Double Treaded Wheelset Riding Regime Change in Strongly Curved Track from the Derailment-safety Point of View

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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 by the rail - wheel contact. Exactly with the aim to reduce these undesirable effects we designed a tram bogie with steered wheelsets. Moreower, for the vehicle passability trough strongly curved track inproovement, we proposed spcific, double treaded wheelset and coresponding track section. This invention is also registered under Patent Aplications Nr. a201701589 and Nr. a 201706685. A comparison of safety against derailment results for a tram vehicle running through a S-curve with considering of tread change is given in this paper. Three cases are compared: the first case is a T3 tram vehicle with original bogies, the other two cases represent a tram vehicle, which uses proposed inventions. Two ways of bogies placement under the vehicle body are investigated.

Keywords: double wheel tread, strongly curved track, derailment-safety, tramcar ride simulation analysis

1 Introduction

In rail transport, the presence of the twisting of the track is necessary. They result from the arrangement of transitions between a non-superelevated rail and a rail with a lateral superelevation as well as the superelevaton differences. The concurrent occurrence of horizontal force and the load-off of the running wheel in the track arc can result in derailment if both effects are present on a sufficiently long track. [7, 11, 21, 24, 26] Derailment of the vehicle is determined by tests to determine the safety against derailment. This issue was dealt with by M. J. Nadal in 1908 and his knowledge is widely used by railways around the world to this day.

The safety against derailment is impacted by the vehicle by the torsional rigidity of its body, torsional stiffness of the bogie frame, eccentricity of the center of gravity of the vehicle or torsional hysteria during twisting [1, 2, 3, 5, 28]. Security is also affected by track transition curves, surplus or lack of superelevation, or the way these elevations change. The safety of the vehicle is determined by a static test of the vehicle on safety against derailment. The test verifies the ability of the vehicle to ride safely on a twisted track.

Since the initial approval of all vehicles requires the necessary tests that are very financial and time-consuming, it is advisable to carry out a simulation analysis of the vehicle ride dynamics before the test itself [1, 2, 3, 8, 9, 10, 16, 27].

2 Safety against derailment

Safety against derailment is the ratio of the driving forces Y and the wheel forces Q. Derailment occurs if the sum of the vertical components of the normal and tangential forces is sufficient to compensate for the vertical force acting on the wheel. It is assumed that there is a pure downward creep at the point of contact of the wheel flange. The limiting value $(Y/Q)_{\lim}$ for the flange to start climbing is affected by:

- steepness of the wheel,
- frictional forces between the wheel flange and the rail (these forces are determined by the characteristics of the wheel and rail tread at the point of contact and the angle of attack between the wheel and the rail) [4, 6, 12, 20].

When the flange climbs on the rail head, the wheel is guaranteed to touch the rail at only one point and the angle of inclination of the touch plane is β. At that time, the wheel acts on the rail by the critical value of the driving force. Critical safety against derailment ratio is (the individual quantities are shown in Fig. 1):

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

where:
Y ... driving force [N],
Q ... vertical force [N],
N ... vormal force [N],
f ... friction coefficient [-],
β ... angle of the wheel flange [rad].

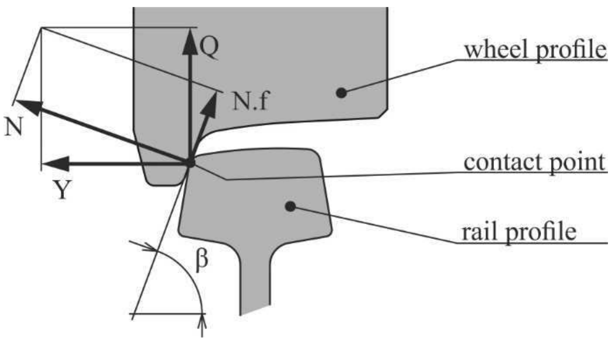

***Fig. 1** Representation of the variables needed to calculate the safety against derailment coefficient*

On the basis of European Rail Management surveys, a limit value for (*Y/Q*) lim was set at 1.2 for a wheel flange slope of 70 °. For other slopes, the limit value is calculated using the Nadal equation:

$$\left(\frac{Y}{Q}\right)_{\lim} = \frac{\tan\beta - 0.36}{1 + 0.36\tan\beta}\,[-], \tag{2}$$

If a referential, tested vehicle with a verified safety against derailment test according to the given test conditions is available, the tests may be omitted if the results of the new calculation are lower than the reduced limiting value $(Y/Q)_{lim}$ = 0.9 x 1.2 = 1.08 (safety factor is 10% of the limit value). [14, 22, 23, 30, 31].

