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INFLUENCE OF GAUGE WIDTH ON RAIL SIDE WEAR ON TRACK CURVES

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Abstract. The main property of the railway system is infrastructure objects and rolling-stock. Holding any kind of a property requires huge expenses and renovation investments. Intensive wearing of the rails on the track curves is observed. This problem is always topical in railways. In this article a possibility to decrease wear of rails on curves is analysed. The purpose of the authors' research was to estimate the influence of rail wearing on the track widening and permissible deviations on curves when radius is less than 650 m. Also, to estimate the possibility to reduce railroad maintenance expenses associated with the change of the worn rails, when gauge on curves with radius less than 650 m is widened. For this reason in this article a mathematical model is presented. This model evaluates the influence of the gauge width on rail wearing on curves. An experiment was carried out on Lithuanian railway line curves. Results and analysis of the experimental research are presented in the article.

Keywords: railway, rail, rail wear, gauge width, curve, rail wearing intensity, wheel flange.

1. Introduction

Rail is the main bearing element of the upper track construction. Loads, caused by the rolling-stock wheels, act on the element. Therefore, rails have to withstand large dynamic loads in vertical, longitudinal and lateral directions. In order to ensure safe railroad traffic, rails must be strong enough and wearproof. Rail head vertical wearing intensity is greater in the straight sections and on the curves of a larger radius. On the curves with radius less than 650 m change of rails is generally caused by exceeded permissible rail head side wear.

Intensive rail side wear on curves is one of the most important problems for the companies maintaining the railway infrastructure. Not only economical aspect conditions the relevance of the problem; very important factor is road safety as well. Side wear of rails depends on many factors, such as road plain and longitudinal profile, rolling-stock and road technical conditions, steel quality of rails and wheels, maintenance quality of rails and wheels, freight haulage intensity and axial loads. It is very difficult to find an integrated solution for decrement of rail side wear. Ways and methods for solving the problem differ in various countries. In America the scientists join forces to improve steel quality, create new types of fastenings etc [1]. In Western Europe and Australia it is aimed to change the construction of wagon wheel pairs (trying to implement wagons with wheel pairs turning in line with track curve radius [2, 3]). In the developing countries rail wear is decreased looking for better ways of road maintenance, implementing more progressive means for lubrication of wheels and rails etc, some countries (for example, Russia, USA, Germany, Poland, Czech Republic and France) have railway testing centres where experimental researches are carried out and the most complicated natural maintenance conditions of railway lines are simulated. At present Lithuania does not have proper economical possibilities to carry out large and qualitative experimental research, whereas the USA and Russia develop special experimental programs for solving a particular problem (in the USA) or implement complex research programs ordered by Ministry of Transport (in Russia) [4–7].

According to the maintenance rules of Lithuanian railways [8], the width of the gauge between rail head internal edges in the straight sections and in the curves with radius ≥ 350 m, must be 1520 mm. In the curves with smaller radius, the gauge width must be as follows: if radius is from 349 m till 300 m – 1530 mm; if radius is ≤ 299 m – 1535 mm. The gauge width in straight sections and curves must not broaden by more than 6 mm and narrow down by more than 4 mm. In the sections with the speed limitation of 50 km/h and higher, deviations must not exceed 10 mm and 4 mm respectively. These norms are the same as in Russia and they do not change since 1970. Till 1970 the gauge width in straight sections and in curves with radius ≥ 350 m was 1524 mm. The width of the gauge in the curves with smaller radius was as follows: radius from 349 m to 300 m – 1530 mm; radius ≤ 299 m – 1540 mm. The gauge width in the curves and in straight sections should not increase by 6 mm and decrease by 2 mm. In 1970 deviation of 4 mm decrement of the gauge width was accepted. As can be seen, norms accepted in 1970 have decreased the gauge width and increased permissible deviations of decrement. As far as it is known, influence of these changes on interaction of trains and rails was not investigated [9].

The larger part of railways maintained in Lithuania has a gauge of 1520 mm (98,7 %), while railways of 1435 mm in gauge make merely 1,3 % of Lithuania's overall railway length. The distribution of curves in Lithuanian railway lines by curve radius R is portrayed in Fig 1. During 2003, 21,09 km of railways were replaced with new rails and 30,72 km were replaced with used rails in Lithuania. This cost 1,793 million Litas (including the purchase and the laying price). Rails replaced due to the exceeded head side wear tolerance for 30–40 % of all replaced rails, ie about 0,717 million Litas.

