COMPARISON OF SELECTED OUTPUTS OF RAIL VEHICLE BOGIE VARIANT SOLUTIONS

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Abstract. Rail vehicles are important transport means, which are used for transportation of plenty of passengers as well as tons of goods almost on all continents in the world. Railway transport represents an effective and sufficiently reliable kind of transport, mainly when it comes to electric trains. Increasing transport speeds together with relative strict requirements on safety and costs needed for operation, maintenance and repairing make high demands on operational properties of rail vehicles. They are especially demands on their dynamical properties, at which, a bogie is a key subsystem of a rail vehicle. This presented research is focused on investigation of dynamical properties of a rail vehicle bogie. Specifically, it is a locomotive bogie. It is a prototype two-axle bogie intended to be mounted on a newly designed electric two-bogie locomotive. The main objective of this work is to compare the selected output quantities of three variant solutions of a bogie. These variants differ to each other by values of the weight of bogie components, the weight distribution as well as the pivot pins distance. The article presents a comparison of two output quantities, namely yaw angles of bogies and deformation of springs in bogies. Parameters of a bogie and a locomotive have been provided by a commercial producer of locomotives. Numerical analyses have been performed for specific operational conditions defined by the running speed in a curved track. There have been performed the number of simulation computations for various running speeds and curve radii, at which, the article includes only the particularly chosen data.

Keywords: locomotive, undercarriage, multibody model, numerical simulation, suspension parameters.

Introduction

Railway transport is one of the most important kinds of transport in many countries not only in the Europe, but also on other continents. There are specific characteristics of this kind of transport, among them, there is the most significant the possibility to transport large amounts of goods for longer distances and in case of passenger railway transport the large number of passengers at high running speed. Further, there are namely low friction and rolling resistance, which contributes to reduce the total running resistance. The current trend of the development of transport means is reflected by electrification of more and more track networks. They are locomotives with a traction source, which depends on available electrified infrastructure, however, on the other hand, these locomotives are more friendly to the environment thanks to the lower released exhaust emissions. Every newly designed locomotive has to be tested not only as a unit for the running properties in terms of safety, but also other important safety components, as the brakes [1-5], must be strictly tested and verified.

Materials and methods

A bogie is one of the most important subsystems of a rail vehicle. The main task and functionality of this subsystem is to support and to guide the rail vehicle in a railway track [6; 7]. Moreover, it is a crucial component regarding to the dynamics and safety of a rail vehicle [8; 9]. As this research is focused on investigation of a locomotive bogie, it is needed to note that the locomotive bogie also generates traction forces, braking forces and it has to carry a braking system. The investigated bogie is a two-axle bogie. It is a prototype of a newly designed bogie for an electric locomotive. It is obvious that successful implementation of the newly designed bogie (or the entire locomotive) requires to evaluate the bogie's prototype regarding to many outputs and that it will meet the strict requirements given both by the standards and by customers [10-13]. In case of a bogie prototype, many parameters are assessed and verified. Within the given range of the article, there are presented only two selected output quantities, namely the yaw angle and the deformation of springs. On the other hand, there are assessed and compared parameters not only for one designed parameter, but there are compared the results for three variants of the bogie. These variants are different from each other by some parameters, which are presented below.

The basic model is called VAR1 bogie (or VAR1). Its main important parameters are listed in Table 1.

Table 1

List of parameters of the analysed bogie, VAR1

Parameter	Value	Unit
Weight of the bogie frame (including 33% of the traction motor's weight)	6 480	kg
Weight of the wheelset (including 66% of the traction motor's weight)	3 550	kg
Weight of the drive-train	1 830	kg
Weight of the axlebox	137	kg
Wheel diameter	1.1	m
Distance of centre pivots	9.5	m
Wheelbase	2.4	m
Height of the bogie centre of gravity over the rail	0.581	m
Height of transmission of the traction/braking forces	0.34	m
Height of the floor level over the rail	1.4	m
Stiffness of primary suspension	$80.8 \cdot 10^4$	$N \cdot m^{-1}$
Stiffness of secondary suspension	$53 \cdot 8 \cdot 10^4$	$N \cdot m^{-1}$

Other two variants of the bogie are derived from the original variant VAR1. The second variant, called VAR2, is different from the original variant VAR1 by the mass properties of the main components, i.e. of the bogie frame, wheelsets and the traction motor and some dimensional parameters, namely the wheel diameter as well as the position of the centre of gravity and the height of transmission of traction and braking forces. In case of VAR2 bogie, the entire mass of the traction motor belongs to the bogie mass. Therefore, any part of the traction mass is a part of the wheelset mass. The described differences are listed in Table 2.

