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ANALYSIS OF PASSENGER TRAIN RUNNING STABILITY ON DUAL GAUGE TRACK CURVES OF LINE "RAIL BALTICA"

Summary. The paper deals with the problem of evenness of train running on dual track curves in the route “Kaunas–Poland Border of new built railway line ”Rail Baltica“. Authors examined the stability and smoothness of rail vehicle running on railway track curves of dual gauge. Traffic safety conditions of passenger coach is analysed and assessed according to four parameters: maximum permissible speed, risk of rail vehicle derailment, uncompensated transversal acceleration and lateral displacements of running gear. The train running smoothness was analyzed considering the main parameters as the radius of horizontal curves, the superelevation of outer rail and the impact of unsuspended transversal acceleration. The movement of four-axle coach on track with given vertical and track transversal irregularities was simulated by using software package „Universal Mechanism”. Gained research results are compared with the maximum permitted speed on „Rail Baltica“ track curves. Finally, basic conclusion and recommendations for designing of dual track curves in are given.

1. INTRODUCTION

Rail line „Rail Baltica“ – is an ongoing railway infrastructure project to join Finland (via ferry), Estonia, Latvia, Lithuania and Poland with a European standard gauge rail lines. This transport artery will permanently connect the Baltic States with the European 1435 mm gauge railway network. One of the main purposes of this line is to integrate the Baltic railways into the Trans-European network TET-T. One of the most important criteria for examining the competitiveness of rail passenger transport is travel time, i. e. train average speed on lines. Powerful traction units and high railway line capacity can ensure sufficiently fast train speed. It should be noted that railway lines consist of both straight track sections and track curves. Track curves in Lithuanian railways account for (20-30)% of the total length of the railway track due to the peculiarities of the country landscape. The curves are subject to significantly higher transversal horizontal forces compared to straight track sections. The loads increase as the radius of curves decreases or the train speed increases (the centrifugal forces are proportional to the square of the running speed of the rail vehicle). Increased train force intensifies the wear on the upper railway track structure and wheel set elements, especially the external rail and wheel flange [1, 5, 8]. In addition to the accuracy of the railway track plan parameters, a very important indicator is the rationally selected train running speed in curves.

Another very important indicator of passenger comfort is uncompensated transversal acceleration while running in curves [3, 7]. Without reducing the maximum permitted train speed, this undesirable acceleration can be reduced by building curves with a radius of at least 2000 m and using passenger vehicles with tilting bodies. There are stricter requirements for track structure in horizontal curves and its maintenance, especially the sections with high train speed [6]. Railway track installation on horizontal curves (especially in case of dual gauge) differs that the track gauge is widened in curves with a radius less than 350 m; in addition, external rail superelevation is installed in curves with a radius less than 4000 m [2].

Reaserchers [9] discovered that under the permitting line condition, setting up a curve radius more than 800 to improve driving stability and reduce rail wear will be more effective, compared to a small radius curve. It is stated that when the curve radius increases from 400 m to 800 m, derailment coefficient is reduced by 38%, rate of wheel load reduction is reduced by 41%, wheel–rail lateral force is decreased by 35%, and abrasion power is reduced by 68%. If the radius of the curve increases, all above mentioned indexes become lower [10, 11].

The aim of this study is to analyse the influence of railway track gauge geometrical parameters on train running stability in dual 1435 / 1520 mm gauge track curves of “Rail Baltica“. The relevance of this study is based on the fact that the section of railway line from Mockava (Polish border) to Kaunas is built on an old road structure with former curves up to 700 meters. This paper and investigation is considering thwe dual track gauge curves. This type of track construction is not widely investigated because it is very rare. The geometrical parameters in dual track gauge, the influence of these parameters on wheel–rail interaction, intensity of the wheel–rail vibration, and effect on the running safety and comfort is not investigated in detail. Therefore, it would be useful to further investigate this issue in the future, paying due attention to the complexity of the problem.

After having determined the criteria for possible rail vehicle derailment in curves and assurance of rail vehicles running smoothness, the Authors of this study are aiming to find rational ways to build dual gauge track curves of “Rail Baltica”. Further, to make reasoned proposals for increasing or decreasing train speed on these curves.

2. ASSESSMENT OF RAIL VEHICLE RUNNING SMOOTHNESS IN HORIZONTAL TRACK CURVES

The “Rail Baltica“ is the most important railway infrastructure project in the Baltic region that will integrate the Baltic States into the European railway network. Railway track fragment of built “Rail Baltica“ sector dual gauge is provided in Fig. 1.

