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TESTING OF RUNNING SAFETY OF RAILWAY VEHICLES IN ACCORDANCE WITH INTERNATIONAL STANDARDS

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***Abstract** – This paper shows the methodology of experimental testing of running safety of railway vehicles in accordance with international standards. The special attention is concerned to the track quality for testing of dynamic behavior of railway vehicles. The problems of sampling frequency and signal processing are analyzed and discussed. The results of testing of the dynamic behavior of wagon for cars transportation in accordance with exposed methodology are presented and discussed.*

Keywords – Running safety, Dynamic behavior, Railway vehicles

1. INTRODUCTION

One of the main aims on the railway is to increase the ride comfort and safety and security. The assessment of the dynamic behavior of railway vehicles is based on two criteria – testing the safety against derailment and testing the quality of ride comfort. Initially, it was considered that these two criteria were in absolute correlation, i.e., that a high level of ride comfort leads to high safety against derailment. This led to the development of a railway vehicles testing methodology that combines both criteria.

The most common and longest in use is the Sperling criterion [1], which is defined by UIC regulations. According to this criterion, the quiet running is determined by accelerations of the vehicle in the horizontal and vertical direction ($\ddot{y}$, $\ddot{z}$), impacts, i.e., changes in acceleration in time ($\dddot{y}$, $\dddot{z}$), and work of oscillation ($y \cdot \ddot{y}$, $z \cdot \ddot{z}$). The parameter W_z, which determined the quiet running of vehicle according to the Sperling, was corrected with the factor of subjective passenger feeling [2]. Additional criterion for the assessment of the running safety of railway vehicles is based on the determination of the lateral forces H [3] at the height of the axle bearing is introduced (the Martin i.e., Prud 'Homme criterion) [4, 5]. This criterion is valid for speeds up to 120 km/h, while for larger speeds is mandatory to apply the criterion of the ratio of lateral and vertical wheel-rail contact forces Y/Q [6, 7].

The vast efforts of UIC, ERRI, research centers and individuals around the world are focused on improving vehicle design through improved dynamic testing. All this has greatly contributed to increasing the safety and comfort of driving, but insufficient attention has been paid to the quality of the track on which the tests are performed. This shortcoming began to be largely corrected only after the advent of UIC 518 [5]. In accordance with the above, this research is focused on the possibilities and limitations of the application of international regulations on the example of experimental testing of the dynamic behavior of wagon for car transportation DDam which suspension is based on the parabolic spring (Fig. 1).

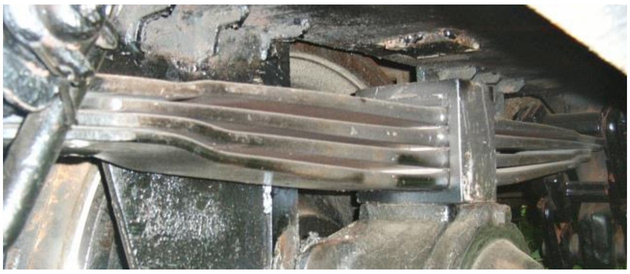

Fig. 1. The suspension of DDam wagon for cars transportation – parabolic spring

2. TRACK CHARACTERISTICS

In accordance to the UIC 518 and EN 14363, the track quality is determined by using the measuring wagon. For assessment of the track quality, measured vertical and lateral irregularities are used. Each

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measuring wagon has its own transfer function between the actual and measured state of the track. The transfer function depends primarily on the applied principle of measurement and distance of the axles of measuring wagon. Therefore, different measuring wagons give different results for the same track section. For this reason, the railway administrations of the countries that participated in the preparation of the regulations performed a comparison of their measuring wagons and as standard they chose the measuring wagon of Holland railway. Measurements of all other measuring wagons are corrected by the correction coefficients *k*, according to the expression:

$$\sigma_{z,y} = k \cdot \sigma_{NSz,y} \tag{1}$$

where $\sigma_{z,y}$ is standard deviation of the vertical σ_z and lateral σ_y track irregularities measured by another measuring wagon, while $\sigma_{NSz,y}$ is standard deviation of the vertical and lateral track irregularities measured by Holland measuring wagon.

