Reducing Tram Car's Curve-Pasing Resistance by Double Treaded Wheel Profile

Olena Nozhenko, Vladimír Hauser, Kateryna Kravchenko, Mária Loulová
Faculty of Mechanical Engineering, University of Zilina, Univerzitná 8215/1, 010 26 Žilina. Slovak Republic. E-mail: olena.nozhenko@fstroj.uniza.sk, vladimir.hauser@fstroj.uniza.sk, kateryna.kravchenko@fstroj.uniza.sk, maria.loulova@fstroj.uniza.sk

Special attention is taking place in the environment of public transport, for which higher amount of small radius curves being applied is specific. The outcome of such operation of vehicles is an increase in vehicle's effects on the track in the rail-wheel contact resulting in increased ride resistance, creep in the rail-wheel contact patch, speeding up the process of wear in the contact pair as well as noise generation. At present, a variety of technical solutions for the vehicle bogie design as well as track designs focused on decreasing of these negative effects exists. Their use in smaller radius curves however, cannot give acceptable results and often causes complications in bogie design. The authors give a concept of creep reduction in rail-wheel contact by using double wheel tread, which doesn't require complicated bogie design. The proposed solution is supported by dynamical simulation of the tram car vehicle ride with considering of active wheel tread changes, and is also registered under Patent Application Nr. a201701589.

Keywords: wheel with double tread, vehicle curve-pasing resistance reduction, track section of small radius, creep velocitiy in wheel - rail contact.

1 Introduction

The process of vehicle ride in curved track sections is a serious problem of rail transport requiring attention. Particular attention has to be paid in the public transport environment, which features increased number of small radius arches. The effect of operation under such conditions is the increased impact of the vehicle on the track by means of a wheel-rail contact, increasing the vehicle's curve-pasing resistance, the creep velocities in wheel-rail contact, accelerating the wear of the contact pair as well as generating noise [8, 9, 20, 21].

At present, there are a number of technical solutions in the construction of vehicle bogies and tracks designed to suppress these negative phenomena. These include, for example, lubricating devices installed in the track or in a vehicle, expanding the track free channel, adjusting systems for bogie wheelsets to a radial position, independent mount of the wheels in one wheelset, optimizing the wheel profile tread, adding mechatronic components into bogies, placing rubber, noise absorbing components in the bogie and in the track [7, 10, 23, 24]. However, their use in smaller radius arches can not provide acceptable results, and in many cases it complicates the bogie design considerably [5, 16, 17].

In this article, the authors propose a method of eliminating creep in wheel-rail contact in a way that does not require complicating the bogie design [15]. The proposed method is complemented by a simulation analysis of vehicle ride dynamics. Creep in the contact takes place both in the lateral and longitudinal direction. Creep in the lateral direction in the arcs of small radii reaches higher values. However, it can be effectively eliminated by using a bogie design that adjusts the wheelsets to radial position [14]. The goal of the author's work is to propose a solution that would eliminate the cause of the longitudinal creep in the wheel-rail contact and would not further complicate the vehicle design. The proposed solution is complemented by a simulation analysis of vehicle ride dynamics.

2 Analysis of the wheelset ability to pass through an arc of a track

The arc radius *R* [mm], which can be passed without creep, can be determined by the relation (1) [11]:

$$R \geq \frac{2Sr}{\Delta r}\left[mm\right], \quad (1)$$

where:
2S... distance of the contact circles [mm],
r... wheel radius [mm],
Δr... delta r function value at the moment, when the lateral displacement of the wheelset from the track axis is maximal (track free chanel clearance is by the wheelset fully exhausted) [mm].

