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METHODOLOGY FOR ASSESSING RELIABILITY INDICATORS OF BODY FRAMES OF METRO ELECTRIC TRAIN

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ABSTRACT

The article presents a new developed method for assessing the reliability indicators of the frames of the bogies of the metro electric trains based on the results of diagnostics; the numerical studies were performed in the MathCAD 15 programming environment. As a result, a methodology for assessing the reliability indicators of the body of frames of metro electric train wheel pair is proposed based on information on instrumental and non-destructive testing.

In the world, the task of assessing and forecasting the resource of electric trains of the metro has been considered in many scientific works and is relevant at the present time. This is due to both economic and organizational reasons caused by the aging of the fleet of electric rolling stock and the desire to prevent dangerous destruction, based on the standardized parameters of the resource, safety and risks under strength conditions.

Under the influence of cyclic dynamic loads, the strength properties of the metal of the parts and structures of the undercarriage of electric trains (bogie frames, main frames and bodies, parts of wheel pairs, etc.) degrade, their fatigue resistance decreases, the yield strength and brittleness of the material increase, which can lead to their destruction. Therefore, conducting scientific research in this area with the development of a method for calculating the residual life of bogie frames of electric trains with an assessment of their reliability for the conditions of the Republic of Uzbekistan is a relevant topic.

Leading scientists around the world have conducted and are conducting research on this topic, such as C.A. Brebbia (Wessex Institute of Technology, UK), G.M. Carlomagno (University of Naples di Napoli, Italy), A. Varvani-Farahani (Ryeson University, Canada), S.K. Chakrabarti (USA), S.Hernandez (University of La Coruna, Spain), S.-H. Nishida (Saga University, Japan); in the CIS countries, authoritative scientific schools and leading scientists from MIIT, PGUPS, MAI, VNIIZhT, JSC VNIKTI, JSC Russian Railways and others have worked on the issues raised [3,4,5,6]. A significant contribution to the solution of many complex problems and the verification of theoretical conclusions related to the calculation of durability indicators and the determination of the service life of parts and units of rolling stock was made by the Russian Research Institute of Railway Transport (TsNII MPS) and the Russian Research Institute of Carriage Building (NIIV), which, along with theoretical research, conducted a large number of experimental studies, both bench and full-scale.

In Uzbekistan, the problem of optimizing the operation of wheels and rails by reducing contact stresses during the dynamic interaction of wheel pairs of rolling stock, as well as the development of methods for calculating the dynamic strength of frame structures of locomotives of complex configuration and methods for calculating the resource for transport engineering were studied by Academician of the Academy of Sciences of the Republic of Uzbekistan, Professor Glushchenko A.D., Professors Fayzibaev Sh.S., Khromova G.A., Shermukhamedov A.A., Rakhimov R.V., Khamidov O.R., Zainutdinov N.S., Radjibayev D.O. and their students [7,8,9].

The stresses that arise in the parts of the subway car bogie frames during operation are in most cases variable in time, and they are often random functions of time. If the level of variable stresses exceeds a certain limit, then a process of gradual accumulation of damage occurs in the material of the part, leading to the formation of a crack, its development and the final destruction of the part. This process is conventionally called metal fatigue, and the corresponding destruction is called fatigue [1,2].

In this case, the fatigue process is associated with the development of plastic deformation, which occurs during the aging of the material and prepares the origin of the smallest cracks – submicro cracks. The length of these cracks increases, then they unite, forming the first macroscopic crack, which is understood as a crack with a length of 0.1 - 0.5 mm. At the root of this crack, a local increase in stress occurs, called stress concentration, which facilitates its further development. The crack, gradually developing and weakening the section, causes at some point in time a sudden destruction of the part, which is often associated with accidents and very serious consequences.

The Department of Operation of Subway Cars of JSC “Uzbekistan Railways” in Tashkent has identified a significant number of fatigue cracks, despite their repair according to the instruction CT 336, which significantly weakens the most dangerous sections. Figure 1 shows a photograph of a subway car bogie of modification 81-717/714 with fatigue cracks in the bogie frame after 30 years of operation.

This circumstance has caused the need for further improvement of dynamic characteristics and increase in strength, reliability and failure-free operation, as well as justification of the frequency of non-destructive testing during diagnostics [4,5].