This way provides comparability of the results of dynamic testing of the same vehicles on different tracks, and even different vehicles on different tracks. The UIC 518 defines the track quality according to the standard deviations of the vertical σ_z and lateral σ_y track irregularities. The track quality is classified into three categories: QN1, QN2 and QN3, where QN3=1.3·QN2. It is recommended that testing of dynamic behavior of railway vehicles should be performed on a commercial track where 50% of sections have quality better or equal than QN1, 40% of sections have quality between QN1 and QN2, and 10% of sections have quality between QN2 and QN3. If track quality exceeds the QN3 limit values, the results of dynamic behavior of the vehicle is not taken into account in these parts of the track.

In order to be able to analyze the test results, it is necessary to divide the selected track route into sections of the prescribed length ℓ_s. International regulations define the way in which the division into sections and zoning should be done (Fig. 2).

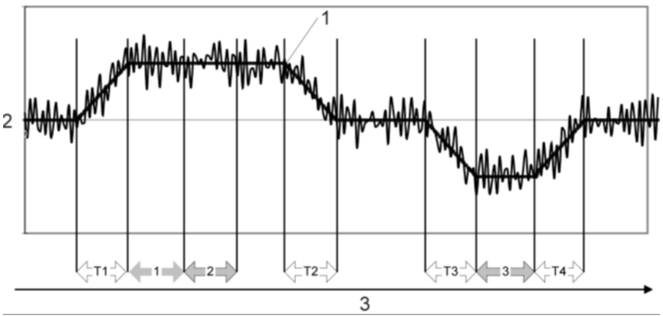

Fig. 2. Track sections in test zones for curved track

The meaning of certain labels in Fig. 2 is: 1 – curvature diagram, 2 – measuring value and 3 – track sections, separated in arc and transition curve. The minimum length of the section ℓ_s and the minimum required number of sections *N* is defined by UIC and EN regulations.

In order perform the analysis of the results of the test, in accordance with the standards it is necessary to divide the selected part of the track into sections of a certain length l_s and number *N*, and then assign them to zones that depend on the radius of the curve R, where distinguish: Z1 - zone of straight track (∞≥R≥2500 m); Z2 - zone of curves with large radius (2500 m>*R*≥600 m); Z3 - zone of curves with small radius (600m>*R*≥ 450 m), this zone is divided into the zone of full curves $Z3_k$ and zone of transition curves $Z3_p$; Z4 - zone of curves with very small radius (450m>R≥250 m), this zone is divided into the zone of full curves $Z4_k$ and zone of transition curves $Z4_p$; and Z5 – zone of point switch. The transition curves in statistical processing are separated from full curves. The individual length l_s and minimum number of sections *N* depend on the zone and are given in the regulations. The number of sections of transition curves and point switches is not defined by regulations.

3. TESTING OF WAGON FOR CARS TRANSPORTATION

The tests of the empty and loaded wagon were carried out on dry rails, on the following routes: Sid - Cuprija. The parameters being measured are shown in Fig. 3, where: H_I, H_{II}, H_{III} – lateral forces at the level of axle bearing on the first, second and third axle; $\ddot{y}_I$, $\ddot{y}_{II}$, $\ddot{y}_{III}$ – horizontal-lateral accelerations on wheelsets on the first, second and third axle; $\ddot{y}^*$ – horizontal-lateral acceleration of the car-body above the last wheelset; $\ddot{z}^*$ – vertical acceleration of the car-body above the last wheelset. The DDam wagon was loosely hooked and placed at the end of the composition, comosed still of the locomotive and the wagon laboratory (Fig. 4).

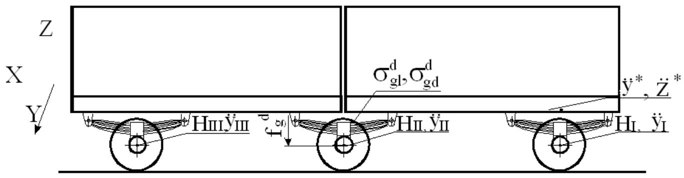

Fig. 3. Layout of measuring points at tests

Fig. 4. The position of tested wagon in composition

The limit values of the lateral forces $(H_{2m})_{\lim}$ measured at 2 m [9]:

$$\left(H_{2m}\right)_{\lim} = \beta \cdot \left(10 + \frac{P_o}{3}\right) \text{ [kN]} \tag{2}$$

where *Po* [kN] is axle load; β=0,75 is coefficient for empty wagon; and β=0,8 is coefficient for laden wagon. The limit values of lateral and vertical accelerations for freight and special wagons are:

$$\begin{aligned} \left(\ddot{y}_s^*\right)_{\lim} &= 4.43 - P_o/140 \text{ [m/s}^2\text{]} \\ \left(\ddot{z}_s^*\right)_{\lim} &= 5 \text{ [m/s}^2\text{]} \end{aligned} \tag{3}$$