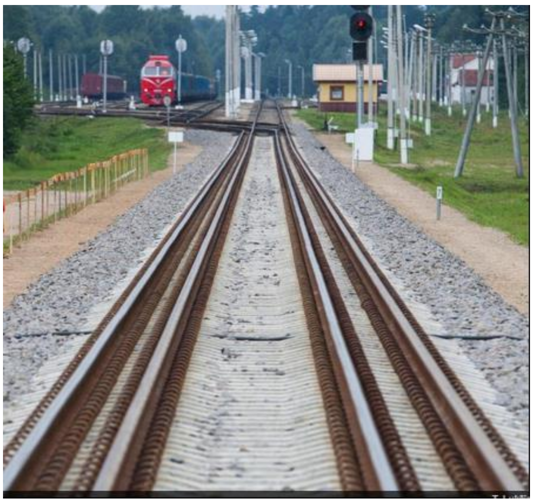

Fig. 1. Dual 1435/ 1520 mm gauge track of built “Rail Baltica“

It is planned to provide the freight and passenger services on the same “Rail Baltica“ line tracks. This causes a problem of road curve installation, as both high-speed passenger trains and much slower freight trains will run on the same track. Passenger trains can run on curves with a significantly higher rail superelevation than freight trains. In order to maintain the maximum speed of passenger trains, it is appropriate to build a railway track with as few curves as possible. Large radius curves must be provided to change the direction of the road in places where the curves cannot be avoided. The default stopping distance of the train shall be such that trains could slow down safely and smoothly without exceeding the permitted deceleration. The requirements for the railway infrastructure to assure the different train speed are provided in Table 1.

Tab. 1

Parameters of 1435 mm and 1520 mm gauge rail track

Parameters	Current 1520 mm gauge up to 120 km/ h	Planning 1435 mm gauge up to 250 km/ h
Train maximum speed, km/h	120	250
Track maximum slope, ‰	3.5	1.5
Minimum radius of track horizontal curve, m	1500	2950
Minimum radius of track vertical curve, m	15000	25000
Average train braking distance, m	1200	3500

The geometrical macro- and micro- unevenness of the track is the most important factor in the interaction of the rail vehicle running gear with the track. The superelevation of external rail is installed in order to achieve higher train speeds on curves; however, running at too low speed poses other dynamic stability issues. The size of superelevation of external rail in curves is one of the most important parameters of track gauge geometry that affects the dynamic interaction between wheel and rail [4, 6].

3. SIMULATION OF SYSTEM “RAIL VEHICLE– TRACK”

During the numerical simulation of passenger coach parameters with software package “Universal Mechanism“ when the rail vehicle runs at the selected track profile, the following objects and factors determining the evenness, smoothness and stability of the coach movement in the track curves were evaluated:

1. Simulated section of rail vehicle running in “Rail Baltica“ track.
2. The dynamic transversal and vertical forces of the coach are determined.
3. Interaction of wheel and rail by evaluating the derailment condition criterion.

The software package allowed carrying out many tests in a relatively short period by avoiding real trail vehicle tests in real conditions. Another advantage of numerical simulation is the limitations of the study: when testing in a virtual environment with a software, it is possible to test limit speeds without real danger (consequences), rail vehicle stability exceeding the standard centre angles of the curve and the superelevation. The general view of passenger coach with two 18-100 type bogies simulated in “UM” environment is provided in Fig. 2.

The following parameters have been established during simulation of passenger coach with UM software package:

1. Longitudinal and transversal forces of rail vehicle interaction with the track, possibility of derailment (safety criterion), contact fatigue, degree of wear, running comfort, movement of a freely selected point, track profile and track unevenness.
2. Various geometric and inertial parameters, suspension spring parameters and friction coefficients of friction elements.
3. Various track and wheel profiles, track stiffness, coefficient of friction of wheel and rail interaction.

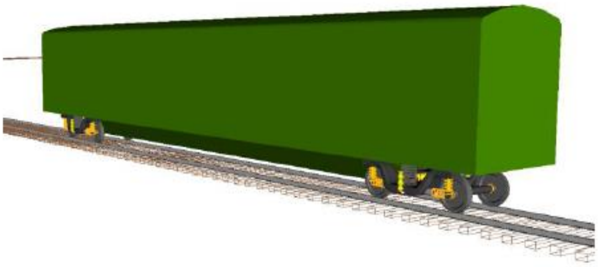

Fig. 2. General view of rail coach computer model

Running stability (derailment conditions) was assessed according to Nadal criterion:

$$K_{Nad} = \frac{F_y}{F_z} = \frac{tg\delta - \mu}{1 + \mu \cdot tg\delta} < 0,85; \quad (1)$$

The meanings of variables of Formula (1) are provided in Fig. 3. According to condition of rail vehicle running stability, Nadal coefficient should not exceed 0.85.

