RATIONAL CHOICE OF VIBRATION PROTECTION PARAMETERS OF THE METRO TRACK

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ABSTRACT

In the article the questions connected with the choice of rational parameters of the vibration protection structures of the metro track superstructure are considered. Results of an assessment of ways to increase the efficiency of vibroprotective properties of blocks LVT-M are given. Proposals are made to improve the methodology for such an assessment, which should take into greater account the deformation characteristics of the track, the structural features of the tunnel and other structures in the metro zone. Particular emphasis is placed on the importance of using materials which dynamic stiffness is slightly higher than the static in the range of the studied frequencies of 2–63 Hz.

Keywords: vibration protection, track superstructure, metro, track stiffness, vibration isolation efficiency.

Background. *An increased level of vibrations near the shallow tunnels of metro is one of the urgent problems of megacities [1]. Most often this threat arises for residential buildings located at a distance of less than 40 meters to the axis of the underground tunnel.*

It is obvious that at the design stage we have the widest range of possibilities for solving the task of reducing vibration levels than after putting objects into operation, and the use of vibration protection structures in the metro and rolling stock with less dynamic impact on the track would significantly facilitate the life of people in the residential area, which gravitates towards the objects of the underground road.

However, it is often necessary to solve the problem with vibration protection designs directly to building projects, and this interferes with the creativity of architects and increases the cost of construction, although it is economically more advantageous to minimize the effects of the vibro-acoustic influence of metro directly in the source of vibrations.

In this case, artificially reducing the levels of vibrations and noise generated by metro trains, for territories along the routes, it is possible to expand the possibilities of their use in accordance with modern requirements of terraefficiency [2].

That is, other things being equal, a more effective way to solve the task is to isolate the source of vibration [8], especially at the design stage of metro, which makes it possible to avoid the need in the future to search for complex technical options to combat transport vibrations.

Objective. *The objective of the authors is to consider the issues of rational choice of vibration protection parameters of the metro track.*

Methods. *The authors use general scientific methods, comparative analysis, scientific description.*

Results. *It should be noted that the cost of constructing a vibration-proof structure of the metro track superstructure is higher than the cost of constructing a standard structure. However, the use of vibration protection contributes to a reduction in operating costs, as evidenced by the use of vibration-proof rail fasteners, sub-ballast mats, LVT blocks and other means in the structures. In addition, the city has the opportunity to compensate for capital costs for the vibration protection of metro facilities by adding to the cost of land near the running tunnels the difference in costs for a standard design of the track superstructure and vibration-proof, taking into account the greater comfort of such land for development.*

Now, when the coverage are of subsurface metro, and with it the zone of high vibrations is rapidly expanding and it is possible to prepare the territory in advance for the future development, it is advisable to expand the range of application of vibration protection structures of the track superstructure.

There is a large number of vibration protection means that meet modern requirements. In particular, such technologies are used to combat the increased level of vibration, such as the arrangement of vibration-proof rail pads vibro-protection plates, mats and systems consisting of several elements [3].

Each means of vibration protection has its own zone of positive efficiency [9] (the interval of vibration frequencies in which vibration protection lowers the level of oscillations) and the zone of negative efficiency (the interval of frequencies when vibration protection increases the level of vibration or does not change it). The presence of a zone of negative efficiency is associated with resonant phenomena that arise when the frequency of the oscillating force and the natural vibration frequency of the vibration protection means coincide.

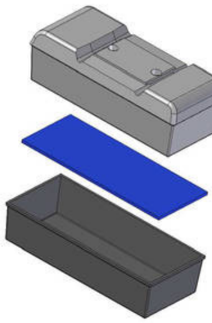
At the same time, it is important to be able to adapt the characteristics of the vibration protection means for effective operation in each case.

One of the vibration protection systems that allow varying and adjusting their characteristics in a fairly wide range is the track superstructure of LVT type (Low Vibration Track) [4, 6]. This system has great prospects in the domestic metro construction, having been tested on the railways of Russia (the first section with the use of LVT technology was opened in 2011); it is adapted to the conditions of the metro and is already being applied on several sections in Moscow and St. Petersburg.

