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Study of the deformation characteristics of the pneumatic spring of the high-speed rolling stock of railways within the cross section of the turnout

Abstract: Investigation of the deformation features of the pneumatic spring of high-speed rolling stock of railways within the frog of the railroad switch. The study object is a pneumatic spring of high-speed rolling stock of the railway. The method of experimental testing of a pneumatic spring using the developed installation for running dynamic spring tests is presented. Experimental tests of the deformability of the pneumatic spring, when the test unit moves along the frog of the railroad switch, are carried out. It is established that the transition of the wheel from the wing rails to the frog and from the core to the frog's moustache, like the frog's rear joint, has a significant impact on the vertical and horizontal deformations of the pneumatic spring. It is determined that the maximum deformations in the vertical plane when the wheel moves from the wing rails to the frog are 2,75 mm; when the wheel moves from the frog to the wing rails, they are 3.7 mm; when the installation passes through the rear joint of the frog, the value of vertical deformations of the pneumatic spring is 6,2 mm. At the same time, the horizontal deformations of the pneumatic spring are 1,0 mm, 1,2 mm and 0,58 mm, respectively. Establishing the deformation features of the pneumatic spring of high-speed railway rolling stock when driving on a railroad switch is an urgent task of scientific research. Since this will make it possible to determine dynamic and safety indicators of high-speed rolling stock in operational conditions.

Keywords: pneumatic spring; high-speed rolling stock; vertical spring deformations; horizontal spring deformations; railroad switch frog.

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Дослідження особливостей деформування пневматичної ресори швидкісного рухомого складу залізниць у межах хрестовини стрілочного переводу

Анотація: Об'єктом досліджень є пневматична ресора швидкісного рухомого складу залізниці. Наведено методику експериментальних випробувань пневматичної ресори із використанням розробленої установки для ходових динамічних випробувань ресори. Проведено експериментальні випробування деформативності пневматичної ресори при русі випробувальної установки по хрестовині стрілочного переводу. Встановлено, що значний вплив на вертикальні та горизонтальні деформації пневматичної ресори має перехід колеса із вусовика на сердечник та із сердечника на вусовик хрестовини, а також задній стик хрестовини. Визначено, що максимальні деформації у вертикальній площині при русі колеса із вусовика на сердечник становлять 2,75 мм, при русі колеса із сердечника на вусовик – 3,7 мм, а при проїзді установки по задньому стику хрестовини, величина вертикальних деформацій пневматичної ресори склала 6,2 мм. При цьому горизонтальні деформації пневматичної ресори відповідно склали: 1,0 мм, 1,2 мм та 0,58 мм. Встановлення особливостей деформування пневматичної ресори швидкісного рухомого складу залізниці при проїзді по стрілочному переводу є актуальною задачею наукових досліджень. Оскільки це дасть змогу визначати динамічні показники та показники безпеки руху швидкісного рухомого складу в експлуатаційних умовах.

Ключові слова: пневматична ресора; швидкісний рухомий склад; вертикальні деформації ресори; горизонтальні деформації ресори; хрестовина стрілочного переводу.

Introduction

In high-speed trains DPKR-2, DPKR-3, ekr-1 "Tarpan" and HRCS2 "Hyundai Rotem", a pneumatic spring is used to dampen the vibration effect on rolling stock, which is given in the appendix (*Figure 1*) (*Kuzyshyn et al., 2023*). In addition, it allows you to dissipate energy during the movement of rolling stock over irregularities on the railway track (*Mendia-Garcia et al., 2022*; *Kovalchuk et al., 2018b*; *Kuzyshyn et al., 2024*; *Mendia-Garcia et al., 2024*).

When rolling stock moves along a rail track, the pneumatic spring accepts vertical and horizontal (longitudinal and transverse) loads, which are caused by the technical condition and design features of the rail track and the mechanical part of the rolling stock. As a result of vibrations, the pneumatic spring undergoes vertical and horizontal deformations. It is worth noting that it is significant to choose the optimal spring performance at the design stage of a pneumatic spring. One of them is the stiffness of the pneumatic spring, which depends on the load that falls on the spring and the amount of deformation of the spring. Therefore, studying the features of spring deformation under operating conditions and determining its maximum vertical and horizontal deformations is an urgent task of scientific research.

