ON RELIABILITY OF ASSESSMENT OF THE RAIL GAUGE STATE IN THE PLAN

Shiler, Valery V., *Omsk State Transport University, Omsk, Russia.*
Shiler, Alexander V., *Omsk State Transport University, Omsk, Russia.*

ABSTRACT

The data presented in the article testify to the urgent need for modernization of methods for studying horizontal geometric irregularities that provide necessary accuracy in assessment of the rail gauge state. The method for measuring the trajectory of the lateral surface of the rail head in the horizontal plane is improved. The method of converting the bending arrows from the base chord to the absolute values of the coordinates of the trajectory of the lateral surface of the rail head in the plan is modified. The influence of lateral wear of rails on traffic safety is evaluated. Particularly, the authors argue that along with the spectral methods of estimating the horizontal irregularities, it is necessary to apply the indicator of the traffic safety factor of single irregularities. According to the research the lateral undercut of the rail head in the longitudinal direction has an uneven wavy character and the results of its measurements should be used in assessing traffic safety, especially in curved sections of the track.

Keywords: *railway, track measuring car, horizontal irregularity, rail gauge, side wear of rails, traffic safety.*

Background. *Deviations from the norms of the maintenance of the geometry of the rail threads in the plan account for 11 % of the total number of deviations in the geometry of the rail gauge and 6 % for deviations from the gauge width standards [1]. Quantitative estimates of the horizontal track irregularities are given in the works of many authors (S. P. Pershin, H. Balukh, E. M. Bromberg, O. P. Ershkov, et al). According to the analysis of the results of rail track measurements obtained by track measuring cars [2], a regular for a satisfactory track condition is the presence of periodic deviations of the rail threads in the plan. The most unfavorable deviations in [3] include short irregularities of a track 10 m long and less with the largest amplitude h = 10 mm, which cause a considerable increase in lateral dynamic forces up to 50 kN.*

As studies show, reducing the gap by 4–5 mm in straight track sections leads to a decrease in the magnitude of the lateral forces by about 20 % when traveling at speeds above 70 km/h [3]. This is confirmed by the nature of track disorders in width, since there is a correlation between the average gauge width and its standard deviation in the loaded state [1]. The results of the calculations [2] indicate that the horizontal irregularities are the determining factor in smoothness of the vehicle movement, and the deviations from the nominal track width are receding into the background. Analytic dependences are also known for specifying disturbances and determining the interaction forces between wheel sets and rails [3].

Recently, the role of statistical analysis predominates in the field of track control [4]. To estimate the statistical characteristics, the ergodicity hypothesis of the random process and the closeness of its distribution to the normal Gaussian law are adopted. The obtained spectral estimates in these studies have bursts at frequencies of 0,09–0,13 Hz, 0,16–0,20 Hz, 0,26–0,30 Hz, which corresponds to irregularities with a wavelength of 11,1–7,69; 6,25–5,0; 3,84–3,33 m. Most of the energy of the perturbation spectrum is found at low and medium frequencies in the wavelength range 5–50 m. It is established that as the track wears, the nature of the gauge track width becomes more chaotic and the predominance of small frequencies becomes less noticeable.

The purpose of the presented work is to identify shortcomings in methods of measuring lateral wear of rails and estimates of deviations in terms of rail threads, including their impact on traffic safety.

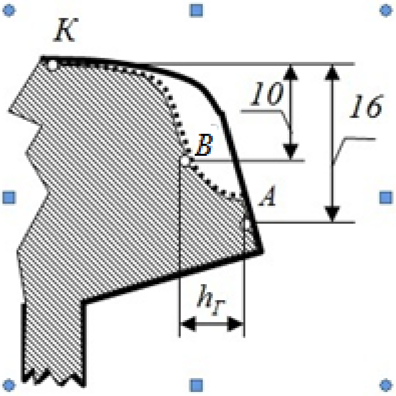
Objective. *The objective of the authors is to assess the rail gauge state in the plan.*