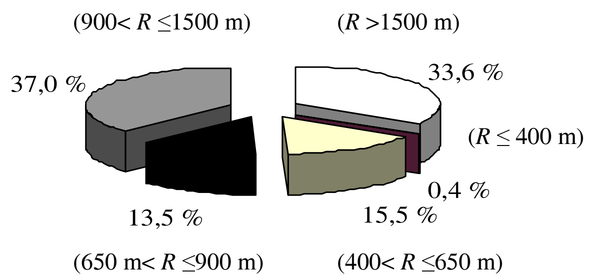

Fig 1. Distribution of curves according to radius R in Lithuanian railways

The purpose of this article is to examine the influence of gauge width on rail head side wear intensity on track curves and to carry out experimental research on rail head side wear intensity on curves in Lithuanian railway lines and to estimate the influence of gauge width on it.

2. Mathematical model of wear formation

Interaction of two surfaces (having in mind that one of the surfaces is moving in respect of another one) causes formation of wear. In the upper layers of a material, mechanical and molecular interaction begins and thus surface micro bindings are broken. Wear of two surfaces is related to a multifold fracture of frictional bindings [10]. There are two types of frictional side wear of rails and wheel flanges: a wear caused by slippage when adjoining surfaces decompose and a wear when abrasive parts act on metal. Two main factors influence frictional side wear. They are: 1) wheel flange slippage on rail head side plain; 2) wheel flange pressure on rail head side plain [11]. Additional factors are: steel quality of rails, its chemical composition and microstructure; toughness and roughness of the upper layers of adjoining surfaces; wheel flange tilt angle in respect to rail head; rolling-stock trolley position on the track, defined as wheel flange rolling angle on rail head; radius of the road curve; friction coefficient; lubrication of rails and wheel flanges; ambient temperature and humidity [12, 13]. As wear does not originate without slippage, the main factor determining the rail and wheel wear is the length of slippage distance of the rail flange on the side plain of the rail head.

In Fig 2 mechanical scheme of wear formation, when one part is slipping on top of another one is presented. Having the same conditions, the longer the slippage distance l, the greater the wear Δh of part 1.

In experimental and theoretical investigations the wear formation of rails and wheels is analysed as the interaction of two steel bodies, taking into consideration mechanical properties of steel. However, the disadvantage of such research is unnatural conditions, ie laboratory conditions are rather different from those of natural ones. Therefore material mass wear volume concept V_N, m^3 is used. It is directly proportional to the slippage distance l and normal load N and inversely proportional to the metal wear resistance H [7, 14, 15]:

$$V_N = \frac{N \cdot f \cdot l}{H}. \tag{1}$$

In order to evaluate the influence of gauge width on intensity of rail head side wear, empirical dimensionless parameter - wearing index, is used. It is convenient to have such an empirical index when mathematical model is used to describe the influence of gauge geometrical parameters on rail head side wear. The wearing index evaluates factors causing wear formation. It is directly proportional to the force N acting on rail by wheel, friction coefficient f and distance of wheel slippage on rails l_s and inversely proportional to the area A of rail contact with wheel. The wearing index R_{N1} may be determined by formula [16, 17]:

$$R_{N1} = \frac{N \cdot f \cdot l_s}{A}. \tag{2}$$

From Eq (2) it follows that in order to reduce the wearing index R_{N1} (and the intensity of rail head side wearing on curves), it is necessary to diminish the wheel load on the rail and the wheel flange slippage distance on side plain of the rail head.

The slippage distance $l_{s.}$ consists of orbicular l_a and longitudinal l_i slippage distances. The orbicular slippage distance on rails is not related to geometrical parameters of tracks but only to wheel parameters.

The gauge width impact on rail wearing is expressed through longitudinal slippage distance l_i on rails. Reduction of longitudinal wheel slippage distance on rails would diminish the wearing index R_{N1}. Longitudinal wheel slippage occurs due to the fact that the outer stretch of rail on the curve is longer than the inner one. It is practically impossible to avoid wheel slippage on rails ($l_i = 0$), but there is a theoretical possibility to calculate gauge S, under which there would be no longitudinal train wheel slippage on rails [12]:

$$S = \frac{2 \cdot p \cdot \rho \cdot c + R \cdot (a + 2b)}{R - p\rho}, \tag{3}$$

where p is the flange tilt angle in respect to horizontal, expressed as 1:p. 1:p of new wheels equals to 1:20, and 1:p reaches 1:100, 1:200 and even more as wheels wear; ρ is the radius of the wheel rolling circle, R – the curve radius, c – distance between side edge of rail head to axis, a – the distance between internal wheel pair flanges at altitude of where gauge width is measured and b – the flange thickness at altitude in the place where gauge width is measured.