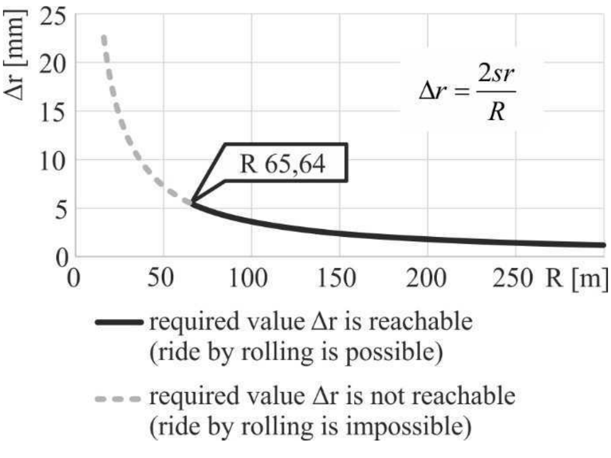

***Fig. 1** Δr value required for ride in curve without creep*

For tram wheelsets designated for a track gauge of 1000 mm, a radius of 340 mm, a KP-1 profile, a contact circles distance of *2S* = 1061.9 mm and a *Δr* value of 5.5 mm, the minimum radius of the arc, which theoretically can be passed without creep is 65.64 m. However, for example, in the area of Bratislava, urban rail vehicles are normally operated on lines with arc radii up to 17 m. It is therefore necessary to evaluate the possibilities of increasing the value of Δr in relation (1). The dependence of the desired Δr value on the radius of the track can be expressed on the basis of the relationship (1) as shown in Fig. 1.

However, increasing the Δr value by increasing the conicity of the tread can not be considered a suitable solution. Such a significant impact on the geometry of the wheel profiles would lead to a more significant undulatory movement of the wheelset and thus to a deterioration of the vehicle's stability during ride at higher speeds. This creates an inconsistent requirement to increase the Δr value without affecting the geometry of the existing wheel profile tread.

3 Principal design of the solution for a wheelset ride through a small radius track curve

However, the requirement to increase the Δr value without affecting the geometry of the existing wheel tread can be fulfilled by creating a new wheel-rail contact area as stated in the patent application [15]. We propose to solve this situation by using a wheel profile with an additional tread designed especially for a ride of a wheelset in a small radius arc, located on the outside of the wheel profile. A schematic representation of the wheelset with a modified profile and the principle of its ride through an arc of the track is shown in Fig. 2.

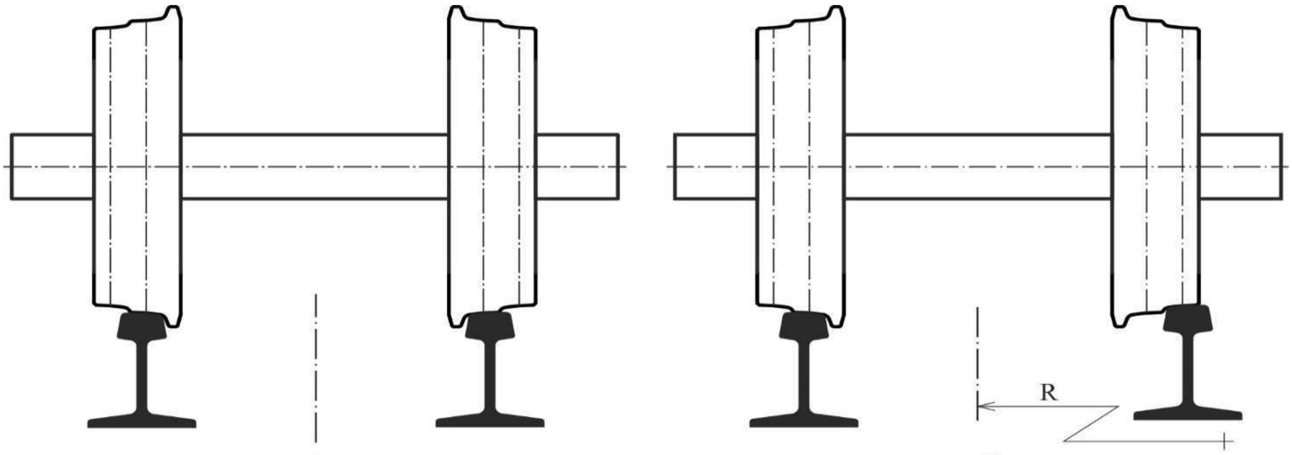

***Fig. 2** Wheelset equipped with additional tread a) when ride on track according formula (1), b) when ride in curve, in which common wheelset can no more ensure passing by „pure“ rolling*

The inner part of the wheel profile is identical to the original profile. Ride characteristics of the vehicle during ride in a straight track or curves according formula (1) will therefore remain unchanged. On the outside of the profile there is an additional tread designed for ride of the wheelset in small radius arches. In the arc, therefore, the outer wheel is rolled over the original tread whereas the inner wheel is rolled over the additional tread with a smaller radius, thereby achieving the necessary displacement in the delta r function course.