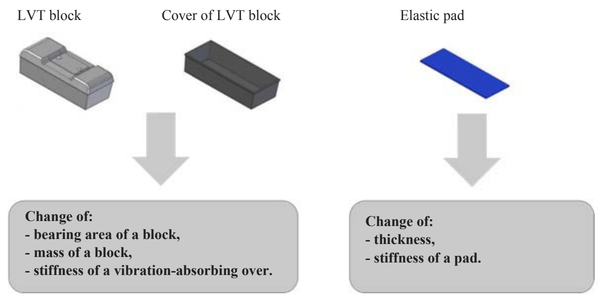
LVT is a ballastless technology of laying a track, composed of half ties, laid in special vibration-proof covers and embedded in the concrete base (Pic. 1).

According to data provided by Moscow Metro [7], the term of service of LVT-tracks before overhaul should reach 40 years, while maintenance will cost 20 % less in comparison with service of standard designs, which makes this system competitive in terms of life cycle cost.

The authors analyzed the possible cases of the dynamics parameters of LVT using the example of LVT-M blocks (modification for metro) to determine the parameters that are most effective with respect to the influence of their changes on change of natural frequency oscillation of the block, and ease adjustment of these parameters. The calculation assumed the establishment of the ability to control



Pic. 1. Half tie.



Pic. 2. The elements of the LVT system that can be changed under the terms of the project.

the effectiveness of vibration protection for all blocks of LVT type.

Pic. 2 presents the considered options for changing the parameters of vibration protection and the element of the structure that they characterize.

The main characteristics for selecting the design of the vibration protection element from the point of view of its response to dynamic effects are mass and dynamic stiffness [5], since they determine the natural vibration frequency (f) of vibration protection:

$$f = \frac{1}{2\pi} \bullet \sqrt{\frac{S}{M}}, \qquad (1)$$

where S – stiffness of the system; M – mass of the system.

Variations in stiffness of the vibration protection of LVT-type blocks can be achieved by changing the material properties (E – modulus of elasticity) and the geometry (S_0, h) of the elastic pad under the block:

$$E = \frac{2G(1+\mu)K_f}{0{,}25}; \qquad (2)$$

$$S = \frac{ES_o}{h}, \qquad (3)$$

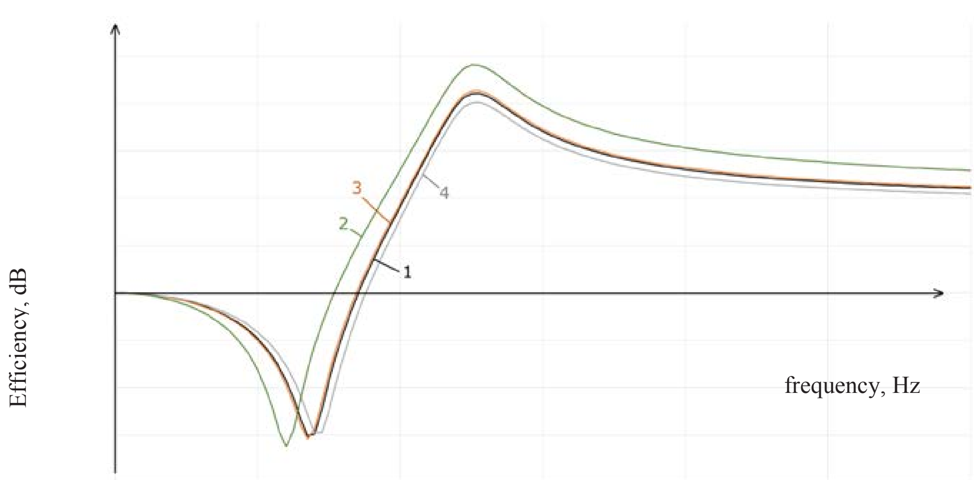
where S_o – reference are of an elastic element from the side of the riffles (if any); G – shear modulus; μ – Poisson ratio; K_f – coefficient of form of the elastic element.