The expression (3) allows calculating S needed to equal the longitudinal slippage distance on curve to 0. Calculations are carried out for the train car's wheel pair ($\rho = 475$ mm, $a = 1440$ mm and $b = 25$ mm) and UIC60-class rails ($c = 36$ mm). The results analysis is presented in Fig 3. Widening of rail gauge on curves would diminish the longitudinal wheel slippage on rails.

3. Experimental research of gauge influence on rail head side wear intensity

The aim of the experimental research was to identify the influence of gauge width on external rail head side wearing intensity.

The research was carried out in June 2001 – Sept 2002 on 19 curves of Lithuanian railway lines. The upper structure of the railway on curves was as follows: rails UIC60 and R65, reinforced concrete sleepers, and crushed stone ballast. The measurements were made in the length of the orbicular curve near every tenth rail axis.

Every curve contained from 25 to 35 measurement points (taking into account curve radius) [18]. In every fixed curve point, cant, gauge and external rail head side wear were measured and rail head side wear intensity $w_s^{'}$ was calculated according to the formula:

$$w_s^{'} = \frac{\Delta w}{I} \cdot 10, \quad \text{mm/10 mln t}, \qquad (4)$$

where Δw – change of rail head side wear during the research period (mm); I – amount of the carried loads during the research period, mln t.

Regression analysis of the relationship between external rail side wearing intensity and value of gauge (confidence level – 95 %) was carried out.

The curves used to examine the impact of gauge width upon rail head side wearing were divided into five groups according to the curve radius R:

1. $R \leq 350$ m;
2. $350 \text{ m} < R \leq 400$ m;
3. $400 \text{ m} < R \leq 650$ m;
4. $650 \text{ m} < R \leq 900$ m;
5. $R > 1500$ m.

On the curves with radius under 350 m, the lowest intensity of rail head side wearing was found at a gauge of 1535–1540 mm (according to the effective standards, when R<300 m, S=1535 mm, when the radius R is between 300 and 350 m, the rail head side wearing S is 1530 mm) (Fig 4). When the gauge is widened up to 1535 mm, the rail head side wearing on the curve of such radius reaches an average of 2,1 mm when 10 mln tons of gross weight loads pass. If the gauge width is equal to 1530 mm, the outer rail head side wear reaches 2,9 mm after handling the same amount of loads, which is 1,4 times higher.

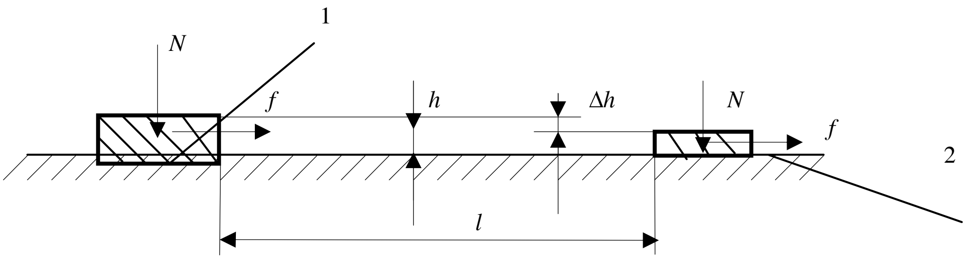

Fig 2. Mechanical scheme of wear (Δh) formation, when one part is slipping on the base: 1 – slipping part; 2 – base on which the part 1 is slipping; N – normal force; f – friction force; l – slippage distance; h – initial height of part 1; Δh – thickness of wear

