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ANALYSIS OF TRAMWAY VEHICLE DERAILMENT SAFETY DURING RIDE IN CURVES WITH SMALL RADIUS

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ОЦЕНКА КОЭФФИЦИЕНТА БЕЗОПАСНОСТИ ОТ СХОДА С РЕЛЬСОВ ВАГОНА ПРИ ДВИЖЕНИИ В КРИВОЙ МАЛОГО РАДИУСА

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An inseparable part of big cities is the mass transit, buses, trolley buses and tramways riding through narrow streets of the city. Tramways in cities often ride in track curves of a small radius, which is followed by an increased effect of the vehicle on the track in the rail- wheel contact and excessive noise generation. Exactly with the aim to reduce these undesirable effects we designed a tram bogie with a possibility to steer the wheelsets. This mechanism is registered under utility model Nr. 201609015. A comparison of safety against derailment results for a tram vehicle riding through a S-curve with a diameter of 25 metres is given in the article. Three cases are compared: the first case is a T3 tram vehicle with original bogies, the other two cases represent a tram vehicle with changes in the bogie design - one with the bogies of the vehicle aligned with front parts facing each other, second with bogies facing each other with the rear part.
Keywords: *safety against derailment, S-curve, wheel profile, tramway, radial steering of the wheelsets.*

Introduction

The existence of buckling of the track of rail is unevitable in rail transport. They arise from the configuration of the rail from sections with and without superelevation as well as from the differencies in superelevation. The contemporary occurance of horizontal force and the buckling of the track wheel lifting force in curves can lead to derailment of the vehicle, if both effects are present during a ride on a track of a sufficient length. The vehicle derailment problem is a subject to safety against derailment testing. The problem was already examined by Nadal in 1908 and the outcomes of his work are widely used by railways over the world up to this day. [4, 5, 11]

The safety against derailment is affected by the vehicle with the torsional stiffness of its car, torsional stiffness of the bogie frame, eccentricity of the centre of gravity or torsional hysteresis during torsion. The track transtion curve, superelevation excess or insufficiency or eventually their difference also influence safety against derailment. [8, 13] Vehicle safety is determined by static testing of the vehicle safety against derailment. The testing verifies the vehicle ability to ride safely on a buckling of the track. [14, 18]

Due to the fact, that by the first approval of all vehicles it is necessary to perform all necessary tests, which are financially and time demanding, it is convenient to perform a dynamical analysis of the vehicle before the testing. [1, 2, 3, 12]

Safety against derailment (SAD)

Safety against derailment is given by the ratio of forces in the horizontal plane (the guiding force) Y to the forces in the vertical plane (wheel force) Q. The derailment takes place, when the sum of the vertical component of the normal and tangential forces is sufficient to compensate the vertical wheel force. It is assumed, that in the point of contact with the wheel flange clear creep in vertical downward direction arises. The limit value (Y/Q)lim for the wheel flange to start climbing up the rail head is affected by:

- steepness of the wheel flange
- frictional forces between the wheel flange and the rail (these forces are determined by the characteristics of the wheel tread and rail in the point of contact and the angle of attack between the wheel and rail).

When it comes to climbing of the flange on the rail head, it is guaranteed that the wheel touches the rail at one point and the angle of inclination of the tangent plane is β. Then the wheel affects the rail with critical value of the guiding forces Y. The critical ratio of SAD is then:

$$\left(\frac{Y}{Q}\right)_{lim} = \frac{N \cdot sin\,\beta - N \cdot f_y\,cos\,\beta}{N \cdot cos\,\beta + N \cdot f_y\,sin\,\beta} = \frac{tg\beta - f_y}{1 + f_y tg\beta} \quad [-] \quad (1)$$

where
Y is the guiding force, N;
Q is the wheel force, N;

N is the normal force, N;
β is the angle of flange, N.