Methods. *The authors use general scientific methods, comparative analysis, engineering, statistical and mathematical methods, computer assisted simulation.*

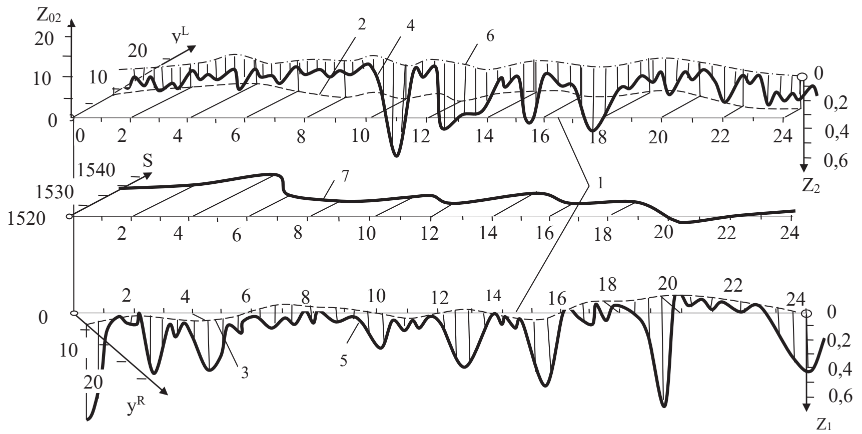
Results.

1.

In the course of operation, the outer rail in the curved section of the track receives significant directional forces, under the influence of which a lateral wear of the rail head is formed (Pic. 1, point B).



Pic. 1. Cross-section of the rail head.



Pic. 2. Trajectories of rail threads and gauge in three-dimensional representation.
Lines: 1 – nominal gauge width (1520 mm); 2 and 3 – horizontal irregularities of left and right rails respectively; 4 and 5 – wavy irregularities of left and right rails, respectively; 6 – elevation at the level of the left rail; 7 – absolute value of the rail gauge.

The disadvantage of controlling the deviations of rails in the plan using the existing track measuring cars and portable devices is that the base and measuring elements move along that part of the side surface of the rail head that is not subject to lateral notching (Pic. 1, point A). This position of the base and measuring rollers is due to the fact that it is technically impossible to ensure their steady position at point B due to the curvature of the lateral surface that is formed during formation of the lateral undercut. In operation, the assessment of the lateral undercut along the entire length of the rail in the curved track section is made from the results of measurements in one section (as a rule, this section is at the beginning of the curve section) and for its entire length is assumed as a constant value.

Continuous measurements of horizontal irregularities of the side surface of the rail head, both at the height of point B, and at the height of point A, are realized using the Izgens-3 track-measuring complex [5].

The results of measurements, obtained with the help of the track-measuring complex, represent the indirect parameters of the unevenness of the track gauge – the bending arrows from the base chord. The transformation of bending arrows into absolute values of the coordinates of the lateral surface of the head of rail threads is carried out according to the recurrence relation using the method of three points:

$$y_m(x) = y_{m-2}(x) - 2 \cdot (y_{m-1}(x) + f_{m-1}, \quad (1)$$

where $y_m(x)$ – unknown coordinate at the m-th point of the rail thread in the plan on which the first reference point of the base chord rests;

$y_{m-1}(x)$ и $y_{m-2}(x)$ –established values of coordinates of two adjacent previous points: the points of the support of the measuring element (m – 1) and the second end of the base chord (m – 2), respectively;

f_{m-1} –values of bending arrows measured by the measuring element in the middle part of the base element – at the point (m – 1);

m – numbering of points, the distance between which is equal to half the length of the horizontal reference chord of the track-measuring complex.