3 Determining scenarios of a series of simulation analysis

For the purpose of examining the impacts of the proposed changes to safety against derailment, a series of three simulation analysis of the vehicle's ride in a contra-directional S-arc track at a speed of 10 km.h^{-1} was performed in SIMPACK 9.10. [28]. A simplified model of a vehicle, similar to the T3 tram by its parameters, was used. The wheelbase of the bogies of 1 900 mm and the wheel diameter of 680 mm were identical in all the cases analyzed. In the calculation, the fixed rail, Young's modulus of elasticity of the wheel material and the rail E = 210 GPa, Poison constant μ = 0.28, damping in the wheel and rail contact 100 000 Ns.m^{-1} and friction coefficient μ_k 0.4 were defined.

The aim of the first simulation analysis was to describe the current state in terms of the courses of the monitored quantities. The reference values obtained served as the basis for comparison with a vehicle equipped with bogies with the possibility of changing the wheelset ride mode in the small radius track arches.

In the second and third simulation analysis, a simplified model of the vehicle, which with its parameters also resembles a T3 tram, has been used, but the vehicle is equipped with bogies of specific design (Fig. 2), characterized by a mechanism for steering the wheelsets and the frame being mounted on the wheelsets using three bearing boxes , which the authors have described in detail in utility model No. u201609015 [18] and No. u201703246 [25].

The wheelset steering mechanism requires a gear segment to be mounted on the bottom of the car by means of an elastic element. The bogie is pivoted by turning around this pivot pin, which is also rotatably mounted in the gear frame. The gear frame further includes levers with a gear segment which are coupled by rods with axle box bearings. Using the mechanism, it is possible to achieve a more favorable position of the wheelsets in an arc, which, in the case of city rail vehicles, can be secured over a wide range of radius of the track arcs.