After measurement the load per axle, the limit values of lateral forces $(H_{2m})_{\lim}$, and the limit values of acceleration, for empty and loaded wagon, are calculated. The parameters related to the running safety are: $\left(\ddot{y}_s^*\right)_{\lim}$ – limit value of horizontal-lateral accelerations on the car-body; $\left(\ddot{z}_s^*\right)_{\lim}$ – limit value of vertical accelerations on the car-body; and $\left(s\ddot{y}_s\right)_{\lim}$ – RMS limit value of horizontal accelerations on the wheelsets [5].

The parameters related to the quiet running are: $\left(\ddot{y}_q^*\right)_{\lim}$ – limit value of horizontal-lateral accelerations on the car-body; $\left(\ddot{z}_q^*\right)_{\lim}$ – limit value of vertical accelerations on the car-body; $\left(s\ddot{y}_q^*\right)_{\lim}$ – RMS limit value of horizontal-lateral accelerations on the car-body; $\left(s\ddot{z}_q^*\right)_{\lim}$ – RMS limit value of vertical accelerations on the car-body; $\left(\ddot{y}_{qst}^*\right)_{\lim}$ – limit value of quasi-static horizontal accelerations on the car-body. The mean square deviation *s* of the statistical sample *x* of number *N* and mean value $\overline{x}$ is [6, 7]:

$$s = \sqrt{\frac{\sum_{i=1}^{N}\left(\overline{x} - x_i\right)^2}{N}} \tag{4}$$

On the test track with a slope of 1:20, the necessary measurements of the geometric characteristics of the track were performed with the test wagon of the Serbian railways. The processing of the recorded data was performed with the AP00 program and software developed at the Railway Vehicles Center in Kraljevo. The mentioned software is based on Instruction 339 on unique criteria for controlling the condition of railways on the Serbian railway network.

Permitted values of track quality QN1, QN2 and QN3 in the horizontal and vertical directions are defined by UIC 518 and are entered into the diagram records of the measured geometrical characteristics of the track (Fig. 5).

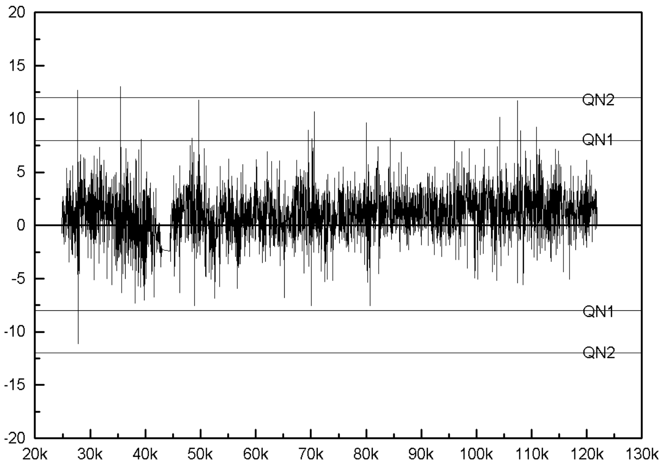

Fig. 5. Geometric characteristics of the track Šid – Nova Pazova – longitudinal level

4. SIGNALS PROCESSING

The test means one continuous measurement, where the vehicle runs on geometrically different parts of the track (straight track, curves of various radii, transition curves and switches). One sample contains sections of one or more zones (Z1, Z2, …, Z5). In order to meet the defined minimum number of sections, the test of quiet running and running safety of DDam wagon was performed with several test runs. Statistical processing of recorded dynamic parameters is based on the regulation UIC 518, where the tests were divided into sections, then statistical processing was performed by sections and from them zones were formed where the final statistical processing was performed.

