

ASSESSMENT OF DERAILMENT QUOTIENT OF LOCOMOTIVE BOGIE

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Abstract. In the conditions of the market economy and increased competition in the market of transport services, railway transport maintains an important position in the economy. Its main importance is due to technical and economic advantages over most other modes of transport. The main element of rail transport is rail vehicles, which must meet modern technical and economic requirements. Only competitive modern and progressive scientific technologies work effectively in a market economy. Traffic safety, technical and economic indicators of railway transport depend on the development of these technologies. The aim of this study is to improve the properties of a two-axle bogie of a locomotive as one of the main components on which the above-mentioned parameters depend. The commercial simulation software package Simpack was used for the research, in which MBS models of three types of bogies were created. Namely, there are modifications of the bogie considering a different distribution of the weight and different dimensions of chosen parameters. The first type of bogie is the basic one. This bogie is operated on railways. The other two are modifications of the first one, namely such parameters as the weight of separate parts of the bogie, dimensions of the bogie and wheelset, and location of the centre pivot. The research was conducted in terms of the derailment quotient, as one of the main parameters on which traffic safety depends, for different speeds and curve radii. After carrying out simulation calculations, the results were processed using Simpack post software. In all cases, the derailment quotient did not exceed the permissible value for all types of bogies. The best derailment quotient was for the third type of bogie, the derailment quotient of the second type was slightly overestimated in comparison with the other two but was still within the norm.

Keywords: rail vehicle, bogie, multibody model, derailment quotient.

Introduction

Rail vehicles require adequate safety measures to prevent accidents and ensure safe transportation of passengers and goods [1]. Safety is particularly important when a rail vehicle is in curvilinear motion [3-5] or braking. Rail brakes are a critical component of the railway system, and their importance cannot be overstated [6; 7]. They play a vital role in controlling the speed and stability of trains, preventing wear and tear on tracks, and ensuring safe railway operation [8; 9]. But in this work, the focus is on the movement of the rail vehicle in the curve. The most important indicator in a curvilinear motion is safety against derailment quotient. The derailment quotient Y/Q is represented by the lateral wheel force Y ratio to the vertical wheel force Q [10]. An unfavourable combination of vertical Q and lateral Y wheel forces in operation, as well as a violation of loading conditions and deviations in the condition of the rail vehicle can be possibly the mounting of a flange, which leads to the derailment of the rail vehicle from the rails [11].

The coefficient is calculated according to the formula [6]:

$$\frac{Y}{Q} = \frac{\tan \beta - f}{1 + f \cdot \tan \beta}, \quad (1)$$

where β – angle of the wheel flange to the horizontal axis, °;
 f – friction coefficient.

The critical value of the derailment quotient Y/Q for curvilinear motion determined for $\beta = 70^\circ$ for the UIC-ORE wheel running profile is included in [12; 13] and it is of 0.8 for the curves with the radius over 250 m and of 1.2 for smaller radii.

The main purpose of the performed and presented research is to analyse the running properties of a locomotive bogie in terms of running safety. As it is indicated above, the derailment quotient Y/Q is the main criterion of running safety.

The research includes analyses of bogie running at various running speeds as well as analyses of three different variants of the bogie. The parameters of these variants of bogie are presented in the section Materials and methods and the results are contained in the section Results and discussion.

Particular numerical values of the derailment quotient were obtained from the simulation analyses. As running in a curve was simulated, waveforms of the derailment quotient are depicted in a form of graphical dependences in time. The most important values of the achieved results are the maximal values of the derailment

quotient. The calculated values of the derailment quotient (the Y/Q ratio) are compared with the limited values given in the codes [12; 13]. For the presented research, the limit value of 0.8.

Materials and methods

Software Simpack was used to make the model of the bogie of the locomotive. Simpack is software for multibody system simulation (MBS). It allows the simulation of any mechanical system's linear or non-linear motion. In Simpack software it is also possible to make a 3D model to predict and visualize dynamic motion and to calculate forces and stresses in the bodies. Simpack is primarily used in the automotive and rail industrial sector but can be applied in any mechanical engineering sector.

The rail vehicle model (Fig. 1) is created by three rigid bodies, i.e. two bogies and a car body with defined inertia and mass parameters [14-17]. Bodies are connected by mechanical and kinematic linkings and flexible components.

