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ALGORITHM FOR PERFORMING NUMERICAL CALCULATIONS OF THE STRENGTH OF THE SECTIONS OF THE SUBWAY CAR BOGIE FRAMES

Khromova Galina Alekseevna[1]
Rajibaev Davran Oktombaevich [2]
Mirzarakhimov Bobur Mirzo Ulugbek ugli[3]
[1]doctor tech. sciences, professor
[2]doctor (of. Sc) tech. sciences, associate professor, of the Department of "Electric rolling stock"
[3]master's student of the Department of "Electric rolling stock", State Transport University, Uzbekistan, Tashkent

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ABSTRACT

The article presents a developed algorithm for performing numerical calculations on the strength of the sections of the subway car bogie frame; the numerical studies were carried out in the MATHCAD 15 programming environment. The proposed method improves dynamic performance and increases strength and reliability (in particular, for subway car bogies) taking into account the modernization of frames.

According to the International Union of Public Transport, a metro is a predominantly intracity passenger transport system with its own railway lines, completely separated from vehicular and pedestrian traffic. As of December 2024, there were 222 metro systems worldwide in 204 cities across 63 countries. The first metro in the world was the London Metro, opened in 1863 and electrified in 1890. The Beijing Metro is the busiest. The Shanghai Metro leads in terms of line length and number of stations, the New York Metro leads in terms of number of lines, and the Saint Petersburg Metro leads in terms of average station depth. 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.

A dramatic increase in passenger traffic in major cities has become a reality in modern Uzbekistan. Existing urban transport systems are struggling to meet their mandated needs of transporting millions of passengers in a timely, safe, and comfortable manner. The metro is one of the primary modes of urban transport in Tashkent, Moscow, St. Petersburg, Nizhny Novgorod, Samara, Yekaterinburg, Novosibirsk, and Kazan. As an off-street urban route that avoids the problems of congested streets, the metro plays a leading role in providing mass passenger transportation in these largest Russian cities.

However, one of the specific features of metro systems is the higher reliability requirements for rolling stock compared to surface transportation, due to the tunnel nature of train travel with minimal headways and poor track infrastructure. In other words, any failure - that is, an event that disrupts the functionality of a metro car -can lead to disruption of the schedule for one line, and, in severe cases, disrupt the entire metro system and the modern city's transportation system.

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 [2,3,4,5]. 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 [6÷10].

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.

In modern literature, the issues of the theory of vibrations and reliability of rolling stock bogie frames, taking into account the optimization of their dynamic characteristics, as well as methods for their rational design and modernization are not sufficiently developed to date [1÷5]. Due to the mass failure of subway cars, JSC Uzbekistan Temir Yollari needs to develop a new method for upgrading the frame of the bogie of a motor-car rolling stock during major repairs in order to improve dynamic characteristics and increase strength and reliability (specifically, for the bogies of a motor-car metro car).

Based on the quasi-static strength calculation, a dynamic calculation of the frame of the metro motor-car bogie was then performed, numerical studies were carried out in the MATHCAD 15 programming environment. The theoretical and numerical studies were carried out based on the works of the authors of this article [6÷10].

The numerical calculation algorithm consists of 4 stages.

Stage 1. Quasi-static calculation for possible unfavorable combinations of static loads [1÷5]. Based on the quasi-static calculation, the design parameters for the reduced moment of inertia and reduced mass for the subway car bogie frame were calculated with the division of the entire longitudinal beam (the side of the bogie frame) into 20 points, subject to a change in $0 \le X \le 2{,}43$ m.

Stage 2. Finding the natural frequencies of the system and studying the natural oscillations. The transcendental frequency equation of the system of the form is solved by the iteration method

$$E_1 \cdot sh\ \omega_K X + E_2 \cdot ch\ \omega_K X + E_3 \cdot sin\ \omega_B X +$$
$$+E_4 \cdot cos\ \omega_B X = 0, \text{ at } X = 1. \qquad (1)$$

The natural frequencies of oscillations for the system are found in the form

$$\omega_K = \sqrt{-\frac{\alpha^2}{2} + \sqrt{\left(\frac{\alpha^2}{2}\right)^2 - (\lambda_n)^2}} \quad , \omega_B = \sqrt{\frac{\alpha^2}{2} + \sqrt{\left(\frac{\alpha^2}{2}\right)^2 - (\lambda_n)^2}} \qquad (2)$$

The study of natural vibration modes is carried out in the form

$$W(X,t) = \{\frac{\aleph_1 \cdot \left(1 + \omega_K^2 / \omega_B^2\right) + \omega_B^2}{\omega_K^3} \cdot sh\ \omega_K X + ch\ \omega_K X + sin\ \omega_B X +$$
$$+\omega_K^2/\omega_B^2 * cos\ \omega_B X\} * (A_n \cos p_{n1,2}\, t + B_n \sin p_{n1,2}\, t), \qquad (3)$$

Stage 3. Dynamic calculation of the subway car bogie frame. A dynamic calculation of the sidewall of the subway car frame is performed as it moves along_a joint unevenness. A solution is sought for dynamic displacements in the form

$$W(X,t) = \sum_{k=1}^{\infty} W_K(X) \cdot W_K(t), \qquad (4)$$

where $W_K(X)$ - natural functions; and dynamic movements of the sections of the sidewall of the subway car bogie frame - $W_K(t)$ represent the dynamic deflection of the sidewall of the bogie frame over time.