Table 2

List of parameters of the analysed bogie, VAR2

Parameter	Value	Unit
Weight of the bogie frame (including 100% of the traction motor's weight)	8 920	kg
Weight of thewheelset (including 0% of the traction motor's weight)	2 330	kg
Weight of the traction motor (including 100% of the gearbox weight)	2 150	kg
Wheel diameter	1	m
Height of the bogie centre of gravity over the rail	0.531	m
Height of transmission of the traction/braking forces	0.29	m

The last analysed and compared variant of the locomotive bogie is called VAR3. It comes again from the VAR1 bogie, however, only minimum parameters are changed. Namely, they are the distance of the centre pivots and the height of the floor level over the rail (Table 3). The rest of the parameters are the same with the VAR1 bogie parameters.

Table 3

List of parameters of the analysed bogie, VAR3

Parameter	Value	Unit
Distance of centre pivots	10	m
Height of the floor level over the rail	1.5	m

In this current state of the research, a comparison of the selected outputs of the rail vehicle bogie's variant solutions has been performed by means of simulation computations. For now, it is a study and the prototype can be manufactured based on the recommendations coming from the research findings. Simulation computations and analyses of the selected parameters (outputs) have been carried out in the Simpack software package. It is the multibody system (MBS) software and it is widely used for the research and practical purposes not only in the field of rail vehicles [14-17], but also for research of other kind of transport and handling machines [18; 19]. Its focus is enhanced by the fact, that the software database includes the specialized modelling elements for calculation of the wheel/rail phenomenon [20; 21], further it includes wheel-pair and wheelset modelling elements for setting-up a proper position of the wheelset in a track axis and other needed modelling elements. Regarding the wheel/rail contact [22-24], the known and the most often used algorithm FASTSIM [25-27] has been applied for calculation of the wheel/rail issue in the created model. The created MBS model of a bogie consists of rigid bogies interconnected by massless flexible elements. Rigid bodies are wheelsets, axleboxes, the bogie frame and the bolster. Massless flexible elements serve for modelling the springs and dampers and they restrain proper positions of individual bodies to each other. The set-up MBS model of the bogie is shown in Fig. 1. It can be noticed that the geometry of individual bodies of the bogie, such as wheelsets, axleboxes, the bogie frame and bolster are adopted from the software database and no CAD models are implemented. The entire model of the locomotive is depicted in Fig. 2. As it can be seen, this model includes two bogies (Fig. 1) and a body of the locomotive. The distance of the centre pivots of both bogies is defined according to Table 1 to Table 3.

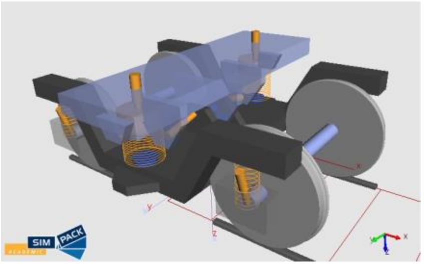

Fig. 1. **MBS model of the bogie**

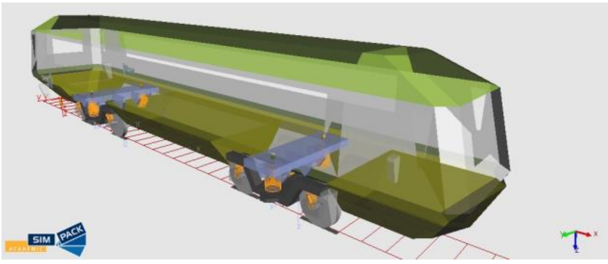

Fig. 2. **MBS model of the locomotive**

The change of the parameters of variants VAR1, VAR2 and VAR3 has been done by means of the advantageous functionality of the software called "substitution variables". It means that it is not necessary to change every number for the parameters with the same characteristics (e.g. the wheelset mass, wheel diameter, etc.), but the user changes only one number and parametrisation of the model automatically changes this number for all corresponding bodies.

