RANDOM DISTURBANCE PROCESSES IN THE DYNAMICS OF RAIL VEHICLES

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ABSTRACT

Previous works contained correlation and spectral analysis of the four-dimensional disturbance process in the form of vertical and horizontal irregularities of left and right rails, causing oscillations in rail vehicles. But when speed increases, the disturbance frequency range shifts to high frequencies and can go beyond natural frequencies of the system. Then disturbance almost ceases to excite a part of vibration frequencies and obtained results will be incorrect.

The article considers requirements to the procedure of computer generating a multidimensional stationary random disturbance process, causing vibrations of rail vehicles. Using modeling, computer simulation, and mathematical analysis it is shown that when the speed alters it is necessary to change terms of the composition of the random process of geometrical irregularities of the track. The requirements for parameters of the probabilistic analysis are determined, examples of generating and the results of spectral analysis of irregularities generated for different speeds are shown.

Keywords: *rail vehicle, random processes of geometric irregularities of the track, terms of an analytical expression, impact of speed, spectral analysis.*

Background. *Work [1] contained correlation and spectral analysis of the four-dimensional disturbance process in the form of vertical and horizontal irregularities of left and right rails, causing oscillations in rail vehicles. However, due to the limited length of the realization of random disturbance, which is equal to 1 km, the maximum of low-frequency part of the spectrum remained within irregularity wave L_{LF}= 50 m and the maximum of high-frequency part corresponded to L_{HF} = 6,25 m. By solving dynamics problem, the disturbance frequency range should be from f_{LF} = 0,2 Hz to f_{HF} =10 Hz.*

These lowest and highest frequencies are associated with corresponding wavelengths by relations:

$f_{LF} = v/L_{LF}$, $f_{HF} = v/ L_{HF}$, (1)

where v is speed, m / s.

For this reason, when speed of rail vehicles grows, the disturbance frequency range shifts to high frequencies and can go beyond natural frequencies of the system. Then disturbance almost ceases to excite a part of vibration frequencies and obtained results will be incorrect.

Objective. *The objective of the author is to investigate random disturbance processes that cause vibrations in rail vehicles.*

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

Results. *Let's define the requirements for the wavelength of irregularities that must be present in the disturbance range for solving problems of the dynamics at speeds from 10 to 150 m/s, i. e. from 36 to 540 km/h. A required realization length will be found using the empirical formula:*

$t_R \geq 10\, t_{LF}$ or $t_R \geq 10/f_{LF}$. (2)

At the assumed value of the lowest frequency of the process, which is equal to 0,2 Hz, the realization length will be t_R = 50 s. This realization length thus corresponds to the wavelength of irregularity, which is equal to

$L_R = vt_R$. (3)

Accordingly, for a speed of 150 m / s the length of realization of disturbance process L_R, required for the correlation and spectral analysis, should be at least 7500 m. Moreover, recording of random disturbance processes of such a length must satisfy the terms of stationarity, i. e. it should be carried out on site with a homogeneous structure when moving on a straight track. It is virtually impossible to make it. Therefore, to obtain a sufficiently long realization it was required to repeat eightfold with corresponding transitions the realization used in [1], of the length L_R = 999, changing its direction each time to avoid overlapping. To obtain this realization in [1] N = 5400 measurements of irregularities were made with interval Δx = 0,185 m.

Thus, the total length of the realization will be $L_{TR} = 8L_R$= 7992 m with a sampling interval Δx = 0,185 m and the total number of measurements N_{TR} = 43200. The spectral analysis of such a realization of the random disturbance process enables to select the components of the spectral density at wavelengths from $L_{LF} \leq v/f_{LF} = (vt_{TR})/10 = L_{TR}/10 \leq 799{,}2$ m to $L_{HF} = v/f_{HF} = v10\Delta t = 10\Delta x = 1{,}85$ m.

Table 1

The parameters of the analytical expression of the correlation function of horizontal irregularity of the left rail