Stage 4. Calculation of static and dynamic stresses for the sections of the sidewall of the subway car bogie frame with varying external load $\eta_{UN}(t)$ and verification of permissible stresses taking into account strength and fatigue conditions.

The smallest permissible value of the actual safety factor under these conditions is determined by the formula

$$n_{oy} = \frac{\sigma_m}{\beta_k(\sigma_y + \sigma_{st})} \ge 1.1. \qquad (5)$$

In this formula $\boldsymbol{(\sigma_y + \sigma_{st})}$ is the maximum total stress under impact (or static loading) with a force of 2.5 MPa along the axis of the automatic coupling, taking into account weight stresses; βk is the stress concentration coefficient.

The calculated frame of the subway car bogie is designed to ensure the absence of stress concentrations in the transition areas from the non-reinforced profile to the reinforced one and in the areas where the transverse elements of the bogie frame adjoin the sidewall. For the bogie frame units whose design was changed simultaneously with the change (reinforcement) of the sidewall, all this allows us to adopt the coefficient $\beta k = 1$. Therefore

$$[\sigma] = [\sigma_y + \sigma_{st}] = 280{,}4 \text{ MPa}. \qquad (6)$$

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 the subway car bogie will be equal to

$$\sigma_{en\ L} = \frac{\sigma_{Tst}}{K\sigma} + \left(1 - \frac{2\sigma_{Tst} - \sigma_0}{\sigma_{Tst}\ \ K\sigma}\right)\sigma_m\ ;\ \sigma_{en\ L} = 131.306 \text{ MPa}. \qquad (7)$$

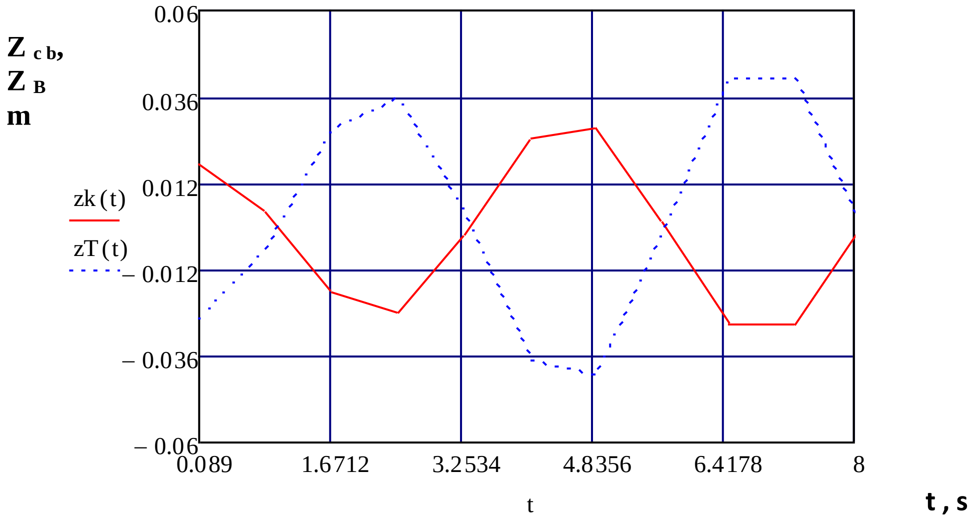

Figure 1. Graph of vertical oscillations of the sidewall sections (A-A) of a subway car bogie as it moves along a track with changes in time.

Based on the results of the theoretical-numerical calculation, the following general conclusions can be made regarding the assessment of *the vibration impact on the cross-sections of the subway car bogie frame*:

1. Figure 1 shows a graph of vertical oscillations of the sidewall sections (A-A) of a subway car bogie **Z cb** and body oscillations **Z B** during its movement along a track with a change in time ***t***. It follows from Figure 1 that the process of oscillations of the bogie frame sections and the subway car body is harmonic. At a design speed of movement $V_{konsr} = 100$ *km/h*, the resulting oscillations (vertical displacements) are insignificant and amount to ± 4.8356 mm. At the same time, with increasing speed, they will increase. At a maximum speed *Vmax = 250 km/h*, the maximum vertical oscillations of the bogie **Z cb** will reach ± 10.6931 mm.

2. The data of the theoretical calculation carried out by the authors of this article are confirmed by the results of experimental studies carried out by the authors of the works [7,8,9,10].

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