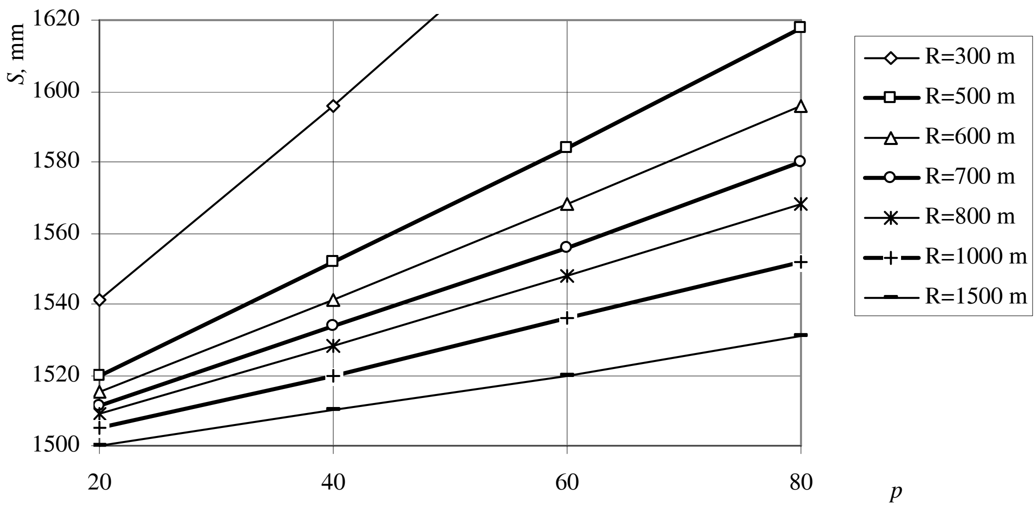

Fig 3. Effect of wheel tilt angle in respect to horizontal, 1:p on gauge width, S, when the longitudinal slippage on rails equals 0 ($l_i = 0$)

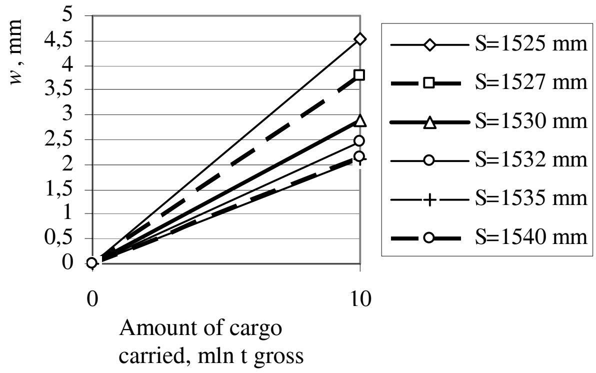

Fig 4. Influence of the amount of loads passed on truck curves with R ≤ 350 m on the rail head side wearing for different gauge widths (R65 class rail)

After widening the gauge from 1520 mm (effective standard) up to 1530 mm on curves of radius from 350 m to 400 m and letting 10 mln tons of gross cargos pass the railway section, the rail head side wearing would be 1,5 mm. Meanwhile, the side wearing would be 2,5 mm if the gauge was left unchanged 1520 mm (Fig 5).

The majority of the curves analysed had a radius from 400 to 650 m. The results of data analysis on these curves corroborated the presumption that widening of the gauge from 1520 to 1524 mm would decrease the intensity of the rail head side wearing by 8–9 % (Fig 6).

On the curves with radius of over 650 m, rails need to be replaced not because of exceeding the rail head side wear tolerance. Experimental research shows that the intensity of rail head side wearing is not high on such curves.

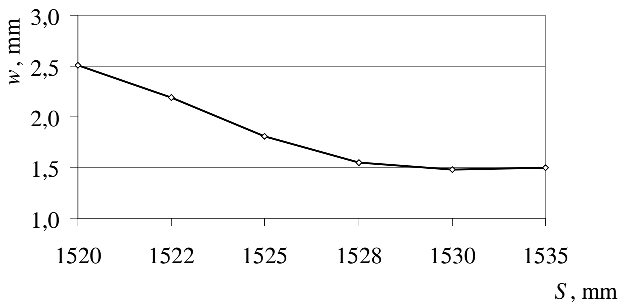

Fig 5. Influence of the amount of loads passed on truck curves with 350 < R ≤ 400 m on the rail head side wearing for different gauge widths (R65 class rail)

Comparison of experimental results with the results obtained by other authors has shown that, on curves with radius from 400 to 650 m, the increase of gauge width from 1520 to 1530 mm would lead to decrease in rail head side wearing intensity: 1,72 times, according to the authors' research, and 1,1–2,5 times, according to researches conducted by the other authors (Fig 7) [19–21].The results of the research conducted by the authors might differ from those of other authors due to the different conditions of experiments (different upper construction of the rails, technical condition of the rolling-stock, train traffic speed etc).