Practically the values of the coordinates in the first initial base point are assumed to be zero, and in the second – equal to half the value of the amplitude of the change in the width of the track gauge. A significant drawback of this method is accumulation of a «recurrence» error at each subsequent step of computation. To compensate for this error for both rail threads, a correction is introduced at each calculation step, which is equal to half the difference between the calculated (s_m^c) and actual (s_m^a) gauge widths in each calculated cross-section:

$$\varepsilon_{m-1} = (s_{m-1}^c - s_{m-1}^a)/2\,, \quad (2)$$

where $s_{m-1}^c = y_{m-1}^R + y_{m-1}^L + 1520$ – calculated gauge width, mm;

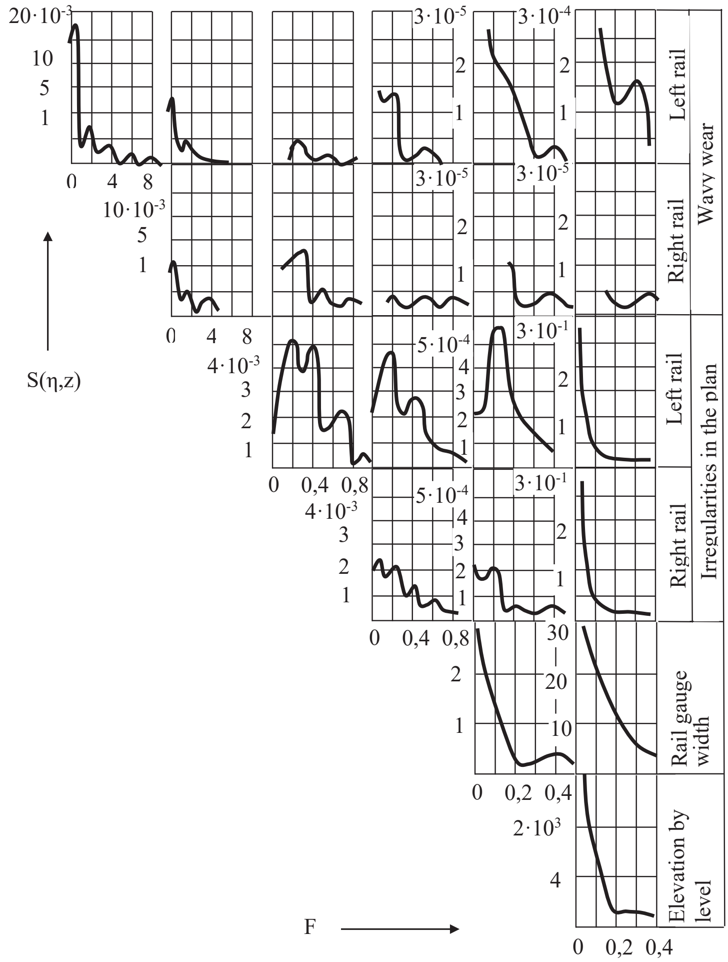
$y_{m-1}^R; y_{m-1}^L$ –calculated coordinates of the points of the right and left rail threads in the plan in one section;

1520 – normal gauge width, mm.

The value of the actual gauge width (s_{m-1}^a) was recorded by the track measuring complex in absolute values and in the same sections as the bending arrows of horizontal irregularities.

In Pic. 2 in the axonometric projection in absolute values of coordinates the results of measurements of all kinds of geometric irregularities of the rail threads of a section of the railway track with a length of 24 m are presented. The order of geometric irregularities is constructed in the following sequence: in the first step the nominal positions of the rail threads in the plan along the width (1520 mm) were set by parallel lines (line 1) taking into account the scale factor. At the second step, the values of the amplitude of the horizontal irregularities (lines 2 and 3) were plotted, the absolute values of which at the height of point A were obtained by converting the bending arrows according to formulas (1 and 2), measured. At the third step, the trajectory of elevation of the left rail (line 6) was constructed from the horizontal unevenness line. At the fourth step, the absolute values of the coordinates of the wave-like wear (line 5) were plotted from the horizontal irregularities line of the right rail, and the absolute values of the coordinates of its wave-like wear (line 4) with the corresponding scale factors from the line of the trajectory of the elevation of the left rail.