4 Position of the additional tread on the wheel profile

For efficient use of the additional tread, it is necessary to determine its displacement to the original profile in the lateral and vertical direction, defined in Fig. 3 using dimensions y and z. To create the second tread geometry, it is possible to use a segment of the original wheel tread.

The displacement in the lateral direction should theoretically be as small as possible to avoid a substantial increase in the volume of the material and hence the weight of the wheel rim. However, its minimum value is limited by the distribution of the contact points of the given wheel-rail pair. We suggest using the outside of the original wheel profile for placing the additional tread, where the wheel profile has no contact points with rail anymore. However, a certain extension of the wheel profile is necessary. In the case of the KP-1 profile being used, the value of the lateral displacement of the additional wheel tread to the original profile y = 50 mm was chosen.

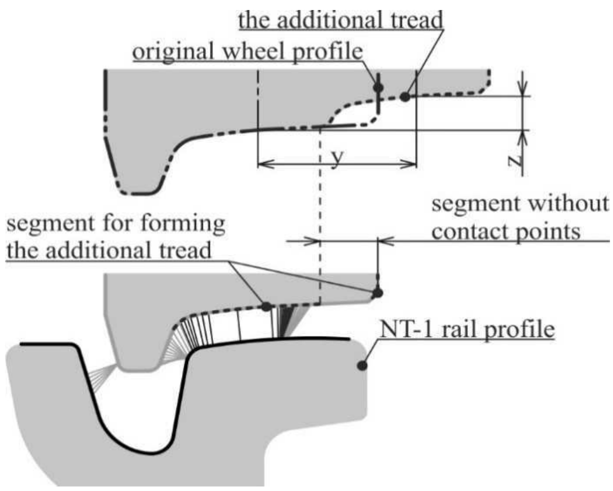

***Fig. 3** Position of the additnal tread on the wheel profile*

The displacement in the vertical direction is dependent on the delta r value of the wheel profile when the clearance provided by the track channel is exhausted. In order to ensure efficient use of the additional tread, the relationship for dimension z [mm] is as follows:

$$z = 2\Delta r + \frac{y \cdot \Delta r}{2S} \left[mm \right]. \quad (2)$$

In case of the original KP-1 profile being considered, the vertical displacement value of the additional wheel tread is z = 11.5 mm. Thus, the course of the desired and achievable Δr value (as shown in Fig. 1) is changed as shown in Fig. 4.

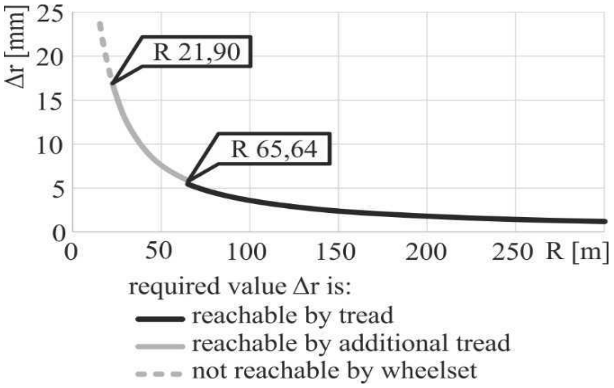

Fig. 4 *Required and achievable Δr value for ride of the wheelset in an arc without creep*

On the basis of theoretical considerations, it is possible to expect a more favorable ride through an arc with a radius of less than 65.64 m thanks to the use of the additional tread. The theoretical prerequisite for ride of the wheelset without creep is created up to the radius of 21.9 m.

