EURASIAN JOURNAL OF ACADEMIC RESEARCH
Innovative Academy Research Support Center
UIF = 8.1 | SJIF = 5.685 www.in-academy.uz

NUMERICAL STUDIES ON ELASTIC THIN-WALLED PLATE MODEL WITH MESH FRAME FOR PNEUMATIC SPRINGS OF HIGH-SPEED ELECTRIC TRAIN

Khromova Galina Alekseevna[1]
Makhamadalieva Malika Alievna[2]
[1]doctor tech. sciences, professor
[2]doctoral student of the Department of “Electric rolling stock”, State Transport University, Uzbekistan, Tashkent
https://www.doi.org/10.5281/zenodo.10058036

ARTICLE INFO

Received: 23th October 2023
Accepted: 30th October 2023
Online: 31th October 2023

KEY WORDS

High-speed electric trains, spring suspension, pneumatic springs, thin-walled plate with mesh frame, strength, reliability, algorithm, program.

ABSTRACT

The article presents the results of numerical studies for a pneumatic springs of a high-speed electric train in the form of a model of an elastic thin-walled plate with a mesh frame under the influence of pulsating pressure.

Analysis of studies on the calculation of pneumatic springs of vehicles with rubber-cord reinforcement showed that in almost all designs of spring suspension of modern electric locomotives, subway cars, high-speed electric trains, pneumatic spring elements of various types are used (for example, in France, Germany, Switzerland, Japan, Russia and China). Pneumatic rubber-cord elastic elements served as the basis for the creation of new types of adjustable suspensions with automatically controlled parameters. The use of air as an elastic body makes it possible to realize great flexibility in a small volume, up to the limit corresponding to the lower limit of natural frequencies of vibrations of the vehicle body [1,2].

The main unit of the pneumatic elastic element is a rubber cord shell consisting of two to four layers of viscose, nylon or capron fabric reinforced from the outside with steel stiffeners. Outside and inside, the shell is covered with layers of oil and gasoline resistant rubber. The internal air pressure presses the flanges of the elastic shell against the steel reinforcement [1,2,3].

Based on the review of the scientific, technical and patent literature, we have developed a numerical and analytical model for the dynamic calculation of the element of the elastic shell of the pneumatic compressor clamped by stiffening ribs, which is a logical continuation of the models and calculation methods presented in the works [5-8].

To justify the design model, we introduce a number of assumptions that are possible for the engineering calculation:

1) Almost all types of pneumatic springs have a «rigid» shell in the form of a metal frame of various types. In this regard, it will be assumed that closed convex rubber-cord surfaces in a metal frame formed as a result of extrusion of elastic shell elements do not allow local deformations of folding in certain areas, for example, curvilinear ends.

2) The metal frame in the form of stiffeners will be considered absolutely rigid.

3) The rubber cord shell is considered extensible. Its elements are clamped between stiffening ribs of metal frame [1,2,3]. We present a design diagram in the form of 2 elements of an elastic shell clamped between two stiffening ribs and an element of a metal frame in the junction of compartments *i* and *(i +1)*. Note here that every element of elastic shell 1, 3 has its initial bending radius R_{01} and R_{03}. The metal frame element 2 also has an initial bending radius R_{02} produced by the initial internal air pressure in the P_{0V} system. Elements of elastic shell 1 and 3 have masses m_1 and m_3, respectively, and element of metal frame clamped between them - m_2.

The whole system bends at the initial moment under the action of the initial internal air pressure of the P_{0V}. Next, we examine the process of vibrations in the system under the action of lateral rolling that occurs during the movement of the vehicle.

4) The whole system moves in the plane due to joint oscillations of the pneumatic spring and, for example, the electric locomotive when it moves along the rail track with periodic mating irregularities.

For the model of the rectangular plate of the element of the side wall of the elastic shell, the pneumatic springs of the high-speed electric train and taking into account the introduced assumptions, we will record the differential equation of bending oscillations in the form [4]

$$\frac{\partial^4 W_p}{\partial X^4} + 2 \cdot \frac{\partial^4 W_p}{\partial X^2 \partial Y^2} + \frac{\partial^4 W_p}{\partial Y^4} = \frac{q_p(X,Y)}{D_p}. \qquad (1)$$

We use the bending functions of the middle layer of the supporting frame model along the axis *OX*, taking into account the own bending functions of the elastic rods of the metal mesh frame, which arise under the quasi-static effect of internal air pressure in the system. In this regard, taking into account the non-linearity of the impact, we assume a dynamic load in the form of harmonic decomposition into a series

$$\frac{q_p(X,Y)}{D_p} = \sum_{i=1,3,5} A_{ip}(Y) \cdot SIN\,\frac{i\pi X}{2 \cdot h_p}\ . \qquad (2)$$

For such assumptions, it is possible by Fourier to represent the solution of equation (2) in the form of the sum of a series of the form

$$W_{ip}(X,Y) = W_{ip}(Y) \cdot SIN\,\frac{i\pi X}{2 \cdot h_p}, \qquad (3)$$

where $i = 1, 3,5 \ldots$

After substituting partial derivatives of (3) into equation (1) for each «*i*» vibration form, we obtain the equation

$$\frac{d^4 W_{pi}}{\partial Y^4} - \frac{\pi^2 \cdot i^2}{4 \cdot h_p^2} \cdot \frac{d^2 W_{pi}}{\partial Y^2} + \frac{\pi^4 \cdot i^4}{16 \cdot h_p^4} \cdot W_{pi} = A_{ip}(Y), \qquad (4)$$

which allows precise solutions to define the function $W_{ip}(X,Y)$.