4.1. Processing by sections

Processing of measurement results is performed for each section separately. The length of one section ranges from 70 to 500 m. From individual measured parameters, for example $\ddot{y}^*$, when filtering, by applying different limit frequencies f_{gr} (which are defined by regulations), filtered values $\ddot{y}_s^*, \ddot{y}_q^*$ and $\ddot{y}_{qst}^*$ were obtained.

4.2. Processing per zones

The statistical values obtained by filtering in processing by sections x_i represents input data for processing by zones. In statistical processing by zones, for each value x_i, a mean value $\overline{x}$ and a mean square deviation *s* are determined. Finally, for each value by zones, a maximum estimated value $\hat{x}_{\max}$ is determined, using the expression:

$$\hat{x}_{max} = \bar{x} + k \cdot s \qquad (5)$$

In the previous expression factor k has following values:
k=3 – for estimated values related to safety;
k=2.2 – for estimated values related to quiet running;
k=0 – for quasi-static estimated values.

Such determined maximum estimated value *x* is compared with the permissible value for each tested parameter, and the final assessment for the tested vehicle is made. Illustration of the obtained results is shown in the diagram on the Fig. 6.

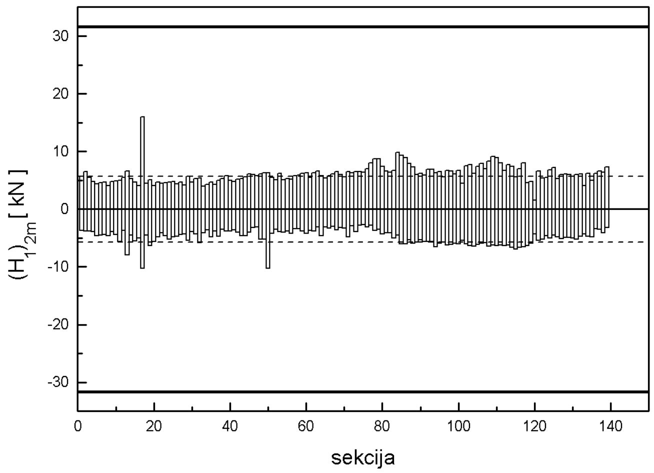

Fig. 6. Diagram of lateral force HI on the first axle determined for the zone of the straight track Šid-Nova Pazova - the movement of the empty DDam wagon at speed of V=130 km/h

5. CONCLUSION

An overview of the development of regulations related to the testing of the quiet running and running safety of railway vehicles is given. In UIC 518 special attention is paid to the quality of the track on which dynamic testing is carried out. From the requirement that tests should be carried out on a commercial track, it follows that the existing test polygons built for this purpose are excluded. Respecting the requirement for testing on a commercial track means even respecting construction regulations for the construction and maintenance of the track, which are different in some countries.

On the other hand, UIC regulations are international and valid in all UIC member countries. Therefore, it is necessary that in every country expert in the field of construction and mechanical engineering consider the possibilities of necessary harmonization. This is particularly related for requirement of UIC 518 regarding the cant deficiency and coefficients of the measuring wagons for testing the track quality.

The results of testing of DDam wagon are presented. The greatest difficulty during the preparation the tests was the selection of the track and the determination of its quality. In most cases, the condition of cant deficiency could not be met.

In addition, the organization of the tests required great efforts. The test was carried out on a commercial track at speeds that were 10% higher than the allowed speeds. As for the analysis of the obtained results, which are feasible in the existing conditions, it was concluded that the DDam wagon meets the criteria related to the quiet running and running safety.

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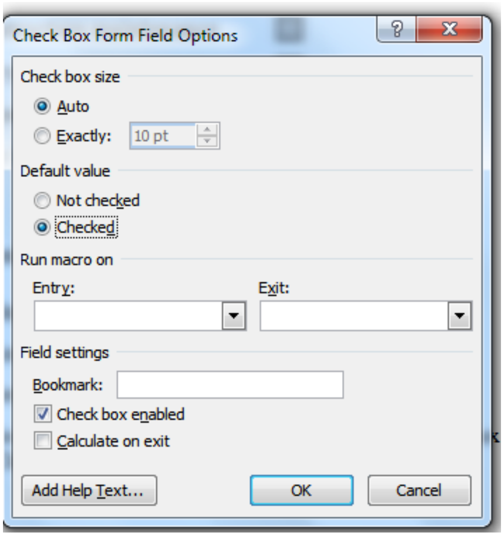

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