5 Simulation analysis of a vehicle ride

In order to verify the vehicle's characteristics, a series of simulation analysis of vehicle ride dynamics were performed in the Simpack calculation program [2, 3, 12, 13, 18]. The aim was to find out the courses of the monitored quantities [1, 4, 6, 17] depending on the radius of the track. From among the measured quantities, the efficiency of the vehicle passing through the track arc is best represented by the power loss, by which the vehicle covers the resistance from the ride through track arc. This article compares its course in three situations. In first case, a vehicle is considered that does not have the possibility of steering wheelsets nor the proposed profile with the additional tread. In the second case, the vehicle being considered is equipped with wheelset steering [14], but without the proposed wheel profile. The third option considers a vehicle with the wheelset steering possibility [14] and equipped with the above-described double wheel tread profile [15]. With its parameters, the vehicle basically resembles a T3 tram.

To obtain an overall overview of the behavior of the vehicle, it is necessary to evaluate the measured quantities, depending on the radius of the track. One way to obtain this dependence is to simulate the vehicle's ride through a theoretical track in shape of transition curve with sufficient length. A transition curve is a part of the track with a smooth change of the radius of the track between straight track and an arc. It may have different shapes. According to the standard [22], a clothoid-shaped transition curve can be used on the track. In case of a clothoid linking a straight track section with a circular arc section, it is possible to use the following relationship for the instant radius R [m] of the clothoid at the considered point:

$$R = \frac{R_2 l}{S} \left[m\right], \tag{3}$$

where:
R ... the instant radius of the arc of the track [m],
R_2 ... radius of the circular arc at the end of the transition curve [m],
l ... total length of the transition curve [m],
s ... the length of the transition curve measured from the beginning to the given point [m].

If the change of the radius is slow enough, it is possible to consider the part of the track on which the vehicle is currently located as an arc with a constant radius. This allows the distance traveled along the track shown on the horizontal axis of the presented courses to be calculated by the relationship (3) to the radius of the track at the given point.

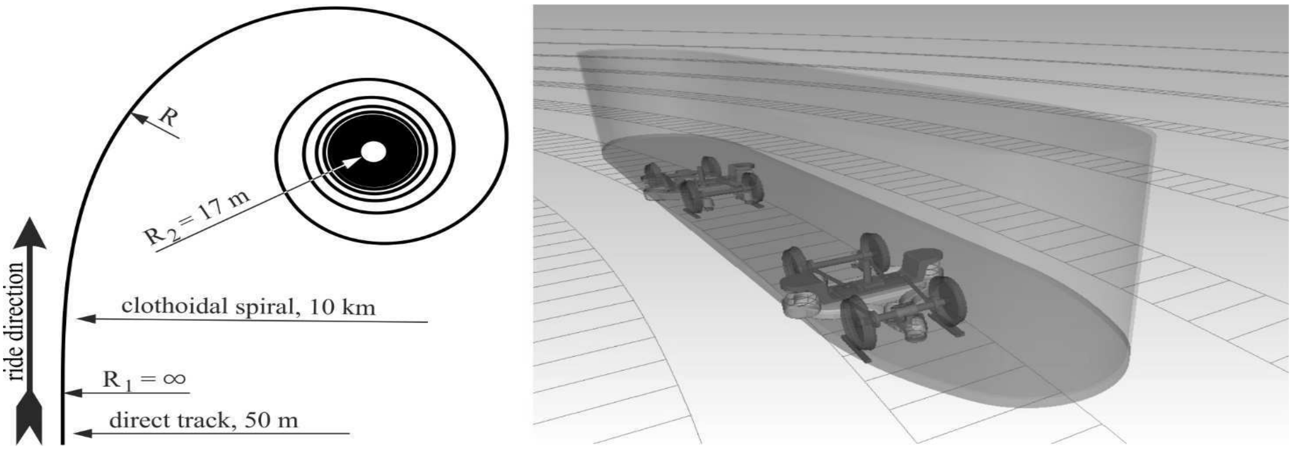

Fig. 5 *Track of clothoid shape and vehicle model running on this track*

In the following simulation, a ride along a track with a straight section designed to stabilize the vehicle ride, a clothoid-shaped 10 km long transition curve, and a circular arc with a radius of 17 meters was considered. The shape of the track is shown in Fig. 5.