The bogie model (Fig. 2) in the Simpack software is created by several rigid bodies. These bodies are the bogie frame, the wheelsets, and the axleboxes, and also these bodies are connected by mechanical and kinematic linkings and flexible components. The simplified theory by Kalker (FASTSIM) was applied in simulation for the wheel-rail contact calculation [18; 19].

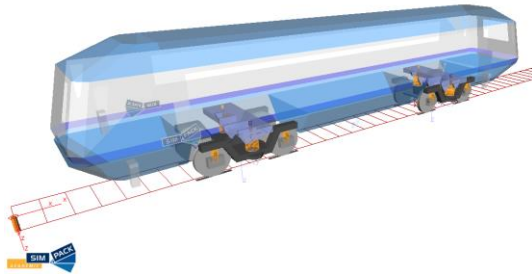


Fig. 1. Rail vehicle model

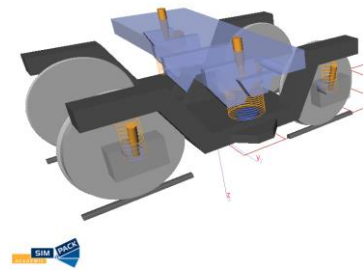


Fig. 2. Bogie model

The necessary parameters for modeling the bogie and simulating its motion at the specified running speeds are displayed in Table 1. The parameters displayed in Table 1 define the base bogie model, which has been named VAR1. The bogie of the diesel-electric shunting locomotive prototype of a commercial company was represented as a VAR1 type of bogie.

Table 1

Input parameters of the bogie VAR1 for the Simpack software

Parameter	Value	Comments
Mass of the bogie	6480 kg	Without wheelsets + 1/3 traction motor
Mass of the wheelset	3550 kg	+ 2/3 traction motor
Mass of the traction motor	1830 kg	-
Mass of the axlebox	137 kg	-
Wheel diameter	1100 mm	-
Wheelbase	2400 mm	-
Distance of centre pivots	9.5 m	-
Height over a rail level	1.4 m	-
Centre of gravity height of the bogie over a rail level	0.581 m	-
Primary suspension spring stiffness	808,000 N·m ⁻¹	Vertical direction
Secondary suspension spring stiffness	538,000 N·m ⁻¹	Vertical direction

For the model VAR 2, the weight characteristics of the parts of the bogie have been changed, such as the mass of the bogie frame, the wheelset, and the traction motor. In this case, the mass of the traction motor was added to the mass of the bogie. In addition to the mass characteristics, the dimensional characteristics have also changed, specifically for the wheel diameter, which has decreased. The changed parameters for the model VAR2 are displayed in Table 2.

Table 2

Input parameters of the bogie VAR2 for the Simpack software

Parameter	Value	Comments
Mass of the bogie	8920 kg	+ traction motor
Mass of the wheelset	2330 kg	-
Mass of the traction motor	2150 kg	+ 900 kg axle gear box
Wheel diameter	1000 mm	-
Centre of gravity height of the bogie over a rail level	0.531 m	-

The next bogie variant is VAR3, its changed parameter values are displayed in Table 3.

Table 3

Input parameters of the bogie VAR3 for the Simpack software

Parameter	Value	Comments
Distance of centre pivots	10 m	-
Height over a rail level	1.5 m	-

In the case of the bogie VAR3, this involves a change in the distance of the centre pivots and the height over a rail level. No other parameters have been changed.

In addition to the rail vehicle model, the rail profile is UIC60, the track gauge is 1435 mm [20; 21], and the contact between the rail and the wheel was determined [22-24]. Simulations were carried out for speeds of 120 and 140 km·h⁻¹ and a curve radius of 250 m [25]. The simulation computations were performed for the track with the superelevation ramp of 0 mm and 150 mm. The results are presented only for 0 mm. The track model did not include any transition section between a straight section and a curve.

Results and discussion

The results of simulation calculations of the derailment quotient have been plotted on the graphs (Fig. 3-5). The derailment quotient for the front left wheel of the front bogie (in the direction of movement) is evaluated. The wheel flange of this wheel is the leading and under the influence of centrifugal forces the radial thrust in it increases. If the centrifugal forces acting on a leading wheel increase, there may be a risk of the bogie derailing because of the possible mounting of a flange.

The numerical values of the derailment quotient are included in Table 4.

