Predictive assessment of change of basic geometric characteristics of rail track during the operation

D O Potapov¹, ⁴, V G Vitolberg¹, A S Malishevskaya¹, P V Plis² and R M Trishchun³

¹ Department of Track and Track Facilities, Ukrainian State University of Railway Transport, Feierbakh Square 7, 61050, Kharkiv, Ukraine
² Kupianskaya Railway Machine Station 133, Str. Sovetskaya, 14, 63709, Kupiansk, Ukraine
³ Department of Tactics, National Academy of the National Guard of Ukraine, Defenders of Ukraine sq. 3, 61001, Kharkiv, Ukraine

⁴ Email: ppx_xiit@kart.edu.ua

Abstract. The frequency and scope of scheduled preventive work depends on multiple factors: type and design of the upper track structure, plan and profile of the track, quality of the track maintenance, as well as operational, climatic and topographical conditions. Also, each type of work is affected by these factors in different ways. In addition, the factors themselves are unstable along the length of the track. Therefore, under different operating conditions, the frequency and scope of routine track maintenance are different. Since currently regulatory technical documents and domestic scientific sources contain no requirements for high-speed sections of the Ukrainian railways and, thus, a problem of organization of control of the track state in these operating conditions appears. The methodology for determining the scope and frequency of the scheduled preventive routine track maintenance work is proposed. The method is based on the use of the normal law of distribution of frequency and depth of the respective geometrical irregularities of the railway track. The maximum effect of the proposed method can be achieved through the use of modern track geometry cars with an automated data collection and interpretation system that are predominantly used in the high-speed traffic areas.

1. Introduction

Safety and smoothness of movement of the rolling stock directly depends on the good operational condition of the entire railway track structure. As the tonnage passes, the basic geometric characteristics of the track change, which in most cases causes the necessity of track repair. Therefore, studying the process of their change during operation is one of the main tasks for optimal conduct of preventive work and the rational use of inventories and technical resources.

The track management system provides periodic check of the state of the railway track using track geometry cars. The track geometry car provides measurement and recording on the tape of geometric parameters of the track which affect the smoothness and safety of train movement. The measured and recorded track parameters include: the relative position of the track lines height along (level), local subsidence (hills and hollows) of each track line, track width, position of the track lines by direction in the plan view.

The frequency and scope of scheduled preventive work depend on many factors [9, 11]: type and design of the upper track structure, plan and profile of the track, quality of the track maintenance, as
well as operational, climatic and topographical conditions. Also, each type of work is affected by these factors in different ways. In addition, the factors themselves are unstable along the length of the track. Therefore, under different operating conditions, the frequency and scope of routine track maintenance are different.

Since according to [1-3], currently regulatory technical documents and domestic scientific sources contain no requirements for high-speed sections of the Ukrainian railways and, thus, a problem of organization of control of the track state in these operating conditions appears.

The purpose of the article is to propose a methodology according which would result in possibility to predict the change of the state of the basic geometric characteristics of the track, which in the future will allow to plan rationally the timing of routine track maintenance, especially in perspective sections of high-speed traffic.

2. Main part

According to [1-3], the estimation of the geometric position of the rail track is based on the influence of deviations from the maintenance norms on the dynamic parameters of interaction of the track and the rolling stock.

Each deviation has a specific degree of influence on the dynamic interaction of the track and rolling stock and on the intensity of accumulations of residual deformations of the track. Five grades are set for all deviations from the track maintenance rates, depending on their size and length. Each deviation is evaluated in points depending on the grade.

Grades I-III include deviations which ensure the safety and smoothness of train movement, as well as economically rational track operation when trains run with established speeds.

Grade IV includes deviations, in the presence of which at established speeds, the smoothness of train movement deteriorates, which leads to an intensive accumulation of residual deformations of the track.

Grade V includes deviations, in the presence of which the forces of interaction of wheels and the rolling stock increase to such critical values, which under unfavourable conditions can lead to very fast accumulation of deformations and to the emergence of a traffic safety threat. Penalty points are given for grade II-V deviations.

Due to the increased dynamic impact [7-9] of the rolling stock on the track at the points of degree V deviations, as well as at combinations of several deviations of degrees III-V (such as slants, subsidence, setback in the plan), measures should be taken immediately to eliminate them as soon as such points are detected.

It is known [4, 5] that after the repair works, the railway track in the vertical and horizontal planes is inequality with different lengths and depths. The methodology is based on the subordination of the law of distribution of geometric inequalities to the normal law of distribution with mean value \( H \) and root-mean-square deviation \( \sigma \).

According to [6], the mean value can statistically be determined as follows:

\[
H = \frac{h_i \cdot n_i}{\sum n_i}, \tag{1}
\]

where \( h_i \) – is relevant geometric inequality of railway track;

\( n_i \) – is inequality rate.

Root-mean-square deviation can be determined as:

\[
\sigma = \sqrt{\frac{(h_i - H)^2 \cdot n_i}{n_i}}. \tag{2}
\]

At the initial stage of their operation, the track irregularities will be within the established standards, usually of degree I, with the mean value of deviation \( H_0 \) and root-mean-square deviation \( \sigma_0 \).
During the operation (figure 1), the above two parameters of geometric irregularities of the railway track gradually change. The average values of $H_0$ and $\sigma_0$ gradually change and, after passing a certain tonnage, these two parameters will be within the range of a certain degree of failure, which in turn will require the implementation of track work to eliminate these faults, after which, in the general case, they will change to values $H_p$ and $\sigma_p$.