Based on the research of the european railway administrations, a limit value for (Y/Q) lim of 1.2 at flange steepness 70° has been set. The limmit value is to be calculated for other flange steepness values (the Nadal equation):

$$\frac{Y}{Q}=\frac{tan\gamma-0.36}{1+0.36tan\gamma}\quad[-]\qquad(2)$$

If a reference tested vehicle exists with a proved calculation of SAD according to given testing conditions, the testing can be omitted, if the results of the new calculation are below the reduced limit value (Y/Q) lim = 0.9 x 1.2 = 1.08 (the safety coefficient is 10%of the limit value). [6, 7, 17]

Conditions of simulation

For the needs of the research of the safety against derailment impact we used improved bogie model of a T3 tram car, which was described in utility model Nr. u201609015. The model was created in CATIA V5R20. The dynamic simulation was performed in SIMPACK 9.10 program. [15, 16] The input parameters of the vehicle were taken from the T3 tram, which was modelled both with the original bogies and with bogies equipped with the designed mechanism allowing radial steering of the wheelsets [9]. We decided to compare the original bogie with the presented adjusted design in the simulation and examine the effects of steering the wheelsets on SAD. Therefore we compare three cases: a tram with original bogies, a tram with changed bogie design and with boogies facing each other with the front of the bogie frame and a tram with changed bogies facing each other with the frame rear (Fig. 1). The part of the bogie frame with wheelset being seated in only one axlebox is considered the frame front.

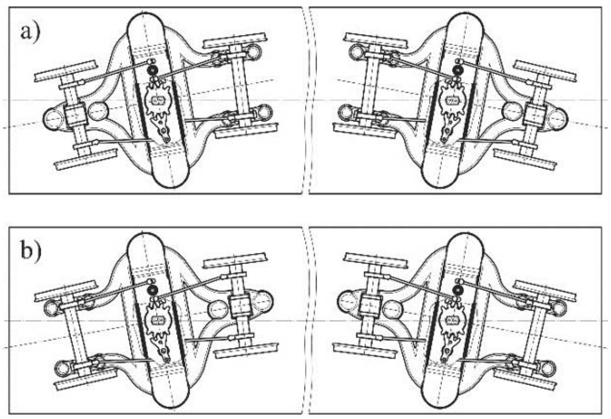

Fig. 1. Bogies under the vehicle
a – with the bogies of the vehicle aligned with front parts facing each other, b – with bogies facing each other with the rear part

The wheelset radial steering mechanism is also used in some other railway vehicles. In general it is made of various types of steering rods connecting axleboxes of individual axles. The mechanism requires a gearwheel segment to be fixed on the bottom of the vehicle car. Steering of the bogie is realised using rotation around the pivot. Levers with gear segment are situated on the gear frame and pivotally mounted on it. They are coupled with axleboxes using steering rods. The mechanism allows achieving a more favorable wheelsets position in curves. However, in case of trams it is necessary to provide steering of the wheelsets in a relatively wide range.

The track used for the calculation was defined according to TNŽ 73 63 61 standard [16], consisting of straight segments, transition segments, and two curves of opposite direction with 25 meters radius. The length of track segments and their layout is shown in Fig. 2.

The rails are seated with a lateral superelevation of 33.6 mm. The track gauge is 1 000 mm. In first case the rails has a NT1 profile all along the track and the wheel profile was set to KP-1.

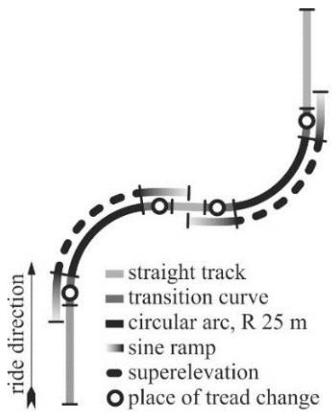

Fig. 2. Track segment layout

In the other two cases the rail has a NT-1 profile on the straight section and a special shape (Fig. 3) in curve sections. In these cases the wheel profile KP-1 was used as well, but it was adjusted using an additional tread on the outer side of the wheel, a detailed description of the profile is given in patent Nr. a201701589. [10].