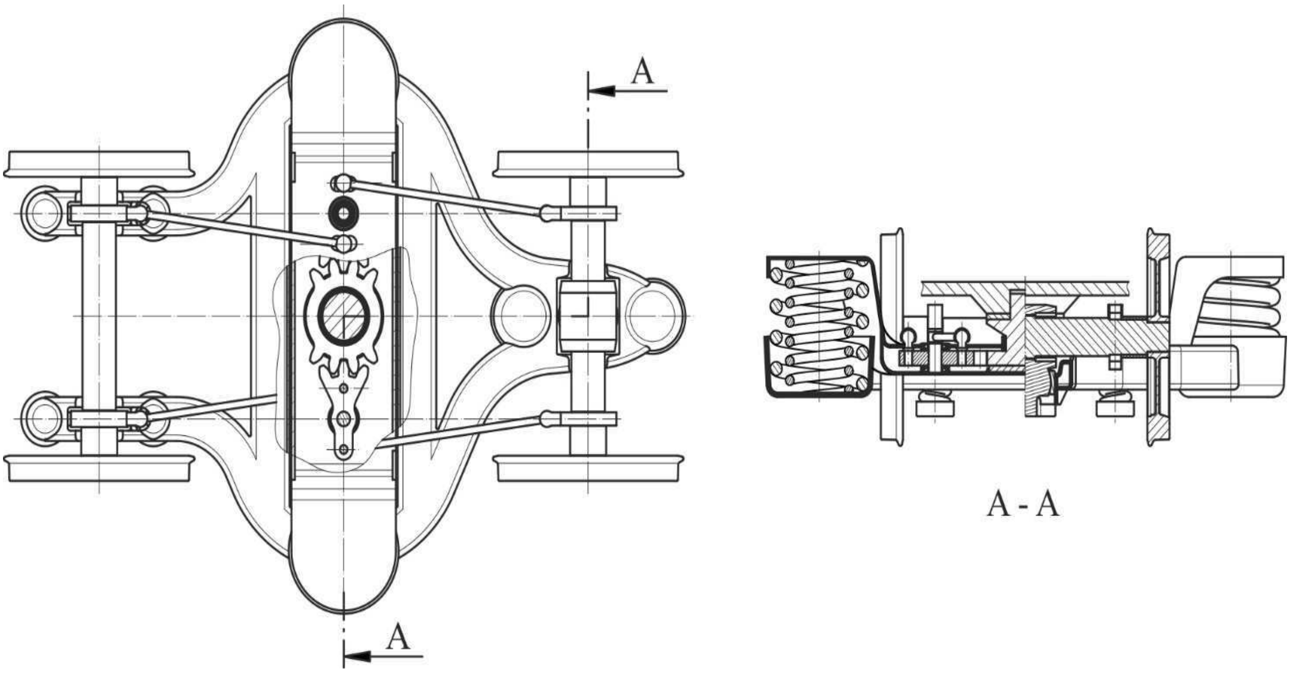

Fig. 2 *Bogie of a specific design used in simulations*

Two possible options for the bogie mounting under the vehicle car body result from the bogie design - the wheelset being mounted to the frame through a single bearing housing may be oriented towards the front or towards the center of the vehicle car body as shown in Fig. 3.

Both cases were evaluated in the simulations analyses. Both bogies of the specific design also have the possibility to change the wheelset ride mode in the small radius arches described in detail by the authors in patent application a201701589.

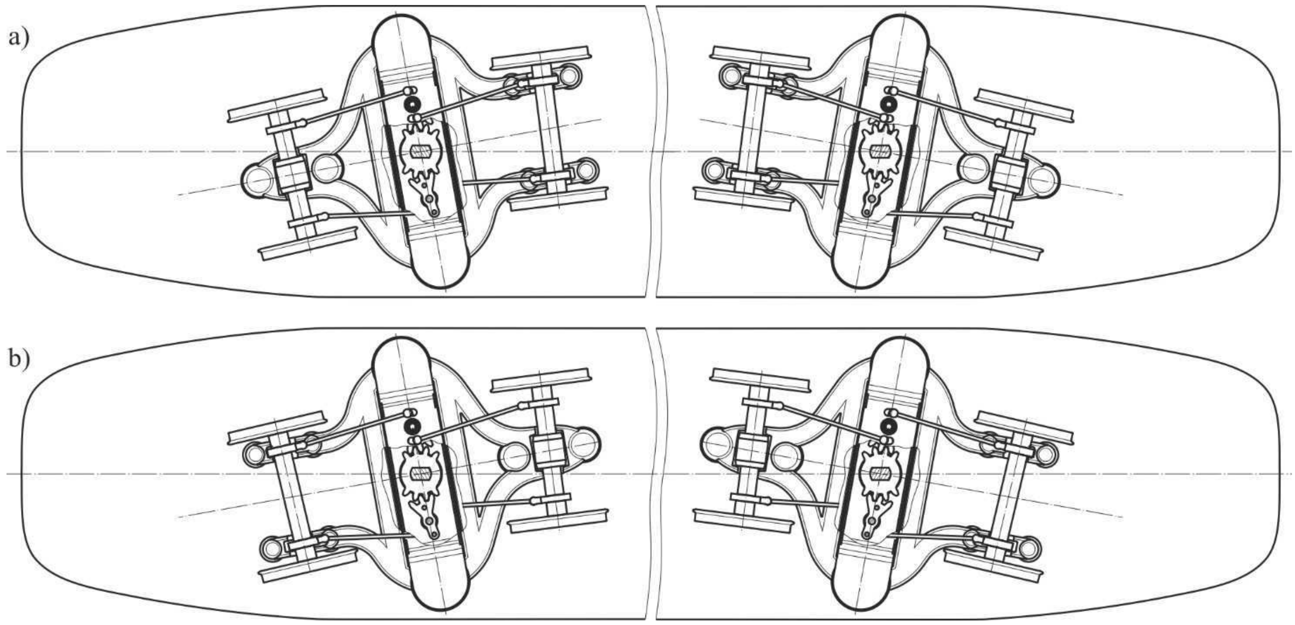

Fig. 3 *Placement of bogies under the vehicle a) back to each other b) front to each other*