Using these parameters, it is possible to achieve optimal efficiency in relation to a particular case, since the natural oscillation frequency of vibration protection and its vibration energy dissipation parameters completely determine the vibration protection transfer function (characteristic of the vibration level change in the system with vibration protection with respect to the system without it):

$$w = 20 \bullet \log_{10} \sqrt{\frac{1+\left(\frac{2 \bullet k_{si} \bullet f}{f_0}\right)^2}{\left(1-\left(\frac{f}{f_0}\right)^2\right)^2} + \left(\frac{2 \bullet k_{si} \bullet f}{f0}\right)^2}, \qquad (4)$$

where w – transfer function; k_{si} – damping; f_0 – natural oscillation frequency of the system; f – oscillation frequency of the driving force.

The article considers the change in the weight of the LVT block (due to the use of various types of concrete), the change in the block geometry (an increase in the LVT block support point), the change in the material of the elastic pad of the block, and the change in the thickness of the elastic pad of the block. Pic. 3 shows the vibration



Pic. 3. Elements of the LVT system that can be changed under the project conditions: 1 – basic block parameters accepted for calculation; 2 – the thickness and stiffness of the elastic pad of the LVT block were changed (the thickness was increased by 25 %, the stiffness was reduced by 25 %); 3 – weight of the LVT block is increased by 25 %: 4 – the block support area is increased by 25 %.

efficiency curves w with respect to the typical track design.

As follows from the analysis of the given diagrams, efficiency curves differ when applying different vibration protection designs not only in reduction or increase in the vibration level, but also in frequencies, on which peak values of vibration protection efficiency emerge.

It is necessary also to pay attention to the content of frequencies, in which vibration protection is efficient or non-efficient, since it seems possible to improve its work not at the expense of increase of peak value of efficiency, but due to «shift» of efficiency curve of vibration protection horizontally. Therefore rational, sound selection of parameters of vibration protection means in each particular case is important.

According to the calculations, change of material and thickness of a pad is the most efficient.

Focusing on the characteristics of the material Sylomer, the calculation with the change of material of vibration protection was conducted. Quantitative values are not provided, at this stage an assessment is used, which allows to take into account the degree of variety of properties of existing materials. Thus, for a typical series of the material Sylomer, presented on the website of the manufacturer, shift modulus changes within the range from 0,03 to 0,9 (30 times). In proportion to G E (2) will change and, correspondingly, S (3), determining natural oscillation frequency.

In course of the operations the maximums of negative and positive efficiency of vibration protection changes only by 4 dB and 1 dB, respectively, the maximum of positive efficiency increased by 3 dB. It is seen on Pic.3 also that in the frequency range over 25 Hz efficiency of vibration protection increased on the entire section of the considered frequencies.

It is obvious that the reduction of stiffness of vibration protection system, as a result of which natural oscillation frequency decreases and moves away from the oscillation driving force, will lead to increase in vibration protection efficiency.

However it should be noted that reduction of stiffness and increase in the thickness of the pad under LVT block increases the track deformation and unnecessary ungrounded change of these parameters can worsen the accountable indicators.

Let's stress: the conducted calculation serves only for the purpose of assessment of the nature of changes of efficiency of vibration protection construction of the metro track superstructure and is not consistent with other operational characteristics of the track (suppose the given reduction of stiffness of the pad or increase of its thickness can lead to violations of the norms of track deformability).

Conclusions. *Proceeding from the analysis of options of rational choice of parameters of vibration protection structure of the metro track, it is expedient to develop criteria and formalize the methodology of the choice of the parameters, the closest to the existing requirements, and conduct quantitive assessment for the conditions of certain projects.*

The outcome should be the method, which allows to take into account not only the need to reduce the vibration level in the frequency range, which is characteristic of the rail transport, but also to take into account deformative characteristics of the track, features of the tunnel design and the design of the protected buildings and structures, located in the zone of vibration influence.

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