The tread change is performed on a wheel situated on the inner side of a track curve at the position of transition curve, where the curve radius measured from the track axis reaches a value of 65,64 m. At this point, a change in the rail profile takes place. The rail profile placed in an curve of a small radius is offset against the original profile in lateral and vertical direction for a value identical with lateral and vertical displacement of the wheel profile. The change of wheel tread is performed through vehicle passing this part of the track, as is shown in Fig. 3.

When a wheelset enters a track curve, it attacks the outer rail. In a curve with a diameter corresponding the change of the tread, the clearance provided by the track free channel is considered to be completely reduced. If the change of the tread would be performed using an instant offset of the rail profile, as shown in Fig. 3, it would result in a step change of the Δr value. The wheelset would suddenly get into a position favourable for a ride in curve with a radius of 21,9 m, although the track radius in the given place is 65,64 m, which would lead to violent attack on the rail. An instant offset of the rail profile would therefore become a source of lateral excitation, which is an unfavourable. It is therefore necessary to prevent a signifficant step change in Δr value of the wheelset at the moment of tread change. This is reached using a varying rail profile near the place of tread change, which minimizes the step change of Δr value.

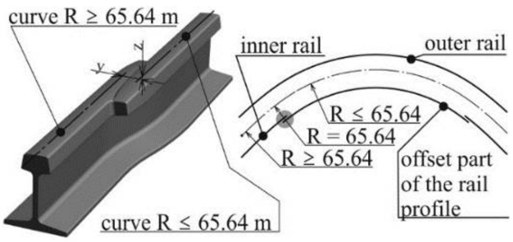

Fig. 3. schematic drawing of the rail

A constant velocity of 10 km.h-1 was chosen. The bogie wheelbase 1 900 mm and wheel diameter 680 mm were also identical for both bogies. Fixed rails were defined in the calculation, Young´s modulus of wheel and rail material E = 210 GPa, Poisson ratio μ = 0.28, damping in rail - wheel contact 100 000 Ns.m-1, friction coefficient μk 0.4.

Comparison of the stability against derailment

The expressionof the SAD as a ratio of guiding forces and wheel forces on individual wheels corresponds the guiding forces curve. Higher values represent a worse state, lower ones represent a safer ratio of horizontal and vertical forces.

From the results in Fig. 4 can be seen, that all values are signifficantly under the generally known allowed value of 0.8. Higher values arise, when entering and coming out from the curve, but even in these cases they do not reach more than 0.5.

From the graphs can be concluded, that a tram with original bogies reaches worse results than bogies equipped with the mechanism. Bogies with the mechanism reach a maximal value of 0.05 and the original ones a value of 0.3. At the moment of entering and leaving the curve, values around 0.5 are reached. The wheelset radial steering mechanism could have a positive impact on SAD.

Conclusion

The described mechanism for steering the wheelsets into radial position is able to ensure a more favorable ride in track curves. With its use, decrease of the SAD index during vehicle ride in track curves with small radius can be reached, which is supported by the performed simulation analysis of a tram vehicle model with two different types of bogie.