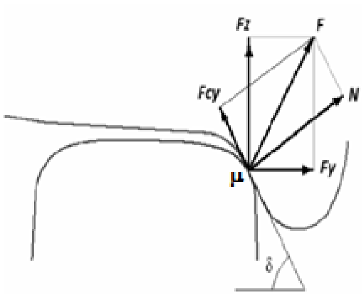

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Fig. 3. Forces acting on rail and wheel contact: N – normal force; F – conatact total force; F_y – transversal force; F_z – vertical force; μ – friction coefficient; δ – angle between rail and wheel flange.

The centrifugal transversal acceleration occurs due to centrifugal force. The Uncompensated transversal acceleration a_{un} arrise because of the difference between centripetal and centrifugal forces. Uncompensated centrifugal force causes discomfort to passengers and reduces train running stability. Uncompensated centrifugal force can cause the rail vehicle to overturn, increase transversal loads and reduce axle loads [3]. In order to ensure the passenger comfort when running on railway track curves, the following normative values of uncompensated transversal acceleration were determined:ne daugiau kaip 0.7 m/s^2, kai traukinių didžiausioas važiavimo greitis v_{max} < 160 km/h;

1) no more than 0.7 m/s2, when the maximum running speed of the train vmax < 160 km/h;
2) no more than 0.6 m/s2, when the maximum running speed of the train 160 < vmax < 200 km/h.

The value of rail superelevation in curve is calculated for 1435 mm gauge by using formula [3]:

$$h_s^{1435} = 11.8 \cdot \frac{v_{aver}^2}{R}; \quad (2)$$

and the following formulae for 1520 mm gauge:

$$h_s^{1520} = 12.5 \cdot \frac{v_{aver}^2}{R}; \quad (3)$$

where: h_s^{1435} – rail superelevation for 1435 mm gauge, mm; h_s^{1520} – rail superelevation for 1520 mm gauge mm; v_{aver} – average speed, km/h; R – curve radius, m.

The maximum speed $v_{\max}$ is verifying considering the superelevation minimum value by using the following formulae [3]:
for 1435 mm gauge:

$$v_{\max}^{1435} = \sqrt{\frac{R \cdot (h_{s\min}^{1435} + 100)}{11.8}}; \quad (4)$$

and for 1520 mm gauge:

$$v_{\max}^{1520} = \sqrt{\frac{R \cdot (h_{s\min}^{1520} + 115)}{12.5}}; \quad (5)$$

where: $h_{s\min}^{1435}$ – calculated rail minimum superelevation for 1435 mm gauge [mm]; $h_{s\min}^{1520}$ – calculated rail minimum superelevation for 1520 mm gauge, mm; $v_{\max}^{1435}, v_{\max}^{1520}$ – passenger train maximum speed on curve, km/h 1435 and 1520 mm track, respectively; 100 and 115 – maximum height decrease value calculated by applying the set acceleration decrease norm (0.7 m/s^2) for 1435 and 1520 mm track, respectively

The train running speed, horizontal curve radius, superelevation of external rail and uncompensated transversal acceleration have a functional dependence v=f(R, h_s, a_n), therefore, these parameters are examined as an integral part of their interconnection.

4. ASSESSMENT OF TRAIN RUNNING ON TRACK CURVES OF DUAL GAUGE

For examination the 10 km 900 m length “Rail Baltica“ track section “Bebruliškės-Vinčiai-Būdviečiai” (Lithuanian Railways) of dual 1435/1520 mm gauge track was selected. Passenger and freight trains run on this section with permited speed 120 km/h and 80 km/h, consequently. According to available actual data, the maximum radius of track curve on track section “Bebruliškės-Vinčiai-Būdviečiai” is 3000 m; the radius of the minimum track curve is 594 m.

The simulated railway section consists of tangent sections, track curves and slopes. The main parameters of track horizontal curve are the radius R and outer rail superelevation h. Horizontal profile parameters of examined rail track section are provided in Table 2 and the vertical profile parameters are presented in Table 3.