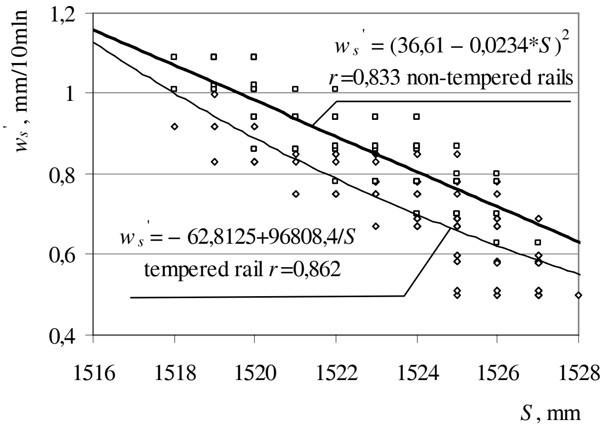

Fig 6. Influence of rail head side wearing intensity on gauge width on curves where radius 400 < R ≤ 650 m (UIC 60 class rail, r – correlation coefficient)

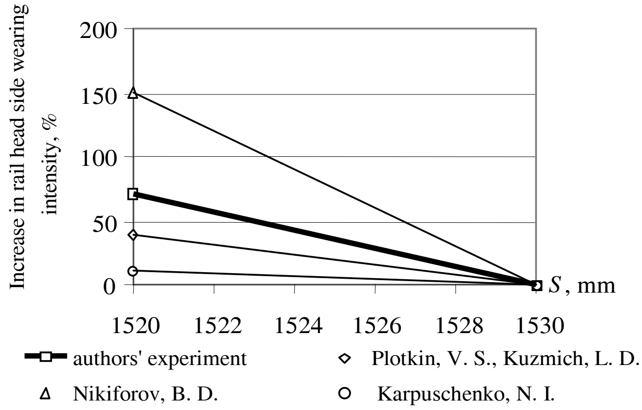

Fig 7. Comparison of relative rail head side wearing versus gauge width from the results of several investigators

4. Possibilities to increase the durability of rails due to the gauge widening

Results of theoretical and experimental research showed that the effective standards that regulate the gauge width increase on curves and tolerances do not assure the lowest wearing intensity of the rail head on curves. Therefore, it was concluded that the standards should be specified to reduce the intensity of the rail head side wearing. The following improvements were suggested:

1. On curves with a radius of over 650 m, the rail wearing intensity is not high, thus there is no need to widen the rail gauge (gauge of 1520 mm should be installed).

2. The gauge should be widened when the curve radius is less than 650 m. On curves with such a radius, rails need to be replaced more often due to the exceeding the permissible side wearing rather than other defects. On the curves with radius from 400 to 650 m, the gauge width should be 1524 mm instead of 1520 mm. Such widening would decrease the rail head side wearing intensity from 28 to 40 % (Fig 8).

3. On the curves with radius from 350 to 400 m, the gauge should be widened from the current 1520 to

1530 mm because the gauge width of 1520 mm would lead to an increase in the rail side wearing intensity by a factor of 2 (Fig 9).

4. On the curves with the radius of less than 350 m, widening the gauge up to 1535 mm ensures the lowest intensity of the rail head side wearing.

The decrement of rails maintenance expenses was calculated. It is related to the purchase and instalment of new rails after implementing the suggested changes. The calculations were done for the entire Lithuanian railway network and have shown that the number of rails that would normally need to be replaced due to the outer rail head side wearing would be reduced by 1,178 km annually, which is estimated at 30,000 EURO. The amount of money could go up in the wake of the modernisation of the Lithuanian railway infrastructure, increase in the axial load of the railways, formation of heavyweight trains and increase in the cargo flows.