A comparison of the power loss of vehicles at a speed of 10 km/h is shown in Fig. 6. For the large amount of calculated data, the power loss courses are presented only for the arc radius interval from 17 to 100 m, i.e. in the area where the proposed solution can be expected to be applied effectively. In the graphs, vehicle curve pasing resistance is presented in form of P_x and P_y components. The power loss component P_x covers creep in the longitudinal direction. The power loss component P_y covers creep in the lateral direction. However, the vehicle will cover both power losses simultaneously during ride.

On the basis of a simulation analysis of ride through a track transition curve, it can be stated that in the case of a vehicle passing through a small radius track using the additional wheel tread, it is possible to achieve more favorable ride parameters in a wider interval of track arc radii.

6 Conclusion

Based on the comparison of these simulation analyses, it is possible to assume that, in terms of power loss, the vehicle ride using the additional tread is more favorable in an arc radius smaller than 62.3 m. It is clear from the above-shown courses that in the area under consideration, the use of the additional tread leads to a significant reduction of the adverse effects. In the area of the track arc radii from 23.55 to 44.88 m, the power loss of the vehicle is virtually eliminated.

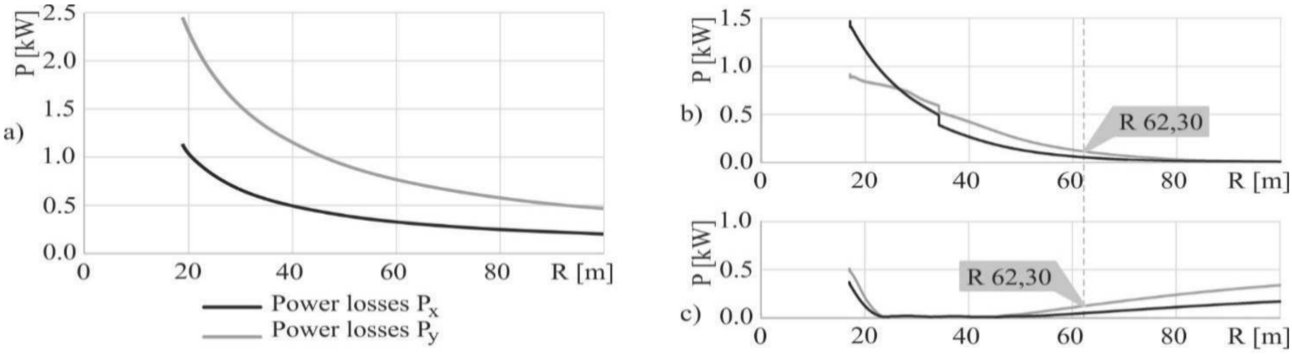

***Fig. 5** Track of clothoid shape*

In order to make use of the described method of ride in small radius arcs of the track, it is necessary to focus on creating a suitable way of changing the wheel roll mode during ride and on identifying the vehicle's response to such a change. This issue is addressed by the team of authors today.

Acknowledgement

The work was supported by the Cultural and Educational Grant Agency of the Ministry of Education of the Slovak Republic in project No. KEGA 077ŽU-4/2017: Modernization of the Vehicles and engines study program. The work was also supported by the project No. APVV-0842-11: Equivalent railway operation load simulator on the roller rig and VEGA Nr. 1/0927/15: Research of the use of alternative fuels and hybrid drives on traction vehicles with aim to reduce fuel consumption and air pollutants production.

Research-Educational Center of Rail Vehicles (VVCKV)

References

[1] DIŽO, J., 2016. Analysis of a goods wagon running on a railway test track. In: *Manufacturing technology*: journal for science, research and production. ISSN 1213-2489. Vol. 16, no. 4 (2016), s. 667-672.

[2] DIŽO, J., BLATNICKÝ, M., 2015. Modelling and simulations of a flexible multibody system of the freight wagon bogie using computer tools In: *Dynamical problems in rail vehicles 2015*: Slovak - Polish scientific workshop: Žilina June 22th and 24th, 2015 Slovak Republic. - Žilina: University of Žilina, 2015. - ISBN 978-80-554-1298-6. - S. 18-27.