Tab. 2

Parameters of horizontal profile of railway line “Bebruliškės–Vinčiai–Būdviečiai”

Track distance *S, m*	Track interval *L*, m	Track curve radiius *R*, m	Superelevation *h*, m
0	100	tangent track	0
100	830	tangent track	0
930	667	3000	0.02
1597	1326	tangent track	0
2923	145	1050	0.045
3068	1382	tangent track	0
4450	113	>1800	0.02

4563	2358	tangent track	0
6921	132	977	0.06
7053	549	tangent track	0
7602	308	tangent track	0,085
7910	329	tangent track	0
8239	313	594	0.14
8552	1149	tangent track	0
9701	204	>806	0,09
9905	156	tangent track	0
10061	649	800	0.09
10710	290	tangent track	0

Tab. 3

Parameters of vertical profile of railway line "Bebruliškės–Vinčiai–Būdviečiai"

Track distance *S, m*	**Track slope (uphill/ downhill)***	
	Track interval length *L*, m	*i*, ‰
0	100	0
100	300	2.4
400	200	4.4
600	400	1.4
1000	350	7.8
1350	350	2.6
1700	400	1.9
2100	370	5.7
2470	680	0
3150	300	-5.1
3450	250	-2.5
3700	300	0.7
4000	200	0
4200	200	-1.5
4400	400	-0.3
4800	800	-0.9
5600	700	0.2
6300	270	-1.2
6570	380	0
6950	350	-1.5
7300	500	-3.5
7800	250	-1.4
8050	500	-3,5
8550	200	1.3
8750	200	0
8950	200	0.8
9150	250	3.8
9400	500	1.9
9900	300	1.1
10200	800	-0.4

* Plus "+" values mean uphills, minus "-" values mean downhills, zero "0" is a horizontal track segment.

Grafically geometrical parameters of longitudinal and transversal profile of examined rail track sector are provided in Fig. 4.

The passengher amximum speed was calculated considering thse parameters: conditions of rail vehicle derailment, uncompensated transversal acceleration and lateral displacements of running gear (suspenssion). The diagram of the distribution of the maximum permitted train speed calculated in track curves of "Rail Baltica " section "Bebruliškės-Vinčiai-Būdviečiai" is provided in Fig. 5.

The maximum permissible speed when running on road curves were calculated by taking into account the geometrical parameters of the track (see Figure 5). The maximum speed at 3000 m radius curve of 1435 mm gauge is 160 km/h; maximum speed in 1520 mm gauge is 166.6 km/h. The speed in curve of minimum radius – 594 m of 1435 mm gauge is 71.2 km/h; the speed in 1520 mm gauge is 74.2 km/h. Total average speed of the section of 1435 mm gauge is 85,6 km/h; the average speed of 1520 mm gauge section is 89.2 km/h. Maximum permissible train speed when running on curves of wider 1520 mm gauge is approximately 4 % larger.

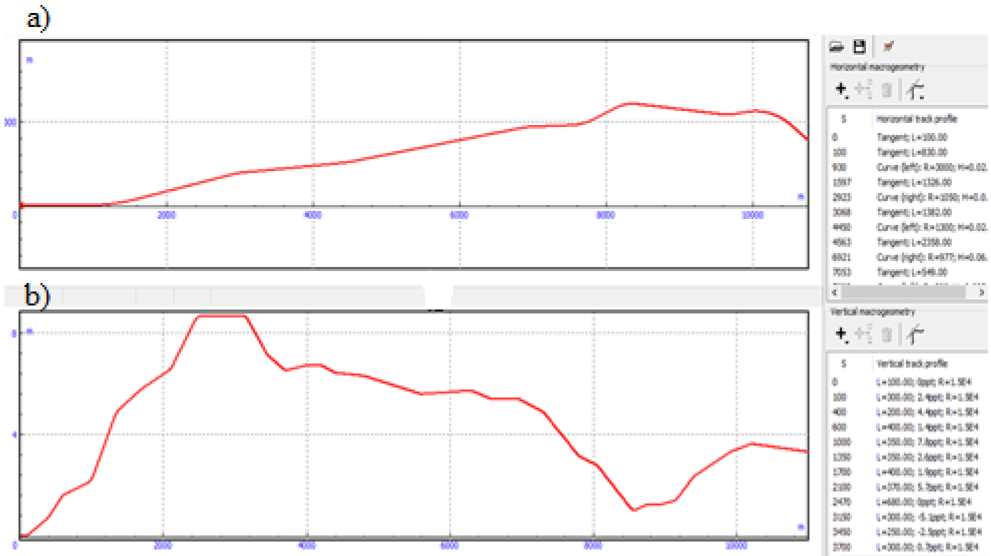

Fig. 4. Macro-geometric track profile diagram (UM view): a — track horizontal profile; b — track vertical profil