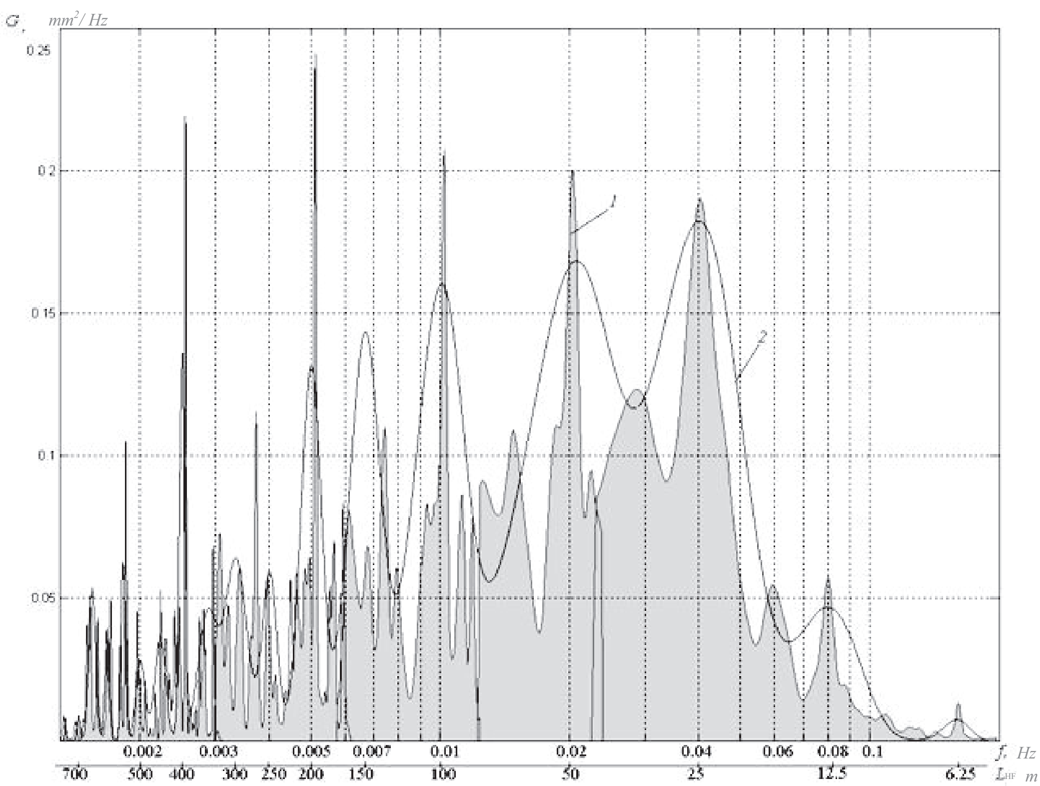
	L_{HF}, m	β, m^{-1}	α, m^{-1}	a	k	L_{HF}, m	β, m^{-1}	α, m^{-1}	a
1	6,25	$16\cdot10^{-2}$	$32\cdot10^{-3}$	$234\cdot10^{-4}$	10	350	$28\cdot10^{-4}$	$8\cdot10^{-5}$	$16\cdot10^{-4}$
2	12,5	$800\cdot10^{-4}$	$22\cdot10^{-3}$	$1953\cdot10^{-4}$	11	400	$25\cdot10^{-4}$	$14\cdot10^{-5}$	$14\cdot10^{-4}$
3	25,0	$400\cdot10^{-4}$	$10\cdot10^{-3}$	$5078\cdot10^{-4}$	12	450	$22\cdot10^{-4}$	$11\cdot10^{-5}$	$65\cdot10^{-5}$
4	50,0	$200\cdot10^{-4}$	$28\cdot10^{-4}$	$1823\cdot10^{-4}$	13	500	$20\cdot10^{-4}$	$25\cdot10^{-5}$	$39\cdot10^{-5}$
5	100	$100\cdot10^{-4}$	$12\cdot10^{-4}$	$521\cdot10^{-4}$	14	550	$18\cdot10^{-4}$	$45\cdot10^{-6}$	$36\cdot10^{-5}$
6	150	$67\cdot10^{-4}$	$6\cdot10^{-4}$	$208\cdot10^{-4}$	15	600	$16\cdot10^{-4}$	$41\cdot10^{-6}$	$20\cdot10^{-5}$
7	200	$60\cdot10^{-4}$	$35\cdot10^{-5}$	$99\cdot10^{-4}$	16	650	$15\cdot10^{-4}$	$61\cdot10^{-6}$	$41\cdot10^{-5}$
8	250	$40\cdot10^{-4}$	$45\cdot10^{-5}$	$26\cdot10^{-4}$	17	700	$14\cdot10^{-4}$	$21\cdot10^{-6}$	$2\cdot10^{-5}$
9	300	$33\cdot10^{-4}$	$31\cdot10^{-5}$	$18\cdot10^{-4}$	18	750	$13\cdot10^{-4}$	$2\cdot10^{-6}$	$1{,}4\cdot10^{-5}$

Note: value β is assumed equal to L^{-1}.