The following boundary conditions are valid for this equation:

- at $Y = 0$ according to the deflections of the elastic rod frame model of the pneumatic springs $W_{ip}(X,Y) = W_{oi}$;

- its turning angles from torsion:

$$\frac{dW_{ip}(0)}{dY} = \dot{W}_{Oi}\ ;\ \ \frac{d^2 W_{ip}(0)}{dY^2} = \ddot{W}_{Oi}\ ;\ \ \frac{d^3 W_{ip}(0)}{dY^3} = \dddot{W}_{Oi}\ . \qquad (5)$$

- at $Y = \pm 0.5\ b_p$:

$$\frac{d^2 W_{ip}(0.5\ p)}{dY^2} = \frac{d^3 p(0.5\ b_p)}{dY^3} = 0\ . \qquad (6)$$

The solution of equation (4) is performed by operating Laplace transformation in time. As a result, we get a solution of the form

$$W_i(Y) = A_{i\Pi} \cdot \left[\frac{16 \cdot h_{\Pi}^4}{\pi^4 \cdot i^4} + \frac{(\rho_1^2 - \rho_2^2) \cdot sh\rho_1 Y \cdot \sin\rho_2 Y - 2\rho_1\rho_2 \cdot ch\rho_1 Y \cdot \cos\rho_2 Y}{2\rho_1\rho_2 \cdot [(\rho_1{}^2 - \rho_2^2) + 4 \cdot \rho_1{}^2 \cdot \rho_2^2]} \right] +$$
$$+W_{oi} \cdot \frac{1}{2\rho_1\rho_2} \cdot [(\rho_1^2 - \rho_2^2) \cdot sh\rho_1 Y \cdot \sin\rho_2 Y - 2\rho_1\rho_2 \cdot ch\rho_1 Y \cdot \cos\rho_2 Y] +$$
$$+\dot{W}_{Oi} \cdot \frac{1}{2\rho_1\rho_2} \cdot [\rho_1 \cdot ch\rho_1 Y \cdot \sin\rho_2 Y - \rho_2 \cdot sh\rho_1 Y \cdot \cos\rho_2 Y] +$$
$$+(\ddot{W}_{Oi} + \frac{\pi^2 i^2}{4 \cdot h_K^2} \cdot W_{oi}) \cdot \frac{1}{2\rho_1\rho_2} \cdot [sh\rho_1 Y \cdot \sin\rho_2 Y] + \qquad (7)$$
$$+(\dddot{W}_{Oi} + \frac{\pi^2 i^2}{4 \cdot h_K^2} \cdot \dot{W}_{oi}) \cdot \frac{1}{2\rho_1\rho_2} \cdot [\rho_1 ch\rho_1 Y \cdot \sin\rho_2 Y - \rho_2 \cdot sh\rho_1 Y \cdot \cos\rho_2 Y].$$

As a result of numerical studies on the bending vibrations of the elastic plate with a mesh frame in the pneumatic compressor of a high-speed electric train in the MATHCAD 15 programming environment, we will obtain a solution on the real structural dimensions of the integral soft container of the pneumatic spring by the numerical method using the ready-made analytical solution $W_{ip}(X, Y)$ for the elastic shell element by piecemeal-linear approximation and binding by iteration by system nodes by analogy with works [5-7].

During numerical studies, the analysis of the solution on the stressed-deformed state was carried out for 3 tasks:

Task 1. Examination of the vibrations of the element of the elastic shell of the pneumatic compressor, clamped by stiffeners, under the assumption of a system with concentrated masses.

Task 2. Loading of the elastic element of the shell in the form of a plate of a pneumatic compressor with a metal mesh frame with a quasi-static load, which takes into account an increase in static loading over a certain interval of τ_0 time. Mode of increasing the internal pressure of the air medium in the elastic shell.

Task 3. Loading of elastic element of pneumatic compressor shell in the form of plate with metal mesh frame with harmonic load arising at movement of high-speed electric train at certain speed V_p .