For the obtained measurement results of geometrical unevenness of the rail gauge (Pic. 2), the spectral densities are calculated. For the purpose of clarifying the interpretation of spectral densities and estimating their statistical interconnection, they are placed in the form of a graphic matrix (Pic. 3). On the diagonal of the graphical matrix there are graphs of



Pic. 3. Graphic matrix of spectral densities of geometric unevenness of rail gauge.

auto spectra for all controlled types of irregularities. The off-diagonal graphs of the table represent their mutual spectra. Since the effect of horizontal unevenness on traffic safety is evaluated in the proposed work, only the analysis of the spectra of the horizontal unevenness of the rail threads (Pic. 5, diagonal graphs 3, 4) and the gauge width is performed (Pic. 3, diagonal graph 5). Thus, the spectra of horizontal irregularities have the same number of peaks, but differ in amplitude and distribution along the frequency axis. The outbursts of the spectral density amplitudes for the right rail (stop thread) are at frequencies corresponding to wavelengths of 6,66 m, 3,5 m, 1,53 m, for the left rail – 20 m, 4 m, 2,5 m. This is explained by the fact that the right rail thread is on the level below the left one and perceives more significant in magnitude vertical and directing forces from rolling stock.

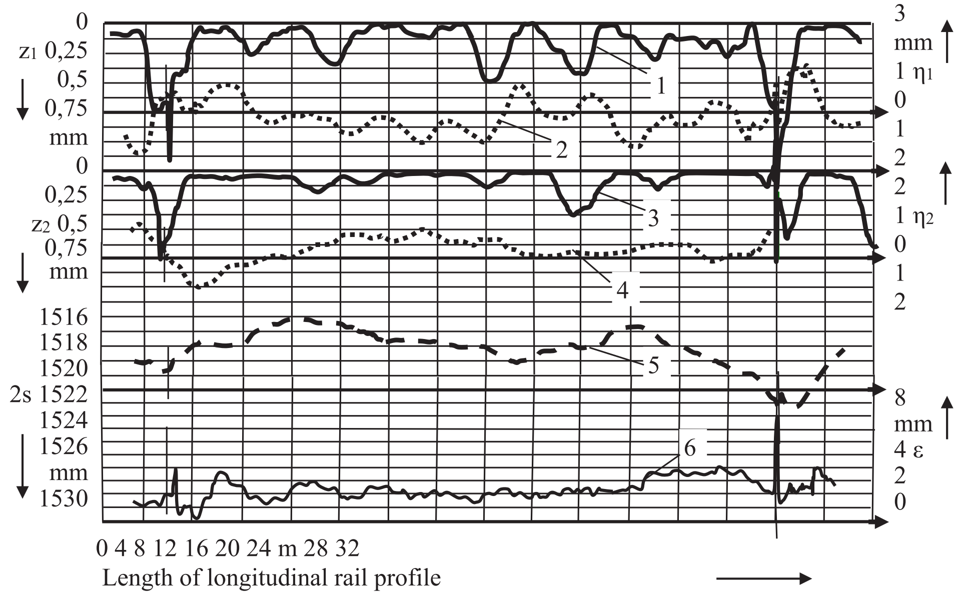
The spectrum of the gauge amplitudes has two bursts of amplitudes in the frequency range corresponding to wavelengths of 2,5 m and in the range of 10–40 m. Horizontal irregularities with wavelengths of 2,5 and 10–40 m are on the right and left rail threads, therefore the values of gauge broadening are formed due to the antiphase arrangement of these irregularities on the rail threads. Irregularities with other wavelengths along the rail threads are located synchronously and therefore do not affect the width of the rail gauge. It is much more difficult to interpret mutual spectra between different kinds of irregularities, since statistical connections are formed through numerous physical processes and are not always reflected in the frequency domain, but this is another topic.