The numerical analyses have been performed for the locomotive curving. There have been considered the number of operational conditions (running speeds, curve radii, sampling rate etc.). However, the allowed range of the contribution allows to present only limited number of the results. On the other hand, there are selected the most important results and, at the same time, it seems clearer for a reader.

The presented research included comparison of these selected output quantities:

- angular yaw deflections of bogies against the locomotive body, designated as "Analysis_A";
- vertical deflections of springs, designated as "Analysis_B".

The next section includes the results for two running conditions as following:

- the curve radius R_1 = 500 m, the speed of v_1 = 120 km·h^{-1}, designated as "Rc_I";
- the curve radius R_2 = 120 m, the speed of v_2 = 35 km·h^{-1}, designated as "Rc_II".

Results and discussion

This section presents the results of the simulation computations for the Analysis A and Analysis B for both running conditions and for all three variants of the bogie (VAR1, VAR2 and VAR3).

Fig. 3 to Fig. 8 show the results of the Analysis A for the described running conditions and for three variants of the bogie, respectively, at which, these graphs show the results for the front bogie (considered in the running direction).

The results of the Analysis_A for the VAR1 bogies show (Fig. 3 and Fig. 4) that the amplitudes of angular yaw deflections are higher for higher running speeds (despite of a higher curve radius), which can lead to lower stability of the locomotive. However, in small radii, it is necessary to decrease the running speed, which is reflected by the yaw range.

In case of the VAR2 bogie variant, it is possible to observe (Fig. 5 and Fig. 6) that the angular yaw deflection has higher values. It means lower running stability of the locomotive, mainly in case of running at higher running speeds. On the other hand, when the derailment quotient will be in the permissible values, higher yaw movement indicates lower wear of the wheel and rails in a curve [28-31]. However, the assessment of the running safety is the sole issue solved in the other contribution within this proceeding.

The last assessed case is the VAR3 variant of the bogie. As it can be seen in Fig. 7 and Fig. 8, the change of the centre of gravity position and the height of the floor do not affect as strongly as the change of the weight of the components (VAR2).