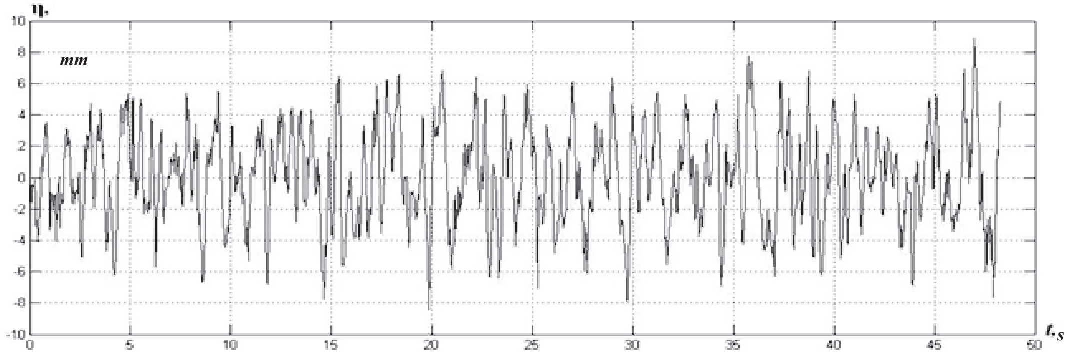
Table 2

Values of the highest and the lowest irregularities to set motion speed

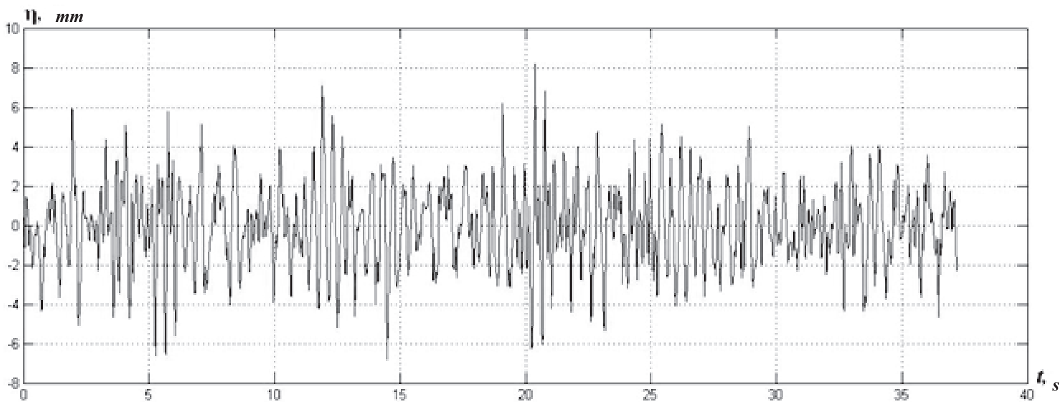
№	Speed range	Interval at realization $k\ \Delta x$	The lowest frequency f_{LF}, Hz	The highest frequency f_{HF}, Hz
1.	10–20 m/s 36–72 km/h	Δx	0,10–0,20	10,0–20
2.	21–40 m/s 75,6–144 km/h	2 Δx	0,105–0,20	10,5–20
3.	41–60 m/s 147,6–180 km/h	3 Δx	0,136–0,20	13,67–20
4.	61–80 m/s 219,6–288 km/h	4 Δx	0,153–0,20	15,25–20
5.	81–100 m/s 291,6–360 km/h	5 Δx	0,162–0,20	16,20–20
6.	101–120 m/s 363,6–432 km/h	6 Δx	0, 168–0,20	16,83–20
7.	121–140 m/s 435,6–504 km/h	7 Δx	0,173–0,20	17,30–20
8.	141–160 m/s 507,6–576 km/h	8 Δx	0,176–0,20	17,6–20



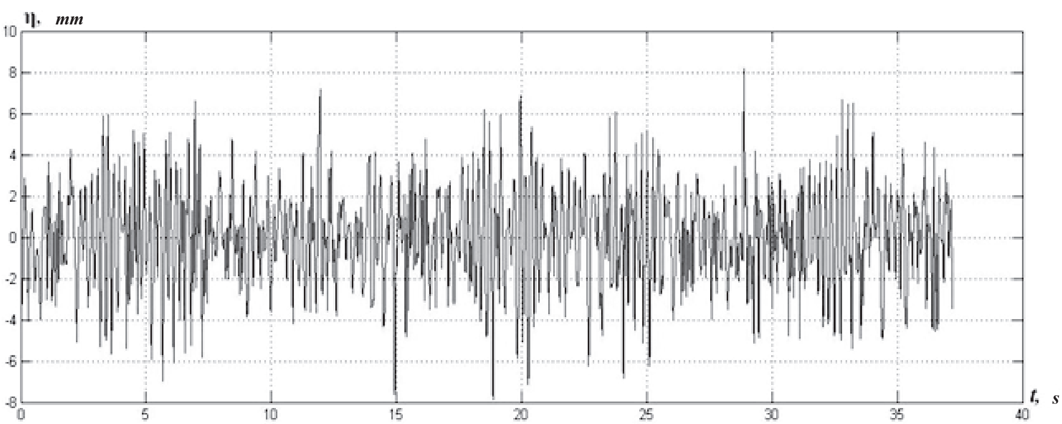
Pic. 1. Graphs of the spectral density of horizontal irregularity of the left rail: 1 – experimental; 2 – by the analytical expression (4).