Table 4

Maximum absolute value of the derailment quotient Y/Q

Running speed	VAR1	VAR2	VAR3
120 km·h ⁻¹	0.178	0.176	0.205
140 km·h ⁻¹	0.203	0.226	0.206

According to the graphs (Fig. 3-5) and Table 4, the derailment quotient increases at higher running speeds. It is related to the fact that the centrifugal forces acting on the wheel increase as the running speed increases. The values displayed in Table 4 for all bogie variants show that none of the bogie variants exceeded the maximum accepted derailment quotient.

As it is described in the methodological section, this research is focused on the analyses of the derailment quotient for three variants of the wagon bogie VAR1, VAR2, and VAR3. The VAR1 type of bogie is the basic one. The other two (VAR2 and VAR3) are modifications of the first one, namely such parameters as the weight of parts of the bogie, dimensions of the bogie and the wheelset, and the location of the centre pivot. A simulation model of the rail vehicle and a railway track was created in a multibody software. The simulations were calculated with the bogie model, which was running at two speeds of 120 km·h⁻¹ and 140 km·h⁻¹ along a curve with a radius of 250 m. The results have been evaluated by means of the Postprocessor of the Simpack software. The waveforms of the derailment quotient for these running speeds and for three analysed variants of the bogie are shown in Fig. 3 to Fig. 5. The achieved values of the derailment quotient for the VAR1, VAR2, and VAR3 types of the bogie differ from each

other, which can be recognized in these figures. Generally, it can be concluded that the higher running speed ($140 \text{ km}\cdot\text{h}^{-1}$) leads to higher values of the derailment quotient in comparison with the running at the lower tested speed ($120 \text{ km}\cdot\text{h}^{-1}$). The particular absolute values for the derailment quotient are for bogies VAR1, VAR2 and VAR3 for the running speed of $120 \text{ km}\cdot\text{h}^{-1}$ as follows: 0.178, 0.176 and 0.205 respectively. From this comparison, the VAR2 bogie seems to be most favourable in terms of running safety. However, the VAR1 bogie achieved very similar value of the derailment quotient. In case of running at the speed of $140 \text{ km}\cdot\text{h}^{-1}$, the achieved values of the derailment quotient for the VAR1, VAR2 and VAR3 bogies are as follows: 0.203, 0.226 and 0.206, respectively. These results have shown, that the VAR2 bogie has achieved the highest values of the Y/Q ratio. The VAR1 and VAR3 bogies can be supposed to be more favourable for operation in terms of running safety. On the other hand, any version of the bogie did not exceed the maximal permissible value of the Y/Q ratio of 0.8 [12; 13]. Hence, all bogies can be accepted for operation.