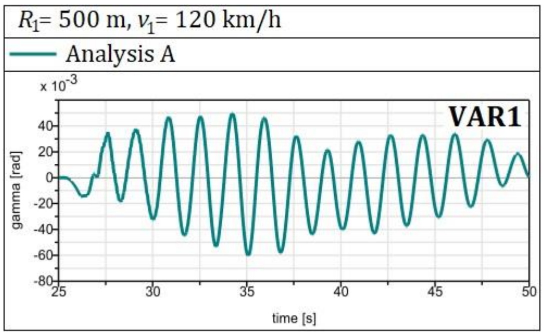

Fig. 3. **Results of the Analysis_A for the VAR1 bogie, Rc_I**

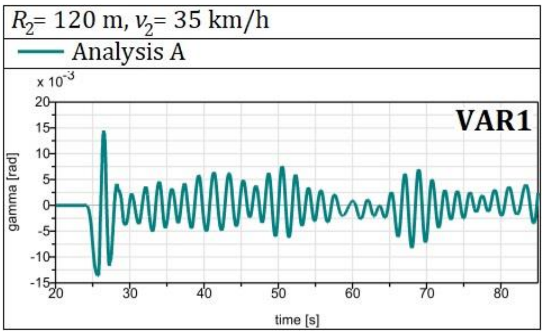

Fig. 4. **Results of the Analysis_A for the VAR1 bogie, Rc_II**

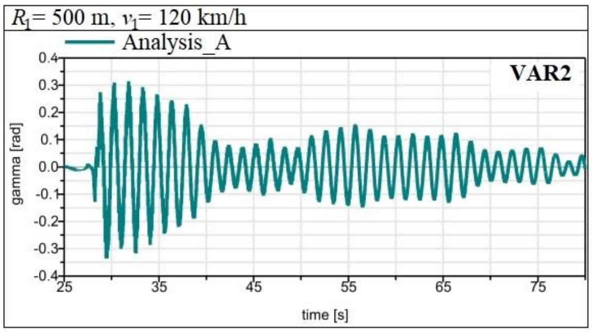

Fig. 5. **Results of the Analysis_A for the VAR2 bogie, Rc_I**

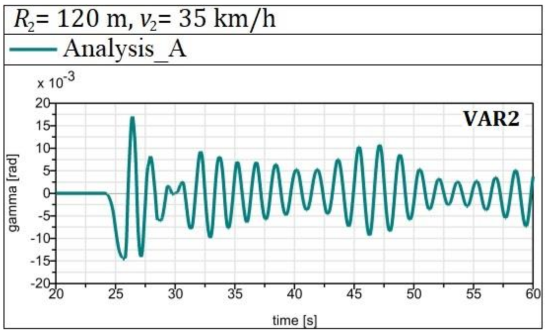

Fig. 6. **Results of the Analysis_A for the VAR2 bogie, Rc_II**

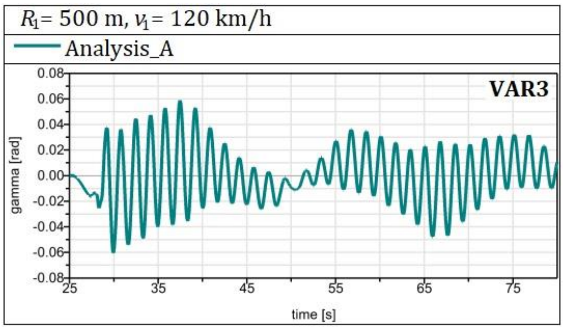

Fig. 7. **Results of the Analysis_A for the VAR3 bogie, Rc_I**

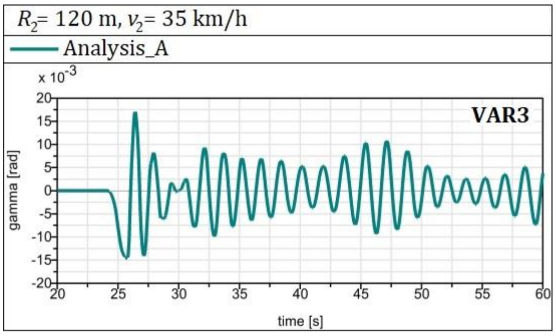

Fig. 8. **Results of the Analysis_A for the VAR3 bogie, Rc_II**

Further graphs (Fig. 9 to Fig. 14) contain the results of the Analysis_B (vertical deflection of springs). For assessment the springs of the right wheels of the front bogie in the running direction are selected. As the left curve is modelled, these springs are supposed as external.

It is possible to identify from the obtained results that the deflection of the springs of the front and the rear wheel of the front bogie is approximately the same. It is observed for both running conditions, Rc_I and Rc_II. It is assumed that it is caused by the used connecting rod guidance of the wheelsets. It can be seen for all three variants of the bogie (VAR1, VAR2 and VAR3). The waveform of the deflection of the front wheel (the green curve) has a similar waveform of the deflection of the rear wheel (the red curve). Regarding the spring deformations, there have been observed only slight differences for individual variants of the bogie for various curve radii and for various running speeds.

