - tolerance field [1,2,3].

When all the parameters that characterize the ability of an object to perform the specified functions are within the tolerance field established by the requirements of the design (project) and normative-technical documentation, then this object is in the operable state. If at least one (or several) parameters go beyond the established tolerances, then this object passes into an inoperable state - it fails.

As a rule, it is not possible to constantly monitor the parameters of the parts. During regular repairs or inspections of traction rolling stock, the controlled parameter is measured. Realization of controlled parameter takes place from the moment of its nominal value, factory or restored, up to its limiting value during several successive measurements [2,3]. As the controlled parameter changes, at a certain operating time, it goes beyond the set limiting value $X_{доп}$, i.e. failure of the part comes. For example, the wear of gear tooth surface or tyre bandage thickness leads to failure of a wheel pair if their value exceeds the minimum (gear tooth thickness 11 mm, bandage thickness 45 mm). In this case, the monitored parameter belongs to the "decreasing".

MTBF is determined by a number of random factors - the quality of part manufacturing, operating conditions, quality of maintenance, repair and materials used, the degree of preparedness of equipment and personnel, and all this is a random variable. Any relationship that establishes the relationship between possible values of a random variable and their corresponding probabilities is a distribution law of a random variable [3,4].

When performing measurements of the controlled parameters of the wheel set: wheel rolling, ridge thickness, tire thickness are carried out according to [4,5,6,7] and the values are measured at least once every 30 days. In the time interval between two measurements, the mileage of the locomotive can be different, which causes a shift in the implementation of the controlled parameter along the mileage axis. Nevertheless, the scatter of values of mileage of different locomotives can be neglected [4] and we can assume that control of technical condition of a locomotive is carried out at the same mileage intervals, and results of measurements of controlled parameters form equally spaced series of observations.

It is reasonable to systematize the information about the values of the monitored parameter and the corresponding operating time of the equipment in order to further process and evaluate reliability indicators in the form of Table 1.

In the given Table 1 in each *i*-line the values of the controlled parameter of the concrete part, received on the same, *i*-th by the account measurement (*i=1...n*) are entered. The number of measurements of the controlled parameter for each measurement can be equal to N_i and decrease in connection with withdrawal of parts from observation, at production of unscheduled types of repairs. An example could be replacement of wheel-engine blocks due to failure of the locomotive axle unit.

Since the value of the controlled parameters and operating time to failure are random, to obtain reliable results the samples of initial data must be sufficiently representative. Minimal necessary sample volume, the number of measurement results of the controlled parameter, according to [5,6,7] is N=41.

The technique and algorithm of definition of conformity of samples of controllable parameters to supposed laws of distribution has been developed and described in works specified in the list of the used literature [2,3,4,5,6,7]. In order to check the compliance of a sample with the supposed theoretical distribution law one can use one of the well-known criteria, for example, Pearson's criterion of agreement. It allows to define the probability of the difference between theoretical and statistical distributions to be larger than actually observed due to random reasons [2]. Samples of controlled parameters of wearing parts correspond to normal law of distribution. Distribution density for this law is expressed by the following formula

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$$f(x) = \frac{1}{\sigma_x \cdot \sqrt{2\pi}} \cdot e^{-\frac{(x-m_x)^2}{2\sigma_x{}^2}} ,$$
(1)

where m_x is the expectation of the controlled parameter value;
σ_x- is the standard deviation of the controlled parameter value;
x - is the current value of the controlled parameter value.

Under the normal distribution law, the following relationships are imposed on the random variable $\sum_{j=1}^{k} P_j^* = 1$ - sum of frequencies over all intervals equals 1 (k - number of intervals); $m_x = m_x^*$; $D_x = D_x^*$ - parameters of statistical and theoretical distributions.

Since the numerical characteristics of the normal distribution law can be expressed through the mathematical expectation and variance of a random variable, we calculate their corresponding estimates: the mean value m_x^*

$$m_x^* = \frac{1}{N} \cdot \sum_{i=1}^{N} x_i$$
(2)

and variance estimation (standard deviation σ_x^*)

$$\sigma_x^* = \sqrt{\frac{1}{N-1} \cdot \sum_{i=1}^{N} \left((x_i - m_x^*)\right)^2} ,$$
(3)

where N - sample volume of the controlled parameter;
x_i - value of the controlled parameter.

The distribution density functions of the tooth thickness of the big toothed wheel of the traction reducer at the fixed operating time of 3VL-80c electric locomotive in the locomotive repair depot Uzbekistan are shown in Figure 1. The values of the numerical characteristics of the distribution law of the controlled parameter make it possible to predict their changes at the longest operating time, which in turn determines the service life, and for this purpose analytical dependences of the average values m_x and the standard deviations σ_x from the run are found.