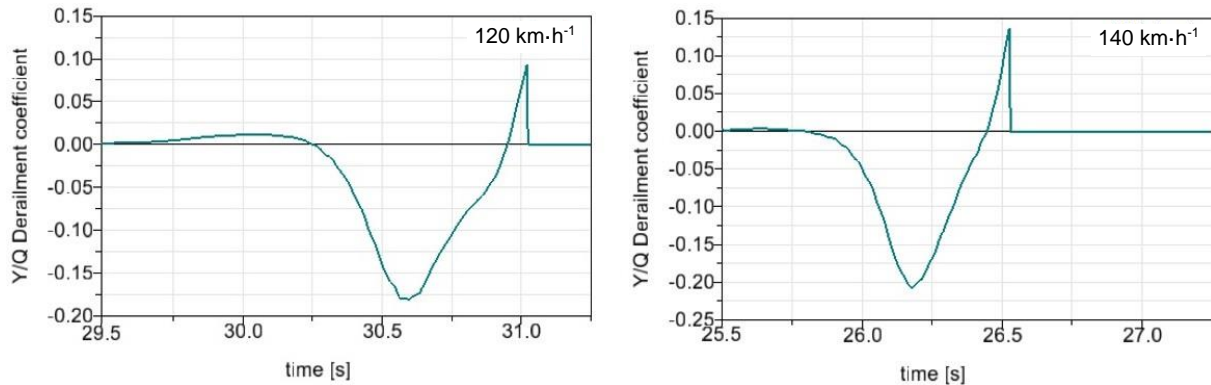


Fig. 3. Derailment quotient of the VAR1 bogie

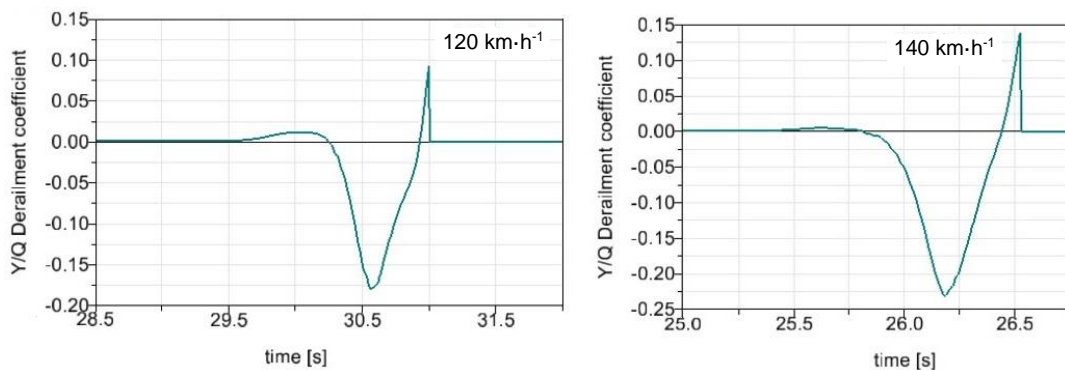


Fig. 4. Derailment quotient of the VAR2 bogie

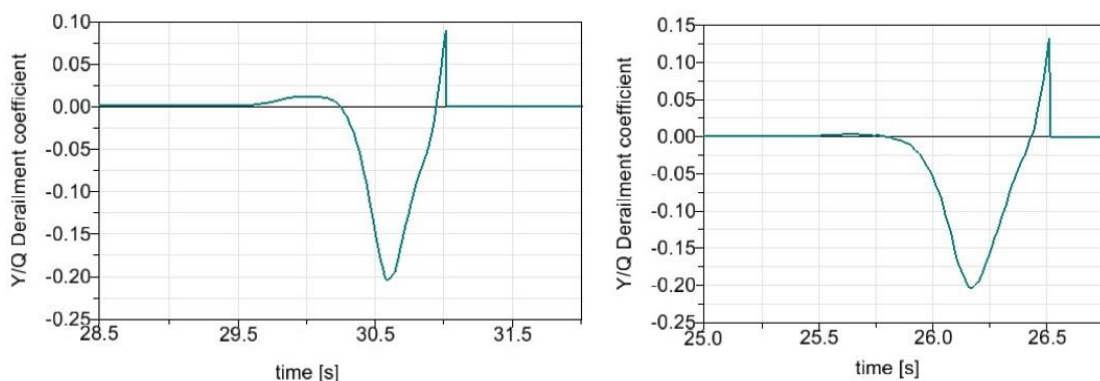


Fig. 5. Derailment quotient of the VAR3 bogie

In the case of the VAR2 bogie, the values on the leading wheel were higher at higher running speeds, but in none of the cases the obtained results approximate the maximum accepted value for the

derailment quotient. For the curve radius ≥ 250 m, the maximum accepted value for the derailment quotient is 0.8 [15; 16].

Conclusions

1. The research was focused on analysis of the derailment quotient of a locomotive bogie for various running conditions.
2. Three variants of the locomotive bogie were created. These variants differ from each other by mass and suspension system parameter values.
3. The simulation calculations showed that the limit value of the derailment quotient was not exceeded for any running conditions and any bogie parameters.
4. All three bogie parameters were evaluated as suitable for operation in terms of running safety.

Acknowledgements

This research was supported by the Cultural and Educational Grant Agency of the Ministry of Education of the Slovak Republic in the project No. KEGA 031ŽU-4/2023: Development of key competencies of the graduate of the study program Vehicles and Engines.

“This publication was realized with support of Operational Program Integrated Infrastructure 2014 - 2020 of the project: Innovative Solutions for Propulsion, Power and Safety Components of Transport Vehicles, code ITMS 313011V334, co-financed by the European Regional Development Fund”.



EUROPEAN UNION
European Regional Development Fund
OP Integrated Infrastructure 2014 – 2020



MINISTRY
OF TRANSPORT
AND CONSTRUCTION
OF THE SLOVAK REPUBLIC

Author contributions

Conceptualization, V.I. and J.D.; methodology, V.I., J.D. and M.B.; software, V.I., J.D. and S.S.; validation, V.I., J.D. and M.B.; formal analysis, V.I. and S.S.; investigation, V.I., J.D. and M.B.; data curation, V.I.; writing—original draft preparation, V.I.; writing—review and editing, J.D.; visualization, V.I. and S.S.; project administration, J.D.; funding acquisition, J.D. All authors have read and agreed to the published version of the manuscript.

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