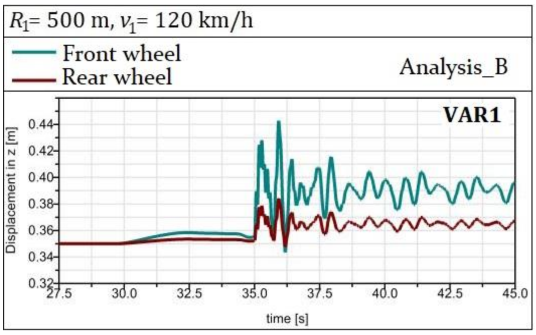

Fig. 9. **Results of the Analysis_B for the VAR1 bogie, Rc_I**

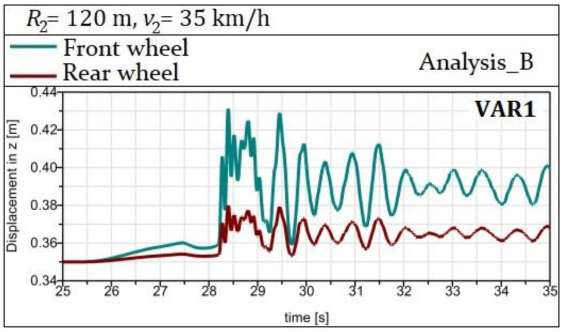

Fig. 10. **Results of the Analysis_B for the VAR1 bogie, Rc_II**

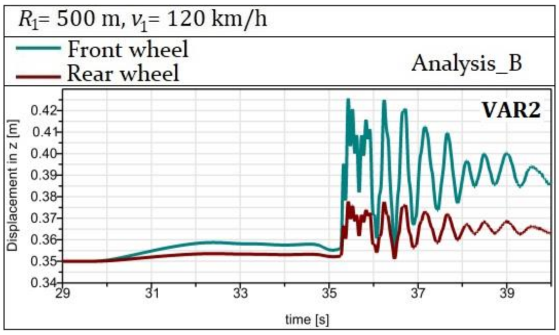

Fig. 11. **Results of the Analysis_B for the VAR2 bogie, Rc_I**

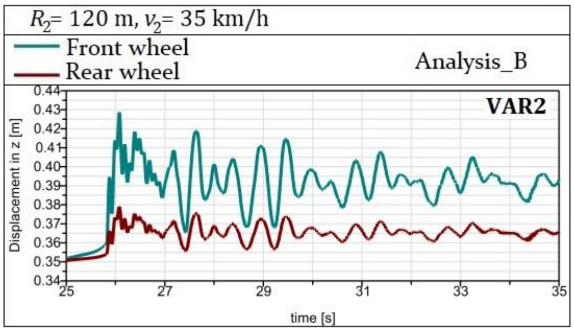

Fig. 12. **Results of the Analysis_B for the VAR2 bogie, Rc_II**

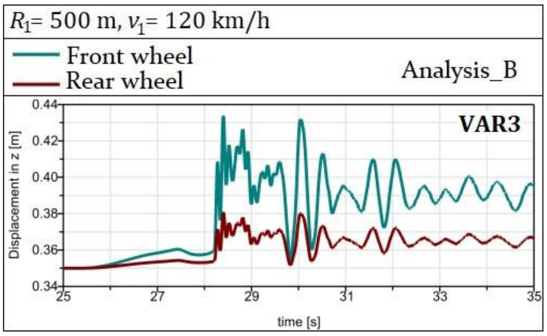

Fig. 13. **Results of the Analysis_C for the VAR3 bogie, Rc_I**

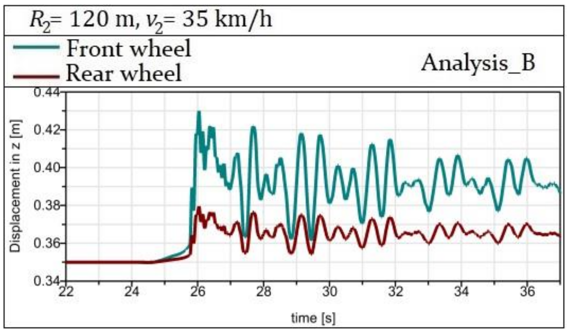

Fig. 14. **Results of the Analysis_B for the VAR3 bogie, Rc_II**

Conclusions

1. The MBS model of the locomotive bogie prototype has been created and analysed.
2. Two output parameters have been selected, i.e. the angular yaw deflection of the bogie and vertical deflections of the front bogie springs. The maximal value of the yaw angle was of 0.31 rad and the maximal displacement of the spring was 0.442 m.
3. The achieved values of the vertical deflections of the front bogie springs have shown that there are not significant differences between the three assessed variants of the bogie (VAR1, VAR2, VAR3).
4. A comparison of the waveforms of the angular yaw deflection of the front bogie has shown that from this selected criterion, the variant VAR1 seems to be the most suitable variant of the assessed locomotive bogie.

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Author contributions

Conceptualization, J.D. and V.I.; methodology, J.D., M.B. and V.I.; software, J.D., V.I. and S.S.; validation, J.D. and M.B. formal analysis, J.D., M.B. and V.I.; investigation, J.D., M.B., V.I. and S.S.; data curation, V.I. and S.S.; writing – original draft preparation, J.D.; writing – review and editing, M.B. and S.S.; visualization, J.D. and V.I.; 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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