This article is devoted to the development of a new method for assessing the reliability indicators of the frames of subway electric train bogies based on the results of diagnostics; numerical studies were performed in the MATHCAD 15 programming environment.

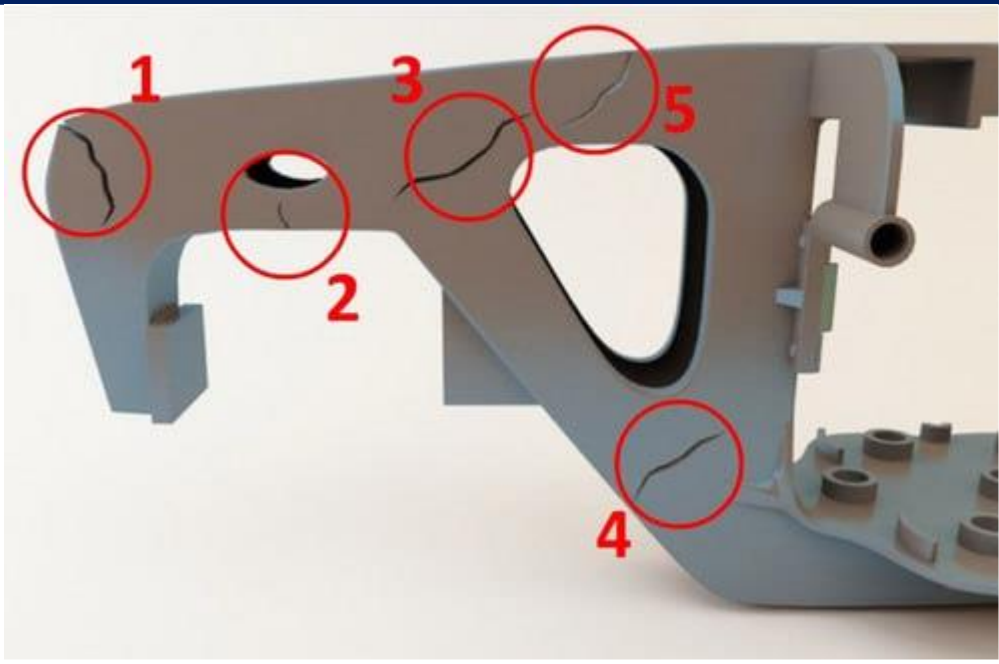


Figure 1. Photograph of the bogie frame of the 81-717/714 subway car with fatigue cracks.

To justify the frequency of non-destructive testing of critical parts and units of rolling stock, which include the frames of metro train bogies, a model of its survivability was developed based on the Paris relationship [1,2], taking into account the development of fatigue cracks, written in the form:

$$\frac{d\ell}{dN} = C(\Delta K)^m , \qquad (1)$$

where $\frac{d\ell}{dN}$ is the crack growth rate; C, m are material constants that depend on the metal crystallography and the cycle asymmetry coefficient $R = \frac{K_{min}}{K_{max}}$; 2ℓ is the crack length; on average $m = 1 \ldots 6$; K is the stress intensity factor (SIF) at the crack tip, determined by the formula

$K = \beta\sigma\sqrt{\pi\ell}$ [1], where K_{min} and K_{max} are the stress intensity factors at the maximum and minimum stresses of the cycle; σ is the applied uniform tensile stress acting on the specimen in the direction perpendicular to the crack plane; β is a dimensionless parameter that depends on the specimen geometry; ΔK is the range of the stress intensity factor

$$\Delta K = K_{max} - K_{min}. \qquad (2)$$

In the case of finite dimensions of the research object, there is a need for a correction function for the SIF parameter, taking into account the geometric features and the loading method of the researched natural object.