a)

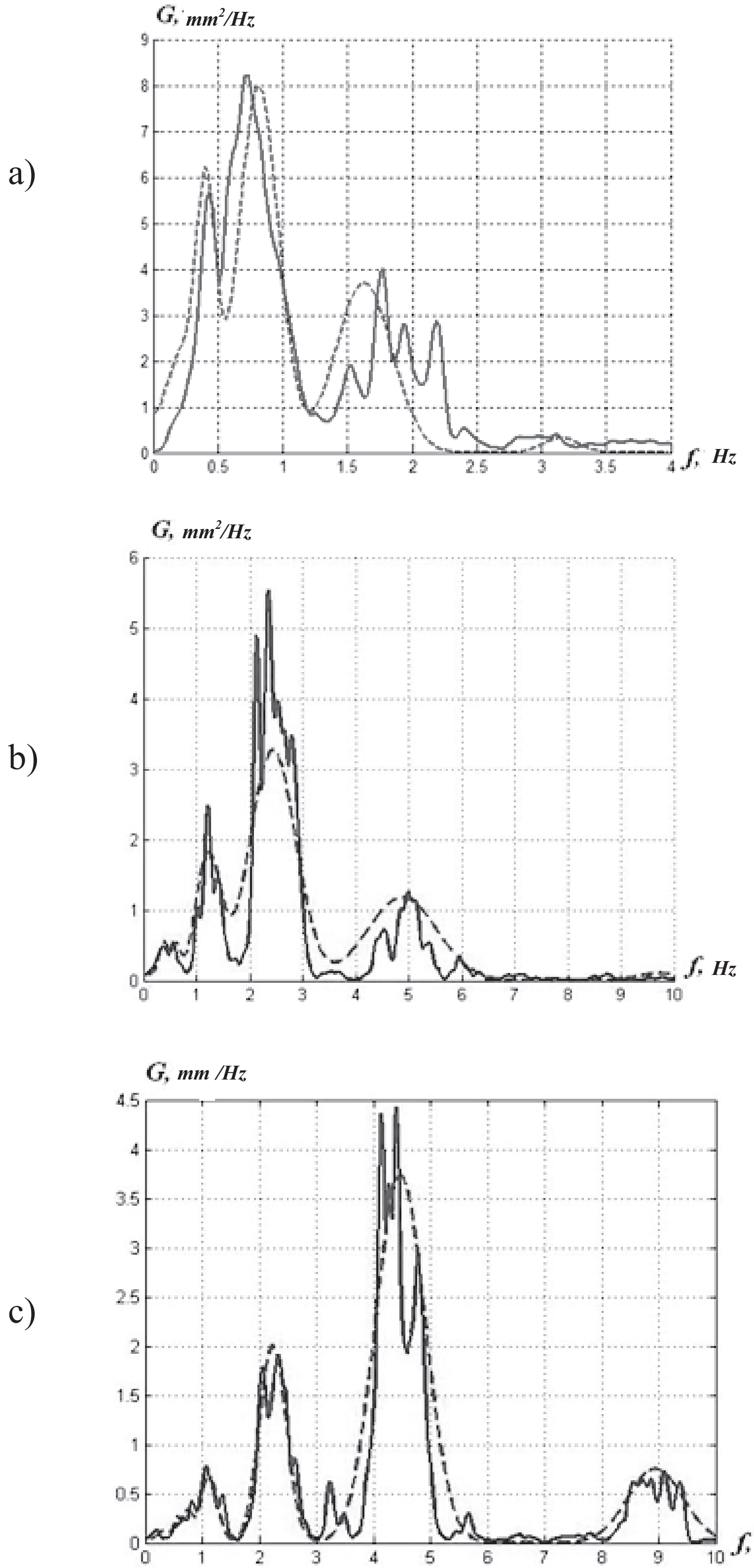


b)



c)

Pic.2. Graphs of generated realizations of the random process of horizontal irregularity of the left rail, built for speeds a) 20 m / s; b) 60 m / s; c) 120 m / s.