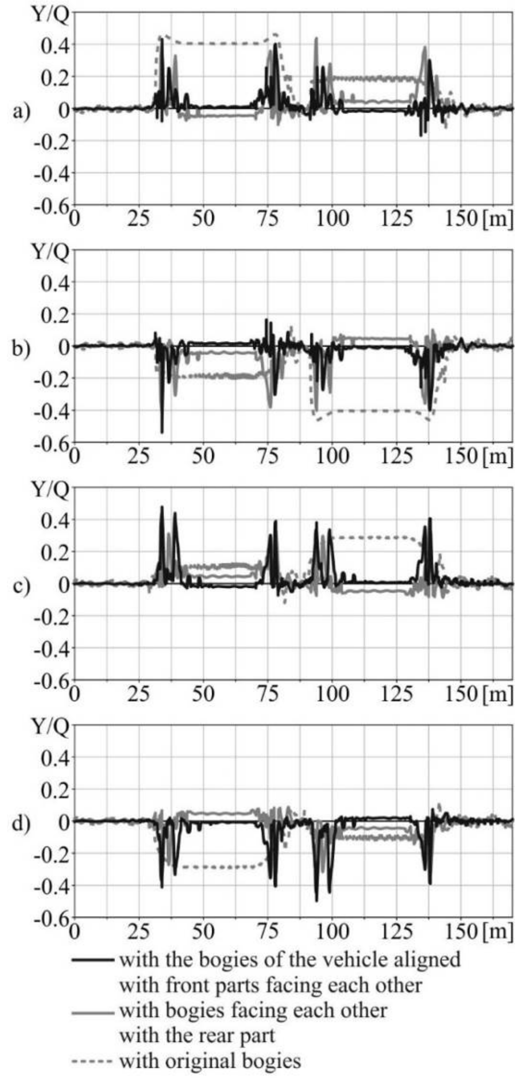

Fig. 4. Safety against derailment of the front bogie:
a – first wheelset, right wheel, b – first wheelset, left wheel,
c – second wheelset, right wheel, d – second wheelset, left wheel

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“Equivalent rail-way operation load simulator on the roller rig”. Research-Educational Center of Rail Vehicles (VVCKV).

R e f e r e n c e s

1. Dižo J. Analysis of a goods wagon running on a railway test track / J. Dižo // In: Manufacturing technology: journal for science, research and production. ISSN 1213-2489. Vol. 16, no. 4 2016. - Pp. 667-672.
2. Dižo J. Computational modelling of the rail vehicle multibody system including flexible bodies / J. Dižo, M. Blatnický, B. Skočilasová // In: Communications: scientific letters of the University of Žilina. ISSN 1335-4205. Vol. 17, no. 3, 2015. - p. 31-36.
3. Evans J.R. Optimising the wheel/rail interface on a modern urban rail system / J.R. Evans, T.K.Y. Lee, C.C. Hon // In Vehicle System Dynamics. 2009. - P. 119-127. ISSN 1744-5159.
4. Fomin O. Modern requirements to carrying systems of railway general-purpose gondola cars / O. Fomin // Scientific and technical journal «Metallurgical and Mining Industry». 2014, No. 5 – P. 31-43.
5. Fomin O. 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. No. 2, 2015.– P.250-256
6. Gerlici J. The Rail – Wheel contact / Gerlici J., Lack T. // Žilina: Žilinská univerzita. 2004. - 200 p. ISBN 80-8070-317-5.
7. Gerlici J. Contact geometry influence on the rail/wheel surface stress distribution / Gerlici J., Lack, T. // In: Procedia Engineering. ISSN 1877-7058. Iss. 1, 2010. - pp. 2249-2257.
8. Gerlici, J. Railway wheel and rail head profiles development based on the geometric characteristics shapes / J. Gerlici, T. Lack // 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), pp. 246-258.
9. Заява на деклараційний патент на корисну модель № u201609015, кл. B61F5/30. Візок вагона / Ю. Герліці, Т. Лак, В. Хаусер, М. Манюрова, О.С. Ноженко, К.О. Кравченко - № u201609015, заявл. 25.08.2016.
10. Заява на деклараційний патент на винахід № a201701589, кл. B61F5/30. Колісна пара візка рейового транспортного засобу та колія криволінійної ділянки / В. Хаусер, Ю. Герліці, Т. Лак, М. Лоулова, О.С. Ноженко, К.О. Кравченко, О.В. Просвірова, заявл. 20.02.2017.
11. Hauser V. Running of public transport vehicles through small radius track / V. Hauser // In: Current problems in rail vehicles PRORAIL 2015, Proceedings of lectures, Žilina, 16.-18.9.2015, Slovak Republic, 2015. - pp. 199-206. ISBN 978-80-89276-48-6
12. Chudzikiewicz A. Modelling and Simulations of Dynamics of the Low-floor Tramcar with Independently Rotating Wheels / A. Chudzikiewicz, M. Sowińska // In Transcom 2015, Žilina, 2015. – 6 p. ISBN 978-80-554-1048-7.
13. Lack T. Rail vehicle dynamics properties investigation by means of simulation computations / T. Lack, J. Gerlici // In: Dynamics of rigid and deformable bodies 2016. Ústí nad Labem, 2016. - 6 p. ISBN 978-80-7561-016-4.
14. Lack T. Railway wheel and rail roughness analysis / T. Lack, J. Gerlici // In: Communications: Scientific Letters of the University of Žilina. ISSN 1335-4205. Vol. 11, No. 2, 2009. - pp. 41-48.
15. SIMPACK A.G. Documentation to the program system SIMPACK. 2014 – 4535 p.
16. TNŽ 73 63 61 Geometrical position and layout of railways with 1000 mm gauge, ŽSR: Bratislava, 2007, - 37 p.
17. Zelenka J. Relationship wheel-rail in tram traffic condition / J. Zelenka, M. Kohout // 2012. Online: http://www.sdpcr.cz/WD_FileDownload.ashx?wd_systemtypeid=34&wd_pk=W-zEzMDMsWzMwXV0%3D
18. Wang W. Running performance of steering truck with independently rotating wheel considering traction and braking / W. Wang, Y. Suda, Y. Michitsuji // In Vehicle System Dynamics. 2008. - pp. 899 – 909. ISSN 1744-5159.