To date, there are many studies of the dynamic behaviour of the pneumatic spring of high-speed rolling stock, which is reflected in the works (*Reidemeister et al., 2016*; *Liufeng et al., 2020*; *Li & Li, 2013*; *Zhu et al., 2017*). However, most works use theoretical methods for studying the pneumatic spring. The paper (*Reidemeister et al., 2016*) considers a model of a pneumatic spring as a dynamic system with three-phase coordinates. Based on the laws of thermodynamics and hydrodynamics, a mathematical model has been developed to study the dynamic characteristics of springs in the vertical direction (*Liufeng et al., 2020*; *Li & Li, 2013*). Labour (*Zhu et al., 2017*) is devoted to the study of considering thermodynamic processes in the calculation of pneumatic Springs. In the paper (*Kuzyshyn et al., 2023*), authors perform theoretical studies of a pneumatic spring's dynamic parameters, considering the geometrical parameters of the connecting pipeline. A study of the effect of the state of the pneumatic spring suspension system on the dynamic behaviour of rolling stock is given in the paper (*Facchinetti et al., 2010*). Based on this, it is concluded that lateral deformation and deformation of the spring roll do not lead to significant fluctuations in the air pressure inside the pneumatic spring.

From the analysis of scientific works, it is established that most works are devoted to theoretical studies of the pneumatic spring of railway rolling stock. There are no experimental sea trials of the pneumatic spring. Therefore, conducting experimental dynamic tests of the pneumatic spring is an urgent task of scientific research, which will allow determining the maximum vertical and horizontal deformations of the pneumatic spring in actual conditions of railway track operation.

Materials and methods

The study's object is a pneumatic spring of high-speed rolling stock that undergoes deformations when moving along the crosspiece of the switch. The proposed installation design for running dynamic tests, given in the appendix (*Figure 2*), determines the pneumatic spring's vertical and horizontal deformations.

When the installation moves along the crosspiece, the pneumatic spring vibrations occur, which cause vertical and horizontal deformations of the spring. The values of vertical and horizontal spring deformations are measured using a potentiometric displacement sensor. To measure vertical spring deformations, the displacement sensor is installed vertically at right angles to the upper metal plate of the spring. A movement sensor installed perpendicular to the side of the rubber cord shell of the pneumatic spring is used to measure the horizontal deformations of the pneumatic spring. The layout of linear displacement potentiometric sensors is shown in the appendix (*Figure 3*).

The measured values of the pneumatic spring's vertical and horizontal deformations are read by a high-frequency analogue-to-digital converter and stored in the laptop's memory.

Results

The results of recording vertical deformations of the pneumatic spring of high-speed rolling stock when moving from the core to the crosspiece tendril and in the opposite direction are shown in the appendix (*Figure 4*). The results of recording vertical deformations of the pneumatic spring showed that the maximum deformations when moving the test unit in the direction from the core to the crosspiece moustache are 3.7 mm, and when moving from the moustache to the core – 2.75 MM.

The results of recording horizontal deformations of the pneumatic spring of high-speed rolling stock when moving from the core to the crosspiece moustache and in the opposite direction are shown in the appendix (*Figure 5*). The maximum value of horizontal deformations of the pneumatic spring, when moving in the direction from the core to the moustache, is 1.2 mm, and when moving from the moustache to the core – 1.0 mm. In addition, when the wheel rolls along the core within a cross-section of 35 mm, peak deformations are observed on the lines of recording spring deformations. This is due to the peculiarities of rolling the wheel in this area of the switch crosspiece (*Kovalchuk et al., 2018c*; *Kovalchuk et al., 2017*; *Kovalchuk et al., 2018a*).

The results of recording vertical and horizontal deformations of the pneumatic spring of high-speed rolling stock during the movement of the test unit along the rear joint of the crosspiece are shown in the appendix (*Figure 6*). From the records of spring deformations when moving along the rear joint of the crosspiece, it can be seen that the maximum vertical deformation of the spring was 6.2 mm, and the maximum horizontal deformation was 0.58 mm. The difference between vertical and horizontal deformations of the pneumatic spring is explained by the significantly higher vertical load on the spring due to the short butt unevenness. As a result of the wheel passing through the joint zone, a dynamic vertical force addition occurs, which causes vertical deformations of the pneumatic spring. At the same time, harmonic vibrations of the spring and their gradual extinction in a short time are observed from the recording line of vertical deformations of the spring. Furthermore, from the lines of recording horizontal deformations of the spring, it can be seen that the spring shifts in the horizontal plane when hitting the crosspiece joint and returns to its original position when leaving.