Pic. 3. Graph of spectral densities of horizontal irregularity of the left rail to meet the challenges of the dynamics at speeds: a) 20 m / s; b) 60 m / s; c) 120 m / s.

At speed of 150 m/s the frequency range from f_{LF} = 0,2 Hz to f_{HF} = 10 Hz corresponds to a wavelength of L_{LF} = 750 m to L_{HF} = 15 m, which is entirely within the wavelength range defined by the specified parameters of realization L_{TR} = 7992 m and Δx = 0,185 m.

Spectral analysis of realization of the random process of horizontal irregularity of the left rail with such parameters ascribed to the speed v = 1 m/s, was performed by the method described in [1]. It has shown that in the spectral density graph G (f) there is a number of terms (Pic. 1). To solve further generation problems of the random process of geometrical irregularities in the time domain, approximation of the graph G (f) was carried out by an analytic expression:

$$G(f)=\frac{s^2}{2}\sum_k a_k\left\{\exp\left[-\frac{(\omega-\beta_k)^2}{4\alpha_k^2}\right]+\exp\left[-\frac{(\omega+\beta_k)^2}{4\alpha_k^2}\right]\right\} \quad (4).$$

In this expression: $a_к$ is dispersion share S^2, attributable to the k–th component of the analytical expression ($\Sigma a_к$=1); β_k and α_k [$м^{-1}$] are respectively frequency and attenuation coefficient of the k-th component.

Values of parameters of the analytical expression (4), shown in Table 1, indicate that within a spectral density there are 18 components having wavelengths from 6,25 to 750 m. The greatest energy is attributable to the component with a wavelength of 25 m; the coefficient a_3 for it is 0, 5078, that exceeds by far coefficients $a_к$ of other components. This is due to the lengths of inventory rails at the initial laying of the track, and to welding portions. Comparison of the calculated values of the spectral density (thin lines), and the values calculated from the analytical expression (4), shows their satisfactory convergence.

On the basis of the analytical expression (1) using method described in [2], the generation of the random process η (x) =η (vt) was performed with the interval Δx = 0,10 m, the number of points N_{total} = 80000 and duration L_{TR} = 8000 m. With this general realization it is possible to perform realization of disturbance for individual ranges of speeds so that the frequency content of the disturbance remains in a given range 0,2<f<10Hz. To obtain such a frequency range it is necessary to read ordinates of generated realization of irregularities η (x) =η (vt) with an interval on the coordinate Δx = 0,10 m and to use only 10000 values of realization of irregularities. In that case, the lowest and highest frequencies in the disturbance process will be:

f_{LF}=10/t_R=10v/L_R=10v/(N·Δx) =0,10 Hz,

f_{HF}=1/10Δt=v/10Δx=10 Hz,

corresponding thus to given frequency range.

These parameters of reading must be maintained up to speed v, determined by the lowest frequency of the process: v= 0,1 f_{LF} L_R= 20 m/s. Here the highest frequency will be f_{HF}=v/10Δx=20 Hz. With further increase in speed the interval on the coordinate should be taken equal to 2Δx; 3Δx; ...; 8Δx, keeping the same number of intervals N = 10000. Speed ranges and values of the highest and lowest frequencies for the reading of realization for such parameters are shown in Table 2.

As it can be seen from the table, the required ranges of the lowest and the highest frequencies are kept at all speeds.

Let's consider only the results of spectral analysis of generated irregularities for the first, third and sixth ranges. Graphs of generated realizations of a random process of a horizontal irregularity of a rail (Pic. 2) computed with the interval k = 1, 3, and 6 for speeds of 20 m / s (Pic. 2 a), 60 m / s (Pic. 2 b) and 120 m / s (Pic. 2 c), respectively, show that with increasing speed, as expected, frequency of disturbance also increases.

Graphs of spectral density of disturbance for considered motion speeds (Pic. 3) show that all the energy of processes is attributable to the selected frequency range 0,2–10 Hz. With the growth of speed the type of spectral densities changes – the share of high-frequency components increases. When v = 20 m / s (Pic. 2 a), the maximum of energy of the spectral density falls on the frequency range 0,3–1,5 Hz, then at the speed v = 60 m / s (Pic. 2 b), the maximum accounts for the range of 1,5–2,7 Hz and at v = 120 m / s (Pic. 2 c) – on a range of 3,2–4,8 Hz. The ordinates of maximums also change.

Conclusion. *Thus, the developed method for generating random process simulates disturbances in the required frequency range for the given speeds from 10 to 160 m/s.*

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