R e f e r e n c e s

1. Dižo J. Analysis of a goods wagon running on a railway test track / J. Dižo // In: Manufacturing technology: journal for science, research and production. ISSN 1213-2489. Vol. 16, no. 4 2016. - Pp. 667-672.
2. Dižo J. Computational modelling of the rail vehicle multibody system including flexible bodies / J. Dižo, M. Blatnický, B. Skočilasová // In: Communications: scientific letters of the University of Žilina. ISSN 1335-4205. Vol. 17, no. 3, 2015. - p. 31-36.
3. Evans J.R. Optimising the wheel/rail interface on a modern urban rail system / J.R. Evans, T.K.Y. Lee, C.C. Hon // In Vehicle System Dynamics. 2009. - P. 119-127. ISSN 1744-5159.
4. Fomin O. Modern requirements to carrying systems of railway general-purpose gondola cars / O. Fomin // Scientific and technical journal «Metallurgical and Mining Industry». 2014, No. 5 – P. 31-43.
5. Fomin O. 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. No. 2, 2015.– P.250-256
6. Gerlici J. The Rail – Wheel contact / Gerlici J., Lack T. // Žilina: Žilinská univerzita. 2004. - 200 p. ISBN 80-8070-317-5.
7. Gerlici J. Contact geometry influence on the rail/wheel surface stress distribution / Gerlici J., Lack, T. // In: Procedia Engineering. ISSN 1877-7058. Iss. 1, 2010. - pp. 2249-2257.
8. Gerlici, J. Railway wheel and rail head profiles development based on the geometric characteristics shapes / J. Gerlici, T. Lack // 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), pp. 246-258.
9. Zayava na deklaracijnij patent na korisnu model' № u201609015, kl. B61F5/30. Vizok vagona / YU. Gerlici, T. Lak, V. Hauser, M. Manyurova, O.S. Nozhenko, K.O. Kravchenko - № u201609015, zayavl. 25.08.2016.
10. Zayava na deklaracijnij patent na vinahid № a201701589, kl. B61F5/30. Kolisna para vizka rejovogo transportnogo zasobu ta koliya krivolinijnoї dilyanki / V. Hauser, YU. Gerlici, T. Lak, M. Loulova, O.S. Nozhenko, K.O. Kravchenko, O.V. Prosvirova, zayavl. 20.02.2017.
11. Hauser V. Running of public transport vehicles through small radius track / V. Hauser // In: Current problems in rail vehicles PRORAIL 2015, Proceedings of lectures, Žilina, 16.-18.9.2015, Slovak Republic, 2015. - pp. 199-206. ISBN 978-80-89276-48-6
12. Chudzikiewicz A. Modelling and Simulations of Dynamics of the Low-floor Tramcar with Independently Rotating Wheels / A. Chudzikiewicz, M. Sowińska // In Transcom 2015, Žilina, 2015. – 6 p. ISBN 978-80-554-1048-7.