Discussion

Evaluation of the dynamic characteristics of a high-speed rolling stock pneumatic spring is a significant scientific research task. This will allow monitoring changes in the characteristics of the spring's rubber-cord shell over time during its operation on rolling stock, according to the established indicators of the new spring. The developed test unit, given in the appendix (*Figure 2*), allows testing the spring in any operating conditions of the railway track, considering the operational and design features.

As part of our work, the pneumatic spring of high-speed rolling stock was tested within the crosspiece of the Switch. The results of experimental studies of the pneumatic spring have shown that the value of vertical deformations (*Figure 4*) is higher than the horizontal deformations of the spring (*Figure 5*). When moving the test unit in the direction from the core to the crosspiece moustache, the maximum value of vertical spring deformations was 3.7 mm, horizontal – 1.2 mm, and when moving from the moustache to the core – 2.75 MM and 1.0 mm, respectively.

It is established that the direction of movement of the test unit has a majestic deformation of the pneumatic spring. Higher values of vertical and horizontal spring deformations occur when the test unit moves in the direction from the core to the moustache. In this direction of movement, the value of vertical deformations was 3.7 mm, and horizontal deformations were 1.2 mm. In the case of movement from the moustache to the core, the value of vertical deformations was 2.75, and horizontal deformations – were 1.0 mm.

The difference in deformations of the pneumatic spring when moving in different directions of the test unit along the crosspiece of the switch is explained by the peculiarity of rolling the rolling stock wheel from the core to the moustache and vice versa, which is reflected in work (*Kovalchuk et al., 2018c*). The wheel passes an unevenness in the vertical plane (*Kovalchuk et al., 2018a*), which causes a dynamic load on the rolling stock and, accordingly, causes deformation of the spring. At the same time, the unevenness, depending on the direction of movement, has different angles of inclination when the wheel moves down and out of the roughness (*Orlovsky et al., 2011*), which, as a result, affects the difference in the values of spring deformations.

If the wheel rolls over the rear joint of the crosspiece, a significant vertical deformation of the spring occurs, measuring 6.2 mm (*Figure 6*). At the same time, the horizontal deformation value was only 0.58 mm. Recording the lines of vertical deformations of the spring in the vertical plane (*Figure 6*) shows that the wheel moves down (causing a blow to the joint), which causes a sharp increase in vertical deformations of the pneumatic spring. On such a short roughness, the wheel hits the joint, causing vertical deformations in the spring. At the same time, the number of horizontal deformations remains insignificant since there is no lateral load from the joint on the moving wheel of the test unit.

In contrast to the deformation features of the pneumatic spring when passing the rail joint, the passage from the core to the moustache or from the moustache to the core causes a more lateral swing of the test unit. This leads to higher values of horizontal deformations of the spring compared to the movement along the rear joint of the crosspiece.

Conclusion

The developed methodology of experimental dynamic testing of a pneumatic spring of high-speed rolling stock allows testing the spring in the operating conditions of a rail track. This will allow you to set the dynamic parameters of the pneumatic spring, considering the technical and structural parameters of the rail track and rolling stock's undercarriage.

The maximum vertical deformations of the pneumatic spring when moving the unit in the direction from the core to the moustache are 3.7 mm, and when moving from the moustache to the core – 2.75 MM. At the same time, the maximum horizontal deformations of the spring were 1.2 mm and 1.0 mm, respectively.

The most significant vertical deformations occur when the test unit moves along the rear joint of the Switch crosspiece. At the same time, the vertical deformation of the pneumatic spring was 6.2 mm against 3.7 mm when moving in the direction from the core to the crosspiece moustache. However, horizontal deformations when moving along the joint of the crosspiece are less than deformations when moving in the direction from the core to the moustache or from the moustache to the core. Horizontal deformations are 0.58 mm, 1.2 mm and 1.0 mm, respectively.

Conflict of interest

The authors declare that there is no conflict of interest.

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Appendix

Figure 1. Pneumatic spring of high-speed rolling stock

Figure 2. Installation for running dynamic tests of a pneumatic spring: 1 – Direction of movement from the core to the crosspiece moustache; 2 – Direction of movement from the crosspiece moustache to the crosspiece core

Figure 3. layout of displacement sensors for measuring vertical and horizontal spring deformations