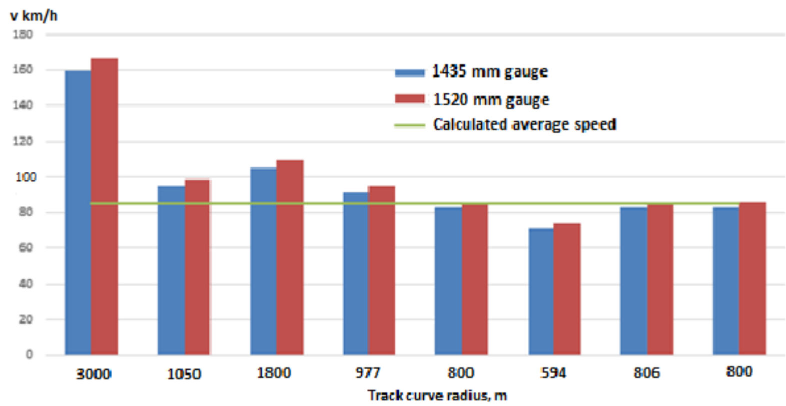

Fig. 5. Maximum train speed on track curves of "Rail Baltica" dual 1435/1520 mm gauge track sector "Bebruliškės–Vinčiai–Būdviečiai" considering the uncompensated transversal acceleration

During simulation and calculation of passenger coach running in curves, it was found that the permissible limit 0.7 m/s2 of the transversal accelerations of the coach body is usually exceeded. The values of the transversal accelerations of the coach body are considered as the main indicator determining the smoothness of the movement of coaches on the track curves.

The maximum permissible speed of passenger coach running on track curves of "Rail Baltica" sector "Bebruliškės–Vinčiai–Būdviečiai" according to analytically calculated comparison of values and results obtained by UM software established by researcher Černiauskaitė [2] is provided in Fig. 6. The results were determined by estimating the permissible limit of the transversal accelerations of the coach body – 0.7 m/s^2.

The results provided in Fig. 6 show that the results of permissible speed established analytically and obtained by UM numerical simulation coincide essentially after assessing Nadal derailment coefficient. However, a rather large difference can be seen compared to the results obtained by the researcher [2] with significantly higher values. It shall be noted that researcher Černiauskaitė [2] examined rail track sections with a different structure, i. e. differently arranged curves and their superelevations.

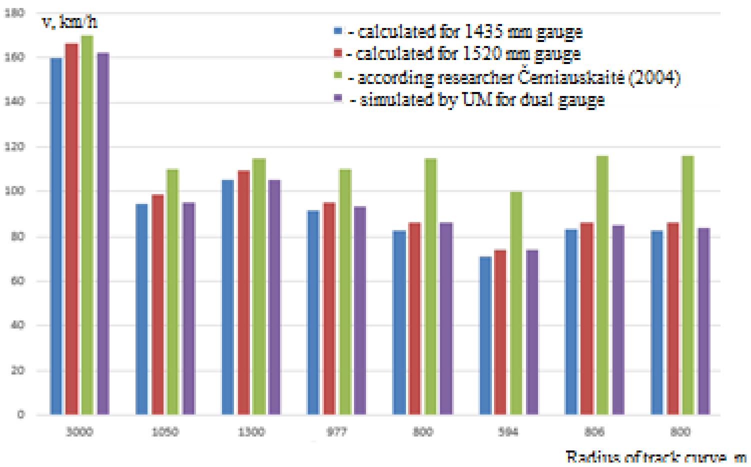

Fig. 6. Comparison of the research results and the calculated maximum speed on „Rail Baltica“ track curves

5. CONCLUSIONS

1. It was established that the value of uncompensated transversal acceleration is the main criterion for determining the smoothness of rail vehicle running on curves. The maximum permissible train speed is 4 % higher when running on curves of 1520 mm gauge track compared to 1435 mm gauge track.
2. In order to ensure the safe and smooth running of passenger trains at 160 km/h speed in “Rail Baltica” line from Polish border to Kaunas, railway track curves must be at least 2300 m radius with 30 mm rail superelevation or at least 1300 m with 130 mm rail superelevation.
3. In order to ensure the safe and smooth running of passenger trains at 200 km/h speed in “Rail Baltica” line from Polish border to Kaunas, railway track curves must be at least 3000 m radius with 70 mm rail superelevation or at least 2000 m radius with 150 mm rail superelevation.

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