с помощью быстрого преобразования Фурье.

В качестве примера на рис. 1 приведен график спектральной плотности эквивалентной геометрической неровности, вычисленный по выражению (1) для v =90 км/ч.

Полученные таким способом неровности могут быть использованы при исследовании колебаний динамических моделей и других типов вагонов метрополитена с близкой нагрузкой от колесной пары на рельс.

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SIMULATION OF IRREGULARITIES OF SUBWAY TUNNEL TRACK

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ABSTRACT

Track in subway tunnel has some differences from the design of ground railway track. Therefore, to proceed with a study using the method of mathematical modeling of linear and nonlinear oscillations of subway cars for solving a system of differential equations, it is necessary to have a «generated» random disturbance process. The objective of the authors was to present methodology and results of simulation of equivalent geometrical irregularities of subway track tunnel to solve the problem of research of random fluctuations of passenger cars. The authors used simulation method, mathematical calculations and analysis. Perturbation process, generated for these purposes, is provided by the approximate method of moving summation. Two possible approaches are shown, each of which includes a range of research and computation. Irregularities obtained by those methods can be used to study oscillations of dynamic models of subway cars with a similar load from a wheel set on a rail.

Keywords: subway, track, rolling stock, tunnel, geometrical irregularity, mathematical model, spectral density.

Background. *Track in subway tunnel has some differences from the design of ground railway track. Therefore, it is necessary to base on a «generated» random disturbance process in the study using the method of mathematical modeling of linear and nonlinear oscillations of subway cars for solving a system of differential equations. As such, generally equivalent geometric irregularity η (t) is taken. The generation of this kind can be carried out by approximate method of moving summation, a detailed description is given in [1].*

Objective. *The objective of the authors is to present methodology and results of simulation of equivalent geometrical irregularities of subway track tunnel.*

Methods. *The authors use simulation method, mathematical calculations and analysis.*

Results. *To solve the problem concerning the dynamics of subway cars, a generation was produced in accordance with a given spectral density of a random process of equivalent geometrical irregularity of tunnel track $G_\eta(\omega)$. Spectral density was used, which was obtained by processing the results of dynamic-strength tests of cars of 81.717 model, conducted in 1984 by Mytishchi machine-building plant in cooperation with the department of «Electric Traction» of MIIT on the ring and Gorky-Zamoskvoretskaya lines of the Moscow Metro. Spectral density was approximated as proposed in [2], with an analytical expression that corresponds to a differentiable random process:*

$$G_\eta(\omega,v)=\frac{S_\eta^2}{2\sqrt{\pi}}\sum_{j=1}^{n}\frac{a_j}{\alpha_j\cdot v}\left\{\begin{array}{l}\exp\left[-\frac{(\omega+\omega_j v)^2}{4\alpha_j^2v^2}\right]+\\ \exp\left[-\frac{(\omega-\omega_j v)^2}{4\alpha_j^2v^2}\right]\end{array}\right\}, \qquad (1)$$

*where S_η^2 is variance of equivalent geometrical irregularity (in calculations S_η^2 = 13,01 mm²); ω is current frequency, rad/s; ω_j is frequency of the **j**-th maximum of spectral density; a_j is proportion of variance attributable to the j-th maximum of spectral density; α_j is half width of the j-th maximum of spectral density at half of its height.*

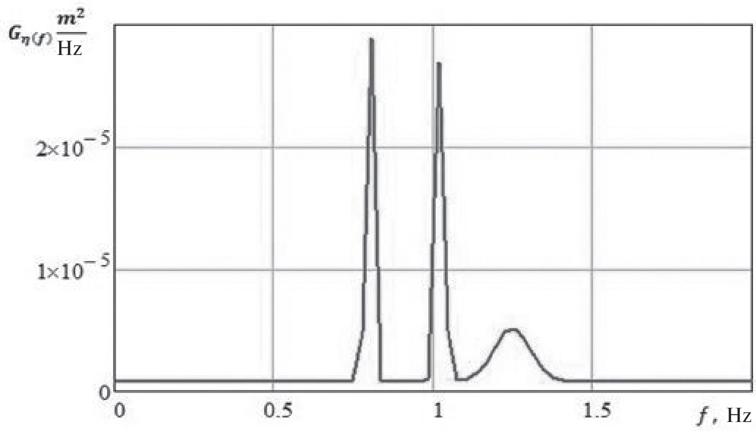
Parameters of an analytical expression $G_\eta(\omega)$ for the velocity of v = 1 m / s, obtained at approximation, are shown in Table 1.

During the simulation of η (t) by moving summation two approaches are possible. Within the first one equivalent geometric irregularity is simulated for the speed of 1 m / s, and then in order to determine the dynamics of subway cars they «move» on this irregularity at the correct speed. This approach dominates

Table 1

Parameters of the analytical expression of the spectral density

Number of spectrum's component	α_j, rad/s: m/s	ω_j, rad/s: m/s	a_j
1	1,0	0	0,697
2	0,0018	0,20096	0,12
3	0,002	0,25749	0,109
4	0,01	0,314	0,074



Pic. 1. The spectral density of equivalent geometrical irregularity at a speed of v = 90 km / h.

in the study of oscillations of mathematical models of rolling stock as they move through simulated sections with variable speed in accordance with the operating schedule. It is known that the movement at variable speed is main process in the operation of subway cars. For example, at the ring line of Moscow metro movement of cars at a constant speed constitutes only 20% of the total travel time.

If we use this approach to study oscillations of mathematical models in their motion at a constant speed, then it is necessary to pass all this simulated part of the track for each speed. Only in this case the spectral density of the simulated random process $\eta(t)$ corresponds to a given by the expression (1). This feature leads to a complication of processing of the results, because at each speed there is a different reaction duration of the random process of dynamic model vehicle- track to the input disturbance.

In the second approach equivalent geometric irregularity is simulated for each speed in the range, established by the research program. At the same time, using the algorithm given in [1], implementation of irregularities is simulated in relation to a set of desired speed, for which the parameters of the expression (1) α_j and β_j (Table 1) were recalculated with v = 1 m / s. At the department «Electric trains and locomotives» of MIIT sampling step in the generation of $\eta(t)$ is usually taken to be equal to Δt = 0,001 s. The length of each implementation of irregularity – t_p = 32,768 s, the number of points of realization of reaction of a dynamical system vehicle-track is N = 32768, which corresponds to 2^{15}. It is necessary to perform spectral analysis using fast Fourier transform.

As an example, Pic. 1 shows a graph of the spectral density of equivalent geometric irregularity calculated by the expression (1), for v = 90 km / h.

Conclusion. *Irregularities simulated by described methods can be used to study oscillations of dynamic models and other types of subway cars with a similar load from a wheel set on a rail.*

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