The analytical dependence can be represented as some non-linear function $\boldsymbol{y} = \boldsymbol{f}(\boldsymbol{a_1}, \boldsymbol{a_2}, \dots, \boldsymbol{a_S}, \boldsymbol{\ell_i})$ of one argument $\boldsymbol{\ell_i}$ in the expression of which S parameters $\boldsymbol{a_1}, \boldsymbol{a_2}, \dots, \boldsymbol{a_S}$. are included. Using this function it is necessary to approximate the empirical regression set as n points $(\boldsymbol{\ell_i}, \boldsymbol{y_i})$ for $= \mathbf{1}, \mathbf{2}, \dots, \boldsymbol{n}$, where $\boldsymbol{y}$ is understood as one of the parameters of the considered distribution law.

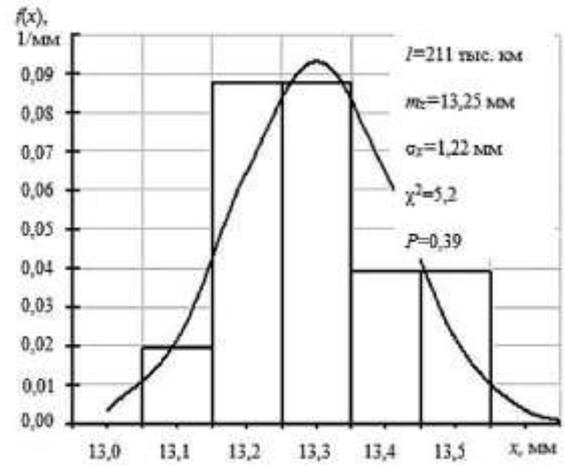

Figure 1. Distribution of the tooth thickness of the gear of the large gear wheel of the traction gearbox for the VL-80s electric locomotive (according to the locomotive repair depot Uzbekistan)

The parameters of the function $\boldsymbol{y}$ are found by the method of least squares, the condition of which is written in the form

$$Z(\boldsymbol{a_1}, \boldsymbol{a_2}, \dots, \boldsymbol{a_S}) = \sum_{i=1}^{n} [\boldsymbol{f}(\boldsymbol{a_1}, \boldsymbol{a_2}, \dots, \boldsymbol{a_S}, \boldsymbol{\ell_i}) - \boldsymbol{y_i}]^2 => min ,$$
(4)

Obtained in practice the values of controlled parameters and empirical dependences $m_x^*(\ell)$ and $\sigma_x^*(\ell)$ of wearing parts of traction rolling stock, can be

described by linear functions [2, 3, 4], that is, the approximating function has the form $y = a\ell + b$.
(5)
The criterion for the correspondence of the approximating function to the empirical dependences is the minimum of the sum of squares of deviations of the empirical and theoretical functions
$$\sum_{i=1}^{n}([\boldsymbol{y_i} - (a\boldsymbol{\ell_i} + b)]^2) \rightarrow min \quad .$$
(6)
Here
$\boldsymbol{y_i} = \begin{cases} m_{xi} \\ \sigma_{xi} \end{cases}$ when approximating the dependencies $\begin{cases} m(\ell) \\ \sigma(\ell) \end{cases}$;
$\boldsymbol{\ell_i}$ – operating time. The coefficient a of linear function is determined by "least squares" method using MATHCAD 15 programming environment according to methods of works [5,6,7] by formula
$$a = r_{y\ell} \cdot \frac{\sigma_y}{\sigma_\ell} \quad ,$$
(7)

where $r_{y\ell}$ is the correlation coefficient between random numbers y and l ;
σ_y, σ_ℓ are the standard deviations of random numbers y and l, respectively.
The coefficient b for the regression equation is determined by the formula
$$b = m_y - am_\ell \quad ,$$
(8)
где m_y – среднее значение величины y ;
m_ℓ - среднее значение наработки.

where m_y is the mean value of y ;
m_ℓ is the mean value of the operating time.
The correlation coefficient $r_{y\ell}$ characterizes the closeness of the linear relationship between the random variables y and l , determined by the formula
$$r_{y\ell} = \frac{k_{y\ell}}{\sigma_y\sigma_\ell} = \frac{\alpha_{11}(y,\ell) - m_y m_\ell}{\sigma_y\sigma_\ell} \quad ,$$
(9)
where $\alpha_{11}(y,\ell) = \frac{1}{N}\sum_{i=1}^{N} y_i\ell_i$ is the second mixed initial moment for the random variables y and l .
For electric locomotives 3VL80s, operated at JSC "Uzbekistan Temir Yullari" (according to the Department of locomotive operation for depot Uzbekistan), calculations were carried out on controllable parameters, such as: the thickness of wheel set tire, the thickness of the large gear wheel of traction reducer. As a result of numerical calculation of empirical regression equation coefficients in MATHCAD 15 programming environment using approximation and spline interpolation methods, regression equation for mileage dependence of the mean square deviation of wear of the gear tooth of the big toothed wheel of the traction reducer was obtained
$\boldsymbol{\sigma_x(\ell)}$ = 0,0000171 * x + 0,2582241,
(10)
where the correlation coefficient r = 0.195.

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