A serious shortcoming of the spectral analysis of irregularities of the rail gauge is the lack of the ability to identify the type and extent of group irregularities with different wavelengths, to establish the shape of the trajectory of a single irregularity, to make a binding to a particular track segment.

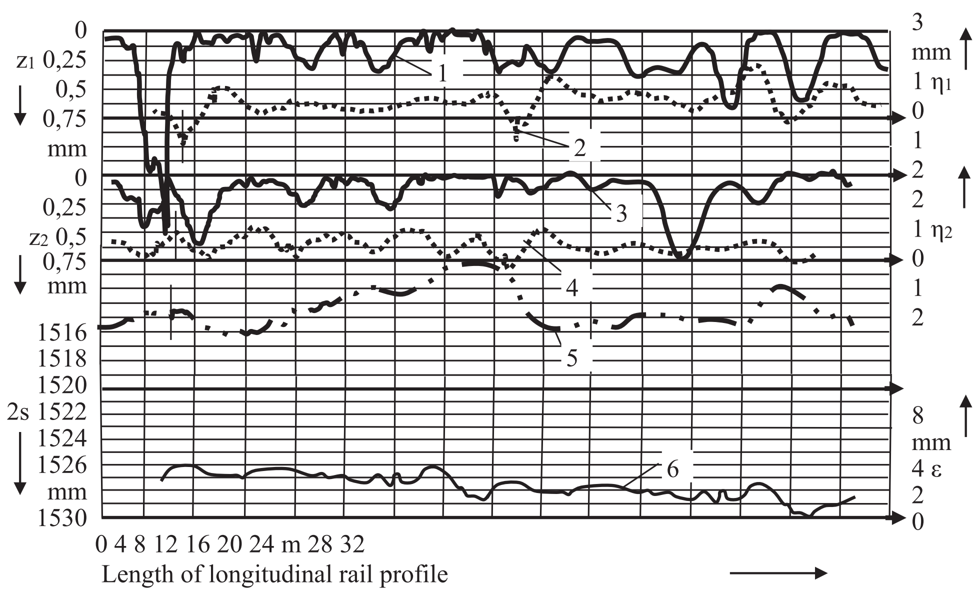
2.

The curvature in terms of the trajectory of the lateral surface of the rail head influences the level of traffic safety of a wheel set in the rail gauge. Therefore, in further studies of the horizontal roughness of the rail gauge, in addition to spectral analysis, an analysis of single irregularities according to intensity of changes in the values of their wavelength and amplitude was made.

According to the operation rules [6], retraction of the trajectory of the rail in the horizontal plane should not exceed the deviation from straightness equal to one mm per one meter of the longitudinal track, which corresponds to one per mil (1‰). This value was offered by the authors as the coefficient of safety factor ($\chi_{WF.C.}$) of a wheel set from collision of a wheel flange to a rail within the trajectory of the investigated single horizontal geometric irregularity.



Pic. 4. Rail gauge section. Lines: 1, 3 – wavy wear of right and left rail threads; 2, 4 – bending arrows in the plan of right and left rail threads; 5 – gauge width; 6 – lateral wear of right rail thread.

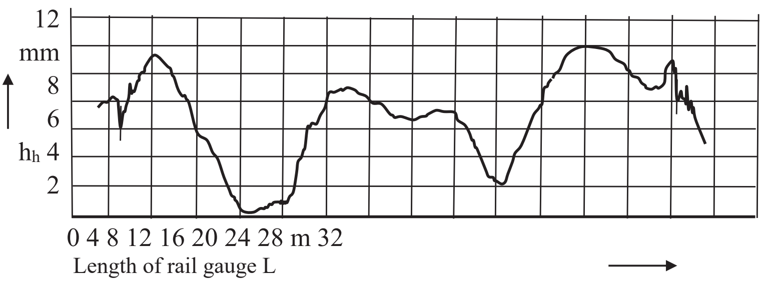


Pic. 5. Rail gauge section. Lines: 1, 3 – wavy wear of right and left rail threads; 2, 4 – bending arrows in the plan of right and left rail threads; 5 – gauge width; 6 – lateral wear of right rail thread.