4 Track model

It is generally known that, in terms of safety against derailment, the ride of the vehicle in an S-arc with the occurrence of twisting of the track [13, 15, 17] appears to be very problematic. The goal of the authors was to verify the vehicle's response to such a situation, which is further complicated by the change of the wheelset ride mode if the radius of the track exceeds a specific value as described in detail in the patent application [19].

In the calculations, the track was defined in accordance with TNŽ 73 63 61 [29] consisting of straight sections, transition curves, and two contradirectional arches with a radius of 25 m. The length of individual sections of the track and its arrangement is shown in Fig. 4 a). The track had a 33.6 mm lateral superelevation. The nominal track gauge is 1 008 mm.

In the first case, the rails had an NT1 profile along the entire length of the track and the KP-1 wheel ride profile was used without the possibility of changing the ride mode. In two other cases, the rail had a straight section of the NT1 profile. In the arc, rails with variable geometry of the profile as schematically shown in Fig. 4 b), allowing the change of the wheelset ride mode, were used. In these cases, the wheel profile KP-1 was used with an additional tread on the outside of the wheel.

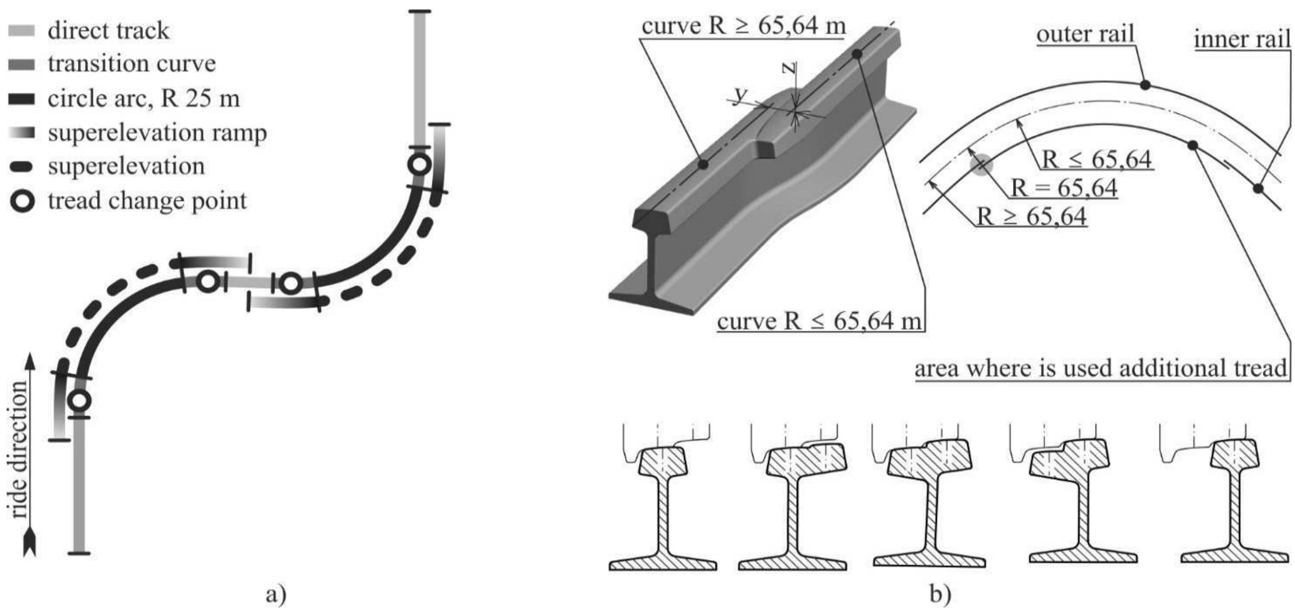

Fig. 4 *Track used in simulation analysis, (a) overall view, (b) location of riding mode change*

The change of ride mode is realised by means of a profile of the wheel tread located on the inside of the track curve at the point of transition curve, where the radius of the curve measured to its axis reaches 65.64 m. A ride mode change is made at this point, characterized in that one of the wheels begins to be rolled on the additional tread of the profile. The rail profile, located in the small radius arc, is laterally and vertically offseted from the original profile by a value identical to the lateral and vertical displacement of the additional wheel profile tread. The changeover of the wheelset ride mode is therefore realised by a simple passage of the vehicle through this point of the track.