[3] DIŽO, J., BLATNICKÝ, M., 2016. Computer analysis of a wagon bogie running with a flexible frame. In: *RAILCON '16: XVII scientific - expert conference on railways*: proceedings: October 13-14, 2016, Niš, Serbia. - Niš: Faculty of Mechanical Engineering, 2016. - ISBN 978-86-6055-060-8. - S. 37-40.

[4] DIŽO, J., BLATNICKÝ, M., 2016. Use of multibody system dynamics as a tool for rail vehicle behaviour diagnostics. In: *Diagnostyka.* ISSN 1641-6414. Vol 17, no. 2 (2016), s. 9-16.

[5] DIŽO, J., BLATNICKÝ, M., SKOČILASOVÁ, B. 2015. Computational modelling of the rail vehicle multibody system including flexible bodies. In: *Communications*: scientific letters of the University of Žilina. ISSN 1335-4205. Vol. 17, no. 3 (2015), p. 31-36.

[6] DOMIN, R., GORBUNOV, N., CHERNYAK, A., KRAVCHENKO, K., KRAVCHENKO, C., 2014 Wear mechanisms analysis and elaboration of measures for improving the interaction of wheelset with rail track. In: *State Economy and Technology University of Transport*, Vol. 24.

[7] EVANS, J. R., LEE, T. K. Y., HON, C. C. 2008. Optimising the wheel/rail interface on a modern urban rail systém. In *Vehicle System Dynamics*. 2009. P. 119-127. ISSN 1744-5159.

[8] FOMIN, O. 2014. Modern requirements to carrying systems of railway general-purpose gondola cars. In: *Scientific and technical journal «Metallurgical and Mining Industry».* 2014, No. 5 – P.31-43.

[9] FOMIN, O. 2015. Development and application of cataloging in structural design of freight car building / O.V. Fomin, O.V. Burlutsky, Yu.V. Fomina / *Scientific and technical journal* «Metallurgical and Mining Industry. 2015, No. 2 – P.250-256

[10] GERLICI J., GORGUNOV M., KRAVCHENKO K., DOMIN R., KOVTANETS M., LACK T., 2017. Slipping and skidding occurrence probability decreasing by means of the friction controlling in the wheel-braking pad and wheel-rail contacts. In: *Manufacturing Technology*. April 2017, Vol. 17 No 2. p. 179-186

[11] GERLICI J., GORBUNOV M., KRAVCHENKO K., KOSTYUKEVICH A., NOZHENKO O., LACK T., 2016. Experimental Rigs for Wheel/Rail Contact Research. In*: Manufacturing Technology*. October 2016, Vol. 16, No. 5. Pp. 909 – 916. ISSN: 1215-2489.

[12] GERLICI, J., LACK, T., 2003. Rail geometry analysis (from the point of view of wearing in the operation). In: *Communications:* scientific letters of the University of Žilina. ISSN 1335-4205. Vol. 5, no. 1 (2003), s. 43-51.

[13] GERLICI, J., LACK, T., 2003 Railway wheel and rail geometry geometry influence on ride properties of the vehicle. In: *Current problems in rail vehicles* - Prorail 2003. XVI. International conference. Žilina 8.-10. October 2003, Slovensko. Žilina: VTS pri ŽU. 2003. S. 163-171. ISBN 80-968823-6-8.

[14] GERLICI, J., LACK, T., 2010. Contact geometry influence on the rail/wheel surface stress distribution. In: *Procedia Engineering*. ISSN 1877-7058. Iss. 1 (2010), (pp. 2249-2257).

[15] GERLICI, J., LACK, T., 2011. Railway wheel and rail head profiles develpment based on the geometric charac-teristics shapes. In: *Wear:* an international journal on the science and technology of friction, lubrication and wear. ISSN 0043-1648. Vol. 271, No. 1-2 Sp. iss. (2011), s. 246-258.

[16] GERLICI, J., LACK, T., 2016. Railway vehicles dynamics properties research by means of simulation computations - background theory. In: *Dynamical problems in rail vehicles 2016*: Slovak - Polish scientific workshop: Žilina December 6th and 7th, 2016 Slovak Republic: proceeding of the workshop. - Žilina: University of Žilina, 2016. - ISBN 978-80-554-1299-3. - S. 122-135.