![Figure 1. Calculation diagram for determining scopes and frequency of routine track maintenance](image)

According to figure 1, as the main criteria for track work are the presence of faults or deviations of grade III and above, then area $S$ is nothing else but the predicted scope of track work.

The average value of $H$ for any passed tonnage can be represented as:

$$H_f = f_1(T).$$

Function $f(T)$ depends on multiple operational factors and most importantly, on the type of geometric inequalities (level position, subsidence, track width, realigning).

Similarly, we can write for the root-mean-square deviation

$$\sigma_f = f_2(T).$$

For the prospective planning of the frequency and scope of track work, the law of change of the average value $H$ and the root-mean-square deviation $\sigma$ should be determined depending on the passed tonnage for each of the geometric parameters of the railway track for a particular section of the railway track.

It is known [6, 11] that in the standard form, the normal law of distribution can be represented as follows:

$$f(x) = \frac{1}{\sqrt{2 \cdot \pi \cdot \sigma}} \cdot e^{\frac{(x-\overline{x})^2}{2\sigma^2}},$$

where $\sigma$ – is root-mean-square deviation;

$\overline{x}$ – is the mean value of the parameter;

$x_i$ – is the current value of the parameter.

Based on expressions (1), (2), two basic parameters of the law of normal distribution can be calculated on the basis of the data of the passage of track geometry cars. For example, figure 2 shows
the curves of the normal distribution of geometric deviations along the track width for one of the track sections.

![Figure 2. Curves of normal distribution of geometric deviations along track width](image)

According to figure 1, area $S$ is the predicted scope of track work which can be determined as follows:

$$ S = \frac{H_T + 3 \sigma_T}{d_{III-IV}} \cdot \frac{1}{\sqrt{2 \cdot \pi \cdot \sigma T}} \cdot e^{-\frac{(H_T - H_T)^2}{2 \sigma_T^2}} \cdot e^{-\frac{(H_T - H_T)^2}{2 \sigma_T^2}}, $$

where $d_{III-IV}$ – are the numerical value of degree III deviation for the respective geometrical characteristics of the railways track;

$H_T, \sigma_T$ are the current values of mean value and root-mean-square deviation of the respective geometrical characteristics of the railways track.

Based on the obtained dependences of the mean value and the root-mean-square deviation from the passed tonnage for a certain period of time, we can write as follows

$$ H_T = H_{T-1} + f_1(T), $$

where $H_T$ is the mean value of the relevant geometric inequality of the railway track; $H_{T-1}$ is the previous mean value of the relevant geometric inequality of the railway track; $\Delta T$ is passed tonnage.

Similarly, for the root-mean-square deviation

$$ \sigma_T = \sigma_{T-1} + f_2(t). $$

It is known [3] that the main criterion for performance of track work is the presence of faults of degree III and above, and with regard to the safety of movement of trains with predetermined speeds – the absence of grade IV, and most importantly grade V faults, i.e.:

$$ H_T + 3 \cdot \sigma_T < d_{III}; $$

$$ H_T + 3 \cdot \sigma_T < d_{IV}; $$

$$ H_T + 3 \cdot \sigma_T < d_V; $$

Formulas (9-11) are the main criteria for determining the frequency of track work. If the respective limit values are exceeded, the scope of track work can be determined using formula (6).
3. Conclusions
The proposed methodology for forecasting the timing and scope of scheduled preventive routine track maintenance works is proposed. The maximum effect of the proposed method can be achieved through the use of modern track geometry cars with an automated data collection and interpretation system that are predominantly used in the high-speed traffic areas.

References
[1] Rules of technical operation of Ukrainian railways 2003 (Kyiv: Poligrafservis) p 136
[2] Danilenko E I, Orlovskiy A M, Umanov M I, Patlasov O M 2012 Instructions for the track laying and maintenance of Ukrainian railway (Kyiv: Poligrafservis) p 455
[3] Patlasov O M, Rybkin V V 2012 Technical instructions on assessment of the condition of the rail track using findings of track geometry cars and ensuring the safety of trains with deviations from the standards of rail track maintenance (Kyiv: Transport Ukraine) p 25
[4] Danilenko E I 2010 Railway track. Arrangement, design and calculation, interaction with the rolling stock / Tutorial for higher education institutions (in 2 volumes) (Kyiv: Inpers) p 528
[5] Bogacz R and Konowrocki R 2012 On new effects of wheel-rail interaction Archive of Applied Mechanics T. 82 № 10-11. 1313-1323
[6] Korn G A and Korn T M 1974 Mathematical handbook (Moscow)
[7] Verigo M F and Kogan A Ya 1986 Interaction of track and rolling stock (Moscow: Transport) p 599
[8] Darenisky O M 2010 Conditions of contact of wheels and rails in the horizontal plane. Power and kinematic connections of a vehicle and the track Coll. of scient. works of UkrDAZT 113 171-177
[9] Darenisky A, Vitolberg V, Fast D, Klymenko A, Leibuk Y 2017 A mathematical model of the rail track presented as a bar on elastic and dissipative supports under the influence of moving loads Materials Science, Engineering and Chemistry – Transbud’2017. MATEC Web of Conferences 116, 03002
[10] Regulations on scheduled preventive track repair works at the Ukrainian railways 2015 (Kyiv: Publishers Devalta LLC) p 48
[11] Buslenko N P, Schreyder Yu A, 1961 Static test method (Moscow: GIFML) p 216