With the correction function, equation (1) looks like

$$\frac{d\ell}{dN} = C\Delta K^m \cdot f(\ell) . \qquad (3)$$

The final equation (3) is

$$\frac{d\ell}{dN} = C\sigma^m \cdot \sqrt{\pi}^m \cdot \ell^{\frac{m}{2}} \cdot f(\ell) , \qquad (4)$$

which is a first-order differential equation with separable variables. After separation of variables, equation (4) has the form

$$\frac{d\ell}{f(\ell)\cdot\ell^{\frac{m}{2}}} = C\sigma^m \cdot \sqrt{\pi}^m \cdot dN\,. \qquad (5)$$

After artificially transforming the numerator by adding and subtracting one, equation (5) takes the form

$$\frac{\ell^{-\frac{m}{2}}\cdot(1-f(\ell))}{f(\ell)}d\ell + \frac{1}{\ell^{\frac{m}{2}}}d\ell = C\sigma^m \cdot \sqrt{\pi}^m \cdot dN\,. \qquad (6)$$

After integration and grouping, equation (6) takes the form

$$\int \frac{\ell^{-\frac{m}{2}}\cdot(1-f(\ell))}{f(\ell)}d\ell = C\sigma^m \cdot \sqrt{\pi}^m \cdot N - \frac{\ell^{1-\frac{m}{2}}}{1-\frac{m}{2}}. \qquad (7)$$

In equation (7) on the right is a quantity that depends on ℓ and N

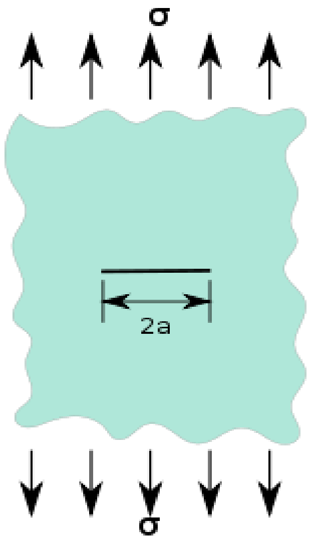
$$\int \frac{\ell^{-\frac{m}{2}}\cdot(1-f(\ell))}{f(\ell)}d\ell = S(\ell, N). \qquad (8)$$

The resulting function $S(\ell, N)$ can be written as a function of one variable ℓ or N, due to the fact that there is a functional dependence between the quantities ℓ and N themselves. Having obtained values for the right-hand side of (8) from the experiment and having written the function $S(\ell)$ in explicit form, the correction function is defined as

$$f(\ell) = \frac{1}{1+\ell^{\frac{m}{2}}\cdot\frac{dS}{d\ell}}\,. \qquad (9)$$

The stress intensity factors are different for different crack configurations. For example, for an infinite plate under uniform uniaxial stress (see Figure 2), the intensity factor is [7]

$$K = \sigma\sqrt{\pi\ell}, \qquad (10)$$



2ℓ

Figure 2. Crack in an infinite plate under uniform uniaxial stress, where 2ℓ is the crack length.

In the monograph [7] and articles [8,9], a calculation analysis was performed to model the strength and reliability indicators of the frame of a subway car bogie of modification 81-717/714 with fatigue cracks (before and after modernization with the installation of reinforcing steel plates). The macro relief of the fracture is largely determined by the rate of propagation of the fatigue crack [3,4,5].

For bogie frame units, the design of which was changed simultaneously with the change (reinforcement) of the sidewall, all this allows us to adopt the coefficient $\beta_к = 1$, while the *permissible stresses* are calculated in the form of the formula

$[\sigma] = [\sigma_d + \sigma_{st}] = 280{,}4$ MPa. (13)

When checking the fatigue strength of the bogie frame, taking into account that the frame elements are subject to alternating asymmetric stress, a material sensitivity *coefficient to cycle asymmetry* $\psi\sigma = 0.6$ is introduced, as well as an additional safety factor due to *the presence of stress concentrators* $K\sigma = 2.4$. In this case, the endurance limit for the frame elements of a subway car bogie will be equal to

$$\sigma_{durability} = \frac{\sigma_T}{K\sigma} + \left(1 - \frac{2\sigma_T - \sigma_0}{\sigma_T\, K\sigma}\right)\sigma_m \text{ ; where}$$

$\sigma_{durability} = 131.306$ MPa. (14)

As shown by operational practice and theoretical generalizations, the causes of failures may be design flaws, poor quality of manufacturing and materials used, violations of maintenance and repair rules, exposure to increased loads and external (climatic) conditions, destruction of auxiliary and related parts, natural processes of wear and aging [7,8,9]

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