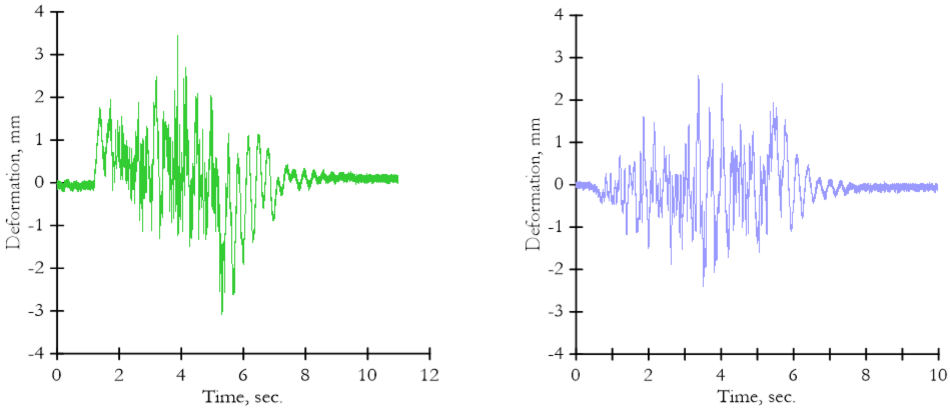

Figure 4. records of vertical deformations of the pneumatic spring of high-speed rolling stock: (a) movement in the direction from the core to the crosspiece mustache; (b) movement in the direction from the crosspiece mustache to the crosspiece core

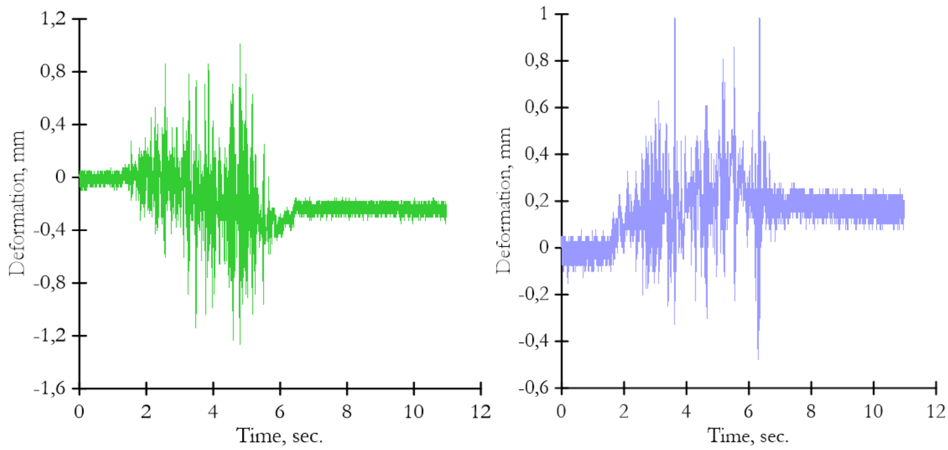

Figure 5. Records of horizontal deformations of the pneumatic spring of high-speed rolling stock: (a) movement in the direction from the core to the crosspiece mustache; (b) movement in the direction from the crosspiece mustache to the crosspiece core

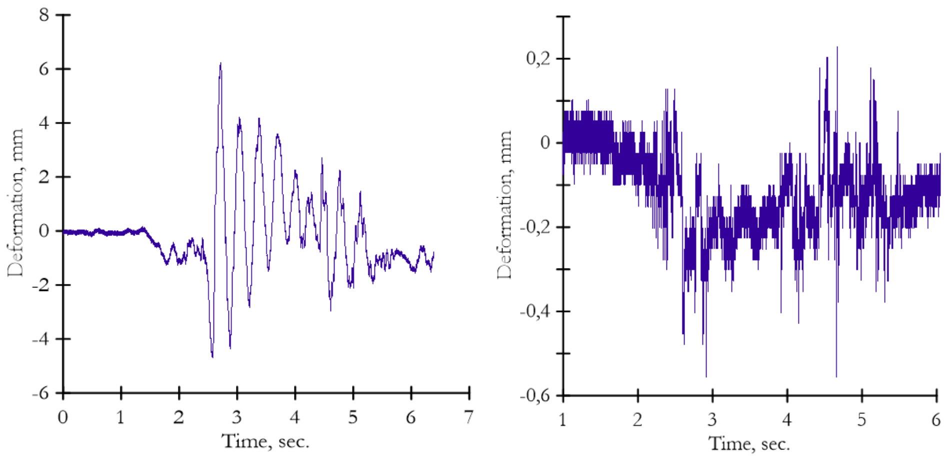

Figure 6. Records of vertical and horizontal deformations of the pneumatic spring of high-speed rolling stock when moving along the rear joint of the crosspiece: (a) vertical deformations of the spring; (b) horizontal deformations of the spring