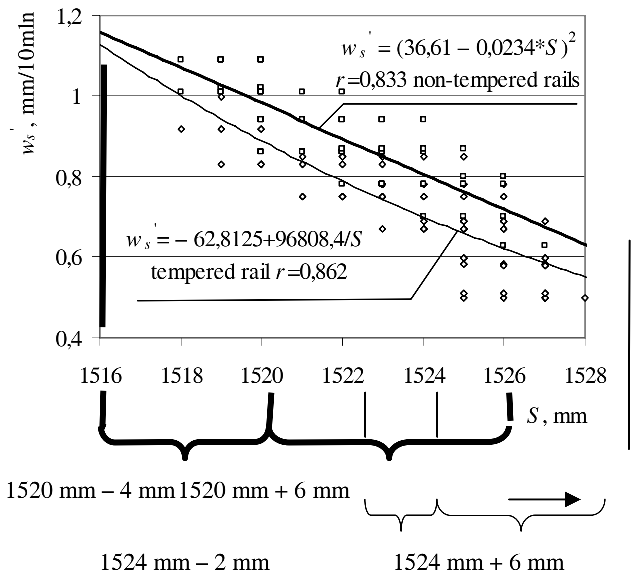

Fig 8. Proposed changes of the gauge widening on curves from 400 to 650 m

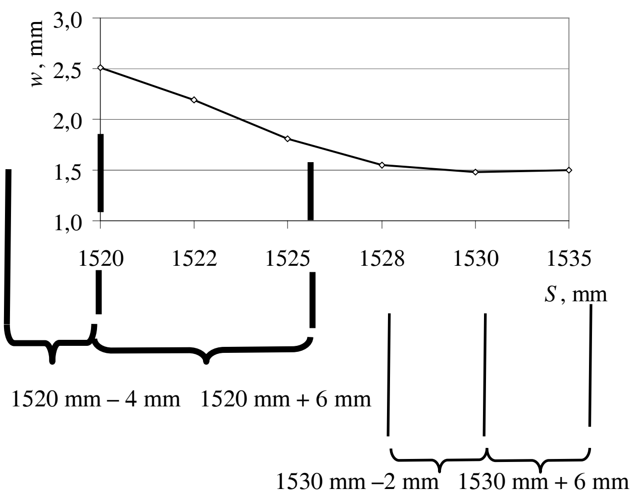

Fig 9. Proposed changes of the gauge widening on curves from 350 to 400 m

5. Conclusions

1. Frequent replacement of defective rails due to excessive rail head wearing on track curves increases railway maintenance expenses. The main factor affecting the rail wearing on curves is gauge width. The investigation of influence of gauge width on the rail wearing intensity and the possibilities of track widening to decrease the wearing is of vital importance.

2. Mathematical modelling of wear formation was done using wearing index R_{N1}. Analysis of the mathematical model shows that widening the gauge on curves leads to a decreased longitudinal wheel slippage path on rails and the rail head side wearing intensity.

3. The results of the experimental research carried out on 19 Lithuanian railway lines have shown that widening the gauge on the curves with radius less than 650 m, decreases rail head side wearing intensity up to 1,72 times.

4. Based on theoretical and experimental research, suggestions are presented to revise the effective standards for installing and maintaining the rail track. After implementation of these changes, rail gauge width should be as follows: 1520 mm in the straight lines and curves with radius of more than 650 m, 1524 mm on the curves with radius of 400 – 600 m, 1530 mm on the curves with radius of 350 – 400 m and 1535 mm on the curves with radius of less than 350 m. The tolerances of the gauge widening are +6 mm to the upper side and –2 mm to the lower side. In the lines with train speed limits of under 50 km/h, the respective deviations are +10 mm and –2 mm.

5. Implementation of proposed gauge widening standards should be gradual through overhaul repairs of the upper track structure repairs, saving up to 30,000 EURO in all Lithuanian railway lines annually. The money could be successfully used for the general repairs of the railroad lines.

References

1. Clayton, P. Predicting the wear of rails on curves from laboratory data. *Wear*, No 181–183. Paris: Elsevier, 1995, p.11–19.
2. Zakharov, S. and Zharov, I. Simulation of mutual wheel/rail wear. *Wear*, 253(1–2). Paris: Elsevier, 2002, p. 100–106.
3. Updhay, R. Decrease of wheel and rail wear. *International Railway Journal*, 7. London: Europa House, 2000, p. 33–34.
4. Bogdanov, V. M.; Zacharov, S. M. Contemporary problems of the system rail-wheel. *International Railways* (Железные дороги мира), 1. Moscow, 2001. 8 p. (in Russian).
5. Lementjev, L. P. Wheels and rails interface and their wearing. *Railway and Railway Economy* (Путь и путевое хозяйство), 11. Moscow: MK-Poligraf, 1999, p. 6–15 (in Russian).
6. Podagelis I. Factors acting on points and inner edges of rails wear. In: Proceedings of Civil Engineering and Environment, Vol 387. Vilnius: Technika, 1998, p. 91–94 (in Russian).