[17] GERLICI, J., LACK, T., 2016. Railway vehicles dynamics properties research by means of simulation computations - computational results. In: *Dynamical problems in rail vehicles 2016*: Slovak - Polish scientific workshop: Žilina December 6th and 7th, 2016 Slovak Republic: ISBN 978-80-554-1299-3. - S. 136-145.

[18] GERLICI, J., LACK, T. and co., 2005. *Transport Means Properties Analysis*. Vol. I. (2005) Monograph, 214 p; ISBN 80-8070-408-2, Printed by EDIS – University of Žilina publishers.

[19] GERLICI, J., LACK, T., HAUSER, V., MAŇUROVÁ, M., NOŽENKO, O., S., KRAVČENKO, K., O., 2017. *Vizok vagona*: Utility model no. UA 114040 U; [Carriage bogie] Kyjiv: Ukrajinskyj instytut promyslovoji vlasnosti (UKRPATENT), 2017. 9 s. Number: u 2016 09015. Kategory: B61F5/30.

[20] HAUSER, V., GERLICI, J., LACK, T., LOULOVÁ, M., NOŽENKO, O., S., KRAVČENKO, K., O., PROSVIROVA O., V., 2017. *Railway bogie wheelset and curved track segment*: Patent application no. a201701589; Kyjiv: Ukrajinskyj instytut promyslovoji vlasnosti, 2017. 11 s. Kategory: 4267/3A/17.

[21] CHUDZIKIEWICZ, A., SOWIŃSKA, M. 2015. Modelling and Simulations of Dynamics of the Low-floor Tramcar with Independently Rotating Wheels. In: *Transcom 2015,* Žilina. ISBN 978-80-554-1048-7.

[22] LACK, T., GERLICI, J. 2009. Railway wheel and rail roughness analysis. In: *Communications:* Scientific Letters of the University of Žilina. ISSN 1335-4205. Vol. 11, No. 2 (2009), (pp. 41-48).

[23] LACK, T., GERLICI, J. 2016. Rail vehicle dynamics properties investigation by means of simulation computations. In: *Dynamics of rigid and deformable bodies 2016*. Ústí nad Labem. ISBN 978-80-7561-016-4.

[24] LACK, T., GERLICI, J., 2016. Tangential stresses for non-elliptical contact patches computed by means of a modified FASTSIM method. In: *Civil-Comp Proceedings*. ISSN 1339-4509. - Iss. 1, 10 s.

[25] MOGILA, V., VASYLIEV, I., NOZHENKO, E., 2012. The use of biofuel on the railway transport In: *TRANSPORT PROBLEMS, 2012,* Volume 7, Issue 1, pp. 21 – 26

[26] PILATAU, A. Y.; VIARSHYNA, H. A.; GORBUNOV, A. V.; NOZHENKO, O. S.; MACIEL, H. S.; BARANOV, V. Y.; MUCHA, O. V.; MAURAO, R.; LACAVA, P. T.; LIAPESHKO, I.; PETRACONI , G. F.; MATUS, A.; 2014. Analysis of syngas formation and ecological efficiency for the system of treating biomass waste and other solid fuels with CO2 recuperation based on integrated gasification combined cycle with diesel engine. In*: Journal of the Brazilian Society of Mechanical Sciences and Engineering.* October 2014, Volume 36, Issue 4. - Pp 673-679.

[27] TNŽ 73 63 61 Geometrical location and layout of track with gauge 1000 mm, ŽSR: Bratislava, 2007.

[28] ZELENKA, J., KOHOUT, M. 2012. *Relationship wheel-rail in tram traffic condition*. Online: www.sdp-cr.cz/WD_FileDownload.ashx?wd_systemtypeid=34&wd_pk=WzEzMDMsWzMwXV0%3D

[29] WANG, W., SUDA, Y., MICHITSUJI, Y. 2008. Running performance of steering truck with independently rotating wheel considering traction and braking. In *Vehicle System Dynamics*. 2008. S. 899 – 909. ISSN 1744-5159.

DOI: 10.21062/ujep/57.2018/a/1213-2489/MT/18/1/79