It is necessary to ensure that at the moment of changing the tread there is no significant change in the value of the difference in instantaneous rolling radii *Δr* of the passing wheel. This can be achieved by using a variable rail profile near the tread changing area, eliminating the jump change of the *Δr* value.

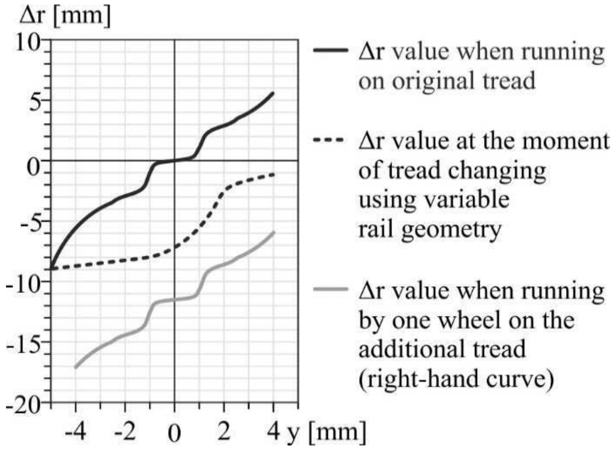

Fig. 5 *The method of changing the Δr value when changing the ride mode in a track with variable rail geometry (right-hand arc)*

The wheelset in the arc runs on the outer rail to maximize the *Δr* value. At the moment when it can no longer be increased using the original tread, the change of the tread takes place. The rail geometry is chosen such that when the condition of a wheelset run on the outer rail is reached, the *Δr* value reached by the wheelset at the moment of change of ride mode is close to the value of *Δr* before changing the driving mode. In Fig. 5, this feature is represented by the point, where the black full and black interrupted curves in the course of the Δr function of the wheelset meet. During further ride on rails with variable geometry of the profile there is a gradual change of *Δr* function. The resulting *Δr* function course of the wheelset after the vehicle passes the track section with a variable track geometry, i.e. during the ride in the changed mode, is shown in Fig. 5 with a gray curve. This method of ride of the wheelset in a track arc is described in detail in the patent application No. a201701589.

After entering all the necessary inputs, it was possible to proceed to the simulation analysis itself and compare the calculated results.

5 Comparison of the safety against derailment coefficient

Expression of safety against derailment as a relative value equal to the proportion of the guiding and wheel forces of individual wheels with their course basically corresponds to the course of the guiding forces. Higher values represent a worse state, lower values represent a safer ratio of horizontal forces to vertical forces.

From the results in Fig. 5, it is clear that all values are significantly below the generally known lower limit value of 0.8. Higher values arise when entering and exiting the arc, but even in these cases it does not exceed 0.5.

The graphs show that the vehicle with original bogies reaches worse results than the vehicle with the specific bogies designed by the authors. The proposed bogies reached a maximum value of 0.05 in the arcs and the original bogies of 0.3. In all three cases, the values during entering and exiting the arc were around 0.5. The function of steering the wheelsets, as well as ride mode change in arcs of small radius have a positive effect on safety against derailment.