$\boldsymbol{W_{ip}(X, Y) \cdot 10^{-4}}$ ***м***

EURASIAN JOURNAL OF ACADEMIC RESEARCH
Innovative Academy Research Support Center
UIF = 8.1 | SJIF = 5.685 www.in-academy.uz

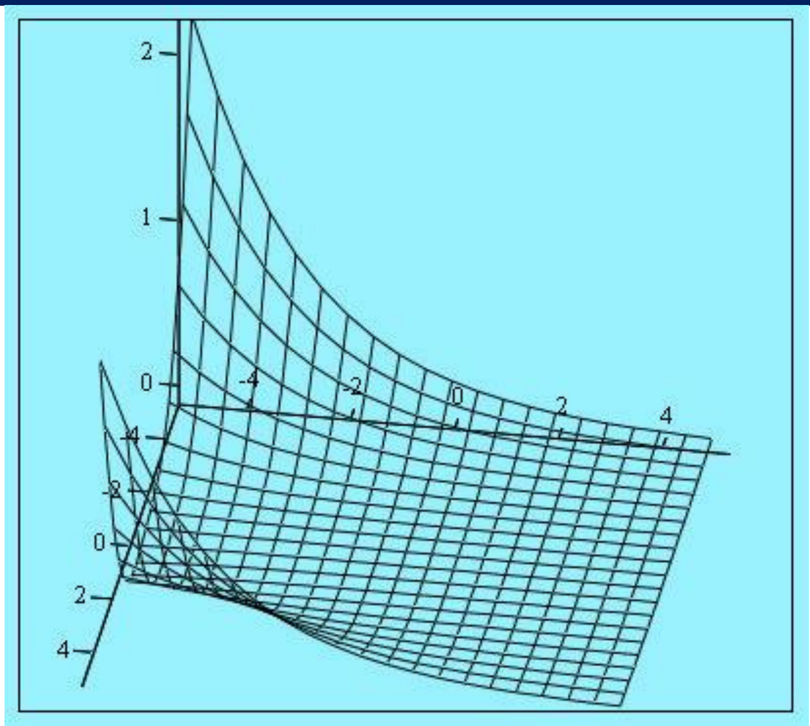

Figure 1. Dynamic Deflection Change Plot $\boldsymbol{W_{ip}(X,Y)}$

of an equivalent supporting frame of a pneumatic compressor (elastic thin-walled plate together with a metal mesh frame).

Algorithms, flowchart, and numerical studies in the MATHCAD 15 programming environment were compiled for all 3 tasks. Natural frequencies of oscillations of the elements of the plate elastic shell of the equivalent metal frame of rods (grid) associated with boundary conditions are based on frequency equations depending on the conditions for fixing the units by iteration.

As an example, Figure 1 plots the dynamic deflections of the $W_{ip}(X,Y)$ of the equivalent supporting frame of the pneumatic compressor (elastic thin-walled plate together with a metal mesh frame) at a speed of a high-speed electric train of V_p =200 km/h.

This article developed a promising complex analytical and numerical method for studying the stress-strain state of the elastic shell of a pneumatic compressor filled with air under pressure, and also developed a methodology for engineering calculation of elastic shells of pneumatic springs and a lightweight lattice frame of a rod type with the selection of their rational parameters for electric rolling stock on the basis of theoretical, experimental and experimental development [5-8].

References:

1. Высокоскоростной железнодорожный транспорт. Общий курс: учеб. пособие: в 2 т./ И.П. Киселёв м др.; под ред. И.П. Киселёва.-М.: ФГБОУ «Учебно-методический центр по образованию на железнодорожном транспорте», 2014. Т.2.-372 с.

2. Andrŕe M. de Roos. Modeling Population Dynamics.1098 SM Amsterdam. Netherlands 2014. - 528 p.

3. Манашкин Л., Мямлин С., Приходько В. Гасители колебаний и амортизаторы ударов рельсовых экипажей (математические модели): Монография: Днепропетровский национальный университет железнодорожного транспорта имени академика В. Лазаряна, Днепропетровск: 2007.-196 с.
4. Вольмир А.С. Оболочки в потоке жидкости и газа (задачи аэроупругости). – М: Наука, 1976. – 416 с.
5. Khromova G., Makhamadalieva M. Разработка математической модели по обоснованию рациональных параметров рессорного подвешивания высокоскоростного электропоезда Afrosiab. // Universum: Technical sciences, 2022, № 10 (103), октябрь 2022, часть 2, С. 62–66. DOI: 10.32743/unitech.2022.103.10.14404. Available at: https://7universum.com/ru/tech/10(103)/10(103_2).pdf (02.00.00; № 2).
6. Khromova G.A., Makhamadalieva M.A., Khromov S.A. Generalized dynamic model of hydrodynamic vibration dampener subject to viscous damping //E3S Web of Conferences. – EDP Sciences, 2021. – Т. 264. – С. 05029. https://doi.org/10.1051/e3sconf/202126405029
7. Khromova G.A., Kamalov I.S., Makhamadalieva M.A. Improved method of calculating the rational dimensions of parts of hydraulic vibrations dampers of electric trains at high speeds. // «Eurasian Journal of Academic Research»: International scientific journal (ISSN: 2181-2020), Volume 2 Issue 12, November 2022, p. 1096-1100. https://doi.org/10.5281/zenodo.7386499
8. Khromova G.A., Kamalov I.S., Makhamadalieva M.A. Elektropoyezdlarning tebranishini richag-diskli ishqalanuvchi so'ndirgichlari konstruktsiyasini hisob-kitob mustahkamlik usullarini yaratish. // Eurasian Journal of Academic Research, Volume 3 Issue 5, Part 3 (2 Part 2), May 2023, pp. 43-47.
9. https://doi.org/10.5281/zenodo.7947173