13. Lack T. Rail vehicle dynamics properties investigation by means of simulation computations / T. Lack, J. Gerlici // In: Dynamics of rigid and deformable bodies 2016. Ústí nad Labem, 2016. - 6 p. ISBN 978-80-7561-016-4.
14. Lack T. Railway wheel and rail roughness analysis / T. Lack, J. Gerlici // In: Communications: Scientific Letters of the University of Žilina. ISSN 1335-4205. Vol. 11, No. 2, 2009. - pp. 41-48.
15. SIMPACK A.G. Documentation to the program system SIMPACK. 2014 – 4535 г.
16. TNŽ 73 63 61 Geometrical position and layout of railways with 1000 mm gauge, ŽSR: Bratislava, 2007, - 37 p.
17. Zelenka J. Relationship wheel-rail in tram traffic condition / J. Zelenka, M. Kohout // 2012. Online: http://www.sdpcr.cz/WD_FileDownload.ashx?wd_systemtypeid=34&wd_pk=W-zEzMDMsWzMwXV0%3D
18. Wang W. Running performance of steering truck with independently rotating wheel considering traction and braking / W. Wang, Y. Suda, Y. Michitsuji // In Vehicle System Dynamics. 2008. - pp. 899 – 909. ISSN 1744-5159.

Лоулова М., Хаусер В., Ноженко О., Кравченко К.О., Оцінка коефіцієнту безпеки від сходу с рейок вагона при русі в кривій малого радіусу.

Невід'ємною частиною великих міст є громадський транспорт, автобуси, тролейбуси і трамвaї, проїжджаючі по вузьких вулицях міста. Трамвайні колії в містах часто рухаються по кривих ділянках колії невеликого радіусу, що призводить до повішенному впливу на колію та утворення значної шуму в місті. Саме з метою зменшення цих небажаних ефектів авторами розроблений візок трамвая з можливістю управління колесами. Цей механізм запатентований заявкою на корисну модель № u201609015. У статті наводиться порівняння коефіцієнту безпеки від сходу з рейок для трамвайного транспортного засобу, що проходить по S-подібній кривій радіусом 25 метрів. Порівнюються три випадки: перший випадок - трамвай Т3 з оригінальними візками, два інших випадки є трамвай зі зміненою конструкцією візка - однин з візками транспортного засобу, лицьова частина яких звернені один до одного, друге - з візками звернені один до одного задньою частиною.

Ключові слова: *коефіцієнт безпеки від сходу з рейок, S-крива, профіль колеса, трамвай, радіальна установка колісних пар.*

Лоулова М., Хаусер В., Ноженко Е.С., Кравченко Е.А., Оценка коэффициента безопасности от схода с рельсов вагона при движении в кривой малого радиуса.

Неотъемлемой частью больших городов является общественный транспорт, автобусы, троллейбусы и трамваи, проезжающие по узким улицам города. Трамвайные пути в городах часто движутся по кривым участкам пути небольшого радиуса, что приводит к повішенному воздействию на путь и образованию значительного шума в городе. Именно с целью уменьшения этих нежелательных эффектов авторами разработана тележка трамвая с возможностью управления колесами. Этот механизм запатентован заявкой на полезную модель № u201609015. В статье приводится сравнение коэффициенту безопасности от схода с рельсов для трамвайного транспортного средства, проходящего по S-образной кривой радиусом 25 метров. Сравниваются три случая: первый случай - трамвай Т3 с оригинальными тележками, два других случая представляют собой трамвайное транспортное средство с изменённой конструкцией тележки - одно с тележками транспортного средства, лицевая часть которых обращены друг к другу, второе - с тележками обращенные друг к другу задней частью.

Ключевые слова: *коэффициент безопасности от схода с рельс, S-кривая, профиль колеса, трамвай, радиальная установка колёсных пар.*

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