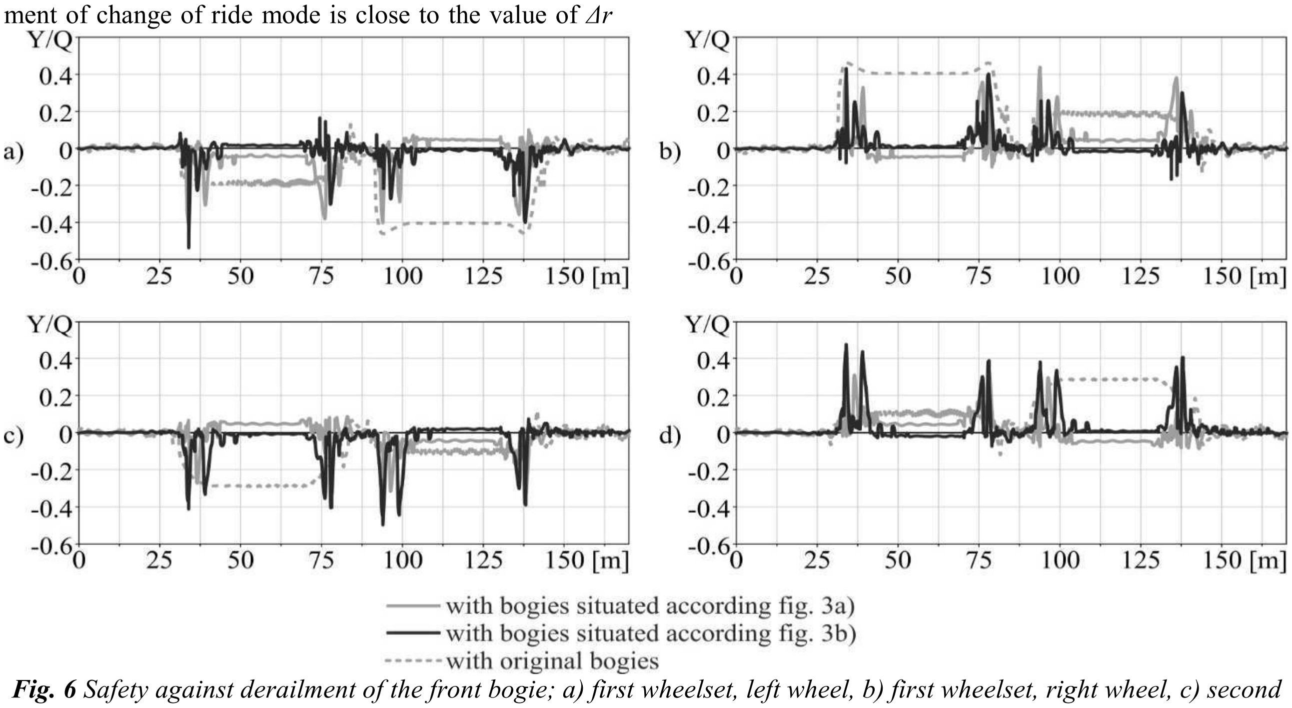

Fig. 6 *Safety against derailment of the front bogie; a) first wheelset, left wheel, b) first wheelset, right wheel, c) second wheelset, left wheel, d) second wheelset, right wheel*

6 Conclusion

The mechanism for steering the bogie wheelsets to radial position is able to ensure ride of the vehicle by the track arc in a more favorable way. With its use, it is possible to achieve a significant reduction in the lateral relative creep speeds in the wheel-rail contact, to reduce the vehicle resistance from the curve passing as well as to reduce the wear of the functional surfaces of the wheel and rail profiles. The accompanying phenomenon is also to reduce the safety factor against derailment when crossing the vehicle with small radius curves, as confirmed by the simulated analysis of the model of a tramcar with two types of chassis.

The possibility of changing the wheelset ride mode results in a more favorable way of ride of the vehicle in curved track, particularly in arcs with an extremely small radius. Thanks to it, it is possible to achieve significant reduction of the longitudinal relative creep speeds in the wheel-rail contact, to reduce the vehicle resistance from the curve travel as well as to reduce the wear of the functional surfaces of the wheel and rail profiles. However, at the moment of the change in ride mode, there is a brief increase in the values of the safety against derailment factor, but the calculated values are significantly below the generally known lower limit value of 0.8. It would be interesting to compare the calculated courses of safety against derailment coefficient with that measured on an actual vehicle when riding through the frog of the point, when the rail's tread changes, which can be considered as an analogue of the process of changing the wheel's tread mode.

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