7. Jendel, T. Prediction of wheel profile wear comparison with field measurements. *Wear*, 253. Paris: Elsevier, 2002, p. 89–99.
8. The rules of railway service (Geležinkelio kelio priežiūros taisyklės). Vilnius: SPAB „Lietuvos geležinkeliai", 2000. 213 p. (in Lithuanian).
9. Povilaitienė, I. and Podagelis, I. Research into rail side wearing on curves. *Transport*, 18(3), 2003, p. 124–129.
10. Andreev, A. I.; Komarov, K. L.; Karpuschenko, N. I. Wearing of rail and wheels. *Railway Transport* (Железнодорожный транспорт), 7. Moscow: Zeleznodoroznoje delo, 1997, p. 31–36 (in Russian).
11. Clayton, P. Tribological aspects of wheel-rail contact: a review of recent experimental research. *Wear*, 191. Paris: Elsevier, 1996, p. 170–183.
12. Ilsiuk, V. S. The reasons and mechanics of rail side wearing of rail and wheels. *Railway and Railway Economy* (Путь и путевое хозяйство), No 5. Moscow: MK-Poligraf, 1996, p. 15–20 (in Russian).
13. Markov, D. Laboratory tests for wear of rail and wheel steels. *Wear*, No 181–183. Paris: Elsevier, 1995, p. 678–686.
14. Olofssom, U. and Telliskivi, T. Wear, plastic deformation and friction of two rail steels – a full-scale test and a laboratory study. *Wear*, 254. Paris: Elsevier, 2003, p. 80–93.
15. Meng, H. C. and Ludema, K. C. Wear models and predictive equations: their form and content. *Wear*, No 181–183. Paris: Elsevier, 1995, p. 443–457.
16. Karpuschenko, R. I. Lubrication – the only way to reduce the wear. *Railway and Railway Economy* (Путь и путевое хозяйство), No 5. Moscow: MK-Poligraf, 2000, p. 15–18 (in Russian).
17. Andreev, A. I.; Komarov, K. L.; Karpuschenko, R. I. Wear of rails and wheels. *Raiway Transport* (Железнодорожный транспорт), 7. Moscow, 1997, p. 31–36 (in Russian).
18. Povilaitiene I. and Laurinavičius A. Reduction of external rail wearing on road curves. *Journal of Civil Engineering and Management*, Vol X, No 2, 2004, p. 123–130.
19. Plotkin V. S. and Kuzmich L. D. About the increased wearing of wheels and rails. *Railway Transport* (Железнодорожный транспорт), No 8, 1997, p. 51–54 (in Russian).
20. Nikiforov B. D. Reasons for rail and wheel wear and ways to decrease it. *Railway Transport* (Железнодорожный транспорт), No 10, 1995, p. 36–40 (in Russian).
21. Karpuschenko N. I.Track parameters and rail wear. *Railway and Railway Economy* (Путь и путевое хозяйство), No 8. Moscow: MK-Poligraf, 1996, p. 6–7 (in Russian).

GELEŽINKELIO VĖŽĖS PLOČIO ĮTAKA BĖGIŲ ŠONINIAM DILIMUI KREIVĖSE

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Santrauka

Pagrindinis geležinkelio sistemos turtas yra infrastruktūros objektai ir riedmenys. Jiems išlaikyti reikia didelių išlaidų, o renovacijai – investicijų. Straipsnyje nagrinėjama nuolat aktuali geležinkelio problema – tai bėgių dilimo mažinimo galimybė kreivėse. Autorių tyrimo tikslas yra nustatyti, kaip vėžės platinimas ir leistinieji nuokrypiai daro įtaką bėgių dilimui kreivėse, kurių spindulys mažesnis nei 650 m. Apskaičiuota, kiek sumažėtų geležinkelio priežiūros išlaidos, susijusios su nudilusių bėgių keitimu kreivėse, kai kelio vėžė kreivėse, kurių spindulys mažesnis nei 650 m, platinama pagal pateiktus siūlymus. Tam tikslui straipsnyje pateikiamas matematinis modelis. Šiuo modeliu įvertinama vėžės pločio įtaka bėgių dilimui kreivėse. Eksperimentiniai tyrimai buvo atlikti Lietuvos geležinkelio linijų kreivėse. Pateikiama eksperimentinių tyrimų rezultatų analizė.

Reikšminiai žodžiai: geležinkelis, bėgis, bėgio nuodyla, vėžės plotis, kreivė, bėgio dilimo intensyvumas, ratų antbriaunis.

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