The coefficient is interpreted as follows: if the geometric irregularity in the plan has an index $\chi_{WF.C} < 1$ ‰, then the movement of a wheel set along it meets the safety requirements, if $\chi_{WF.C} > 1$ ‰, then it does not meet these requirements.

The proposed coefficient of the traffic safety factor allows to obtain an express assessment of the safety of movement from the collision of a wheel flange to a rail on every meter of the trajectory of any horizontal unevenness. Pic. 4 presents in absolute coordinates the trajectory of the rolling surfaces of new rail threads with zero service life, measured in a straight section of a rail gauge 25 m long. The second track section, shown in Pic. 5, has one year of operation. Both sections have rails and sleepers with reinforced concrete sleepers. The first section shows initial horizontal irregularities with an amplitude of 1,5 mm with a wavelength of 2 m (Pic. 4, lines 2 and 4).

The amount of retraction of rails in the plan for these parameters of irregularities corresponds to the maximum allowable value for traffic safety $\chi_{WF.C} = 1$ ‰. The wavelengths of the initial horizontal and wavy



Pic. 6. Trajectory of lateral undercut of the stop rail thread in absolute values of difference between the horizontal coordinates of points A and B.

irregularities have the same wavelength and are located synchronously. These irregularities are formed in the process of their manufacture at metallurgical plants. On the second track section, a narrowing of the rail gauge, equal to 1512 mm (Pic. 5, line 5), was revealed on the interval with marks of 13–17 m. At the site of narrowing of the rail track, formation of a lateral undercut with an amplitude equal to 2 mm was noted (Pic. 5, line 6).

In the curved track section in which lateral wear was formed, measurements were made of horizontal geometric irregularities at the heights of points A and B (Pic. 1). The graph (Pic. 6) shows the absolute values of the difference (h_h) between the horizontal coordinates of the lateral surface trajectories at the level of the points B and A. According to the graph, at the unevenness length equal to 4 m, the maximum increment value of the coordinate difference (h_h) is 9 mm.

When adding horizontal coordinates at points A and B, the increment in the generalized amplitude of the horizontal unevenness was 12 mm at a length of 4 m. In this case, the coefficient of traffic safety factor is equal to $\chi = 3$ ‰, *which corresponds to a decrease in the level of traffic safety by 3 times compared to the data obtained by the existing method.*

As the results of calculations show, the process of rolling of a wheel flange onto a rail at a speed of 30 m/s occurs on the length of the unevenness trajectory equal to 0,82 m [7]. Therefore within the limits of the wave of the considered horizontal irregularity on each meter of its length the probability of derailment of a wheel set from a rail gauge is high.

Conclusions.

1. The results presented in the article, as well as numerous studies in this field by other authors, indicate the urgency of modernizing the methods for studying horizontal geometric irregularities that provide the required accuracy of estimating the state of the rail gauge.

2. Along with the spectral methods of estimating the horizontal irregularities, it is necessary to apply the indicator of the traffic safety factor of single irregularities.

3. The lateral undercut of the rail head in the longitudinal direction has an uneven wavy character and the results of its measurements should be used in assessing traffic safety, especially in curved sections of the track.

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Information about the authors:
Shiler, Valery V. – Ph.D. (Eng), associate professor of the department of rolling stock of electric railways of Omsk State Transport University, Omsk, Russia, shiler_val@inbox.ru.
Shiler, Alexander V. – Ph.D. (Eng), associate professor, head of the department of information security of Omsk State Transport University, Omsk, Russia, shiler_alex@inbox.ru.

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