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COMPARATIVE SIMULATIONS OF GUIDING BEHAVIOUR OF AN ELECTRIC LOCOMOTIVE

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Abstract: *Computer simulations of vehicle running performance create an integral part of research and development of new rail vehicles. The simulations allow e.g. optimization of dynamic behaviour of the vehicle and it may be possible to use them in the certification process instead of results of some track tests in the future. Nowadays, many commercial as well as non-commercial simulation tools are commonly used for these purposes. However, verification of the computational model and validation of its results represent the most significant problems which must be solved to gain relevant data from the simulations. In the framework of solving the R&D project "Competence Centre of Rail Vehicles" of the Technology Agency of the Czech Republic, the attention of the work package WP5 is paid to this problem of model validation among others. This paper deals with results of simulations of an electric locomotive through curves of various radii which were performed by means of four simulation tools (SJKV-L3A, SIMPACK in versions 8900 and 9.4-build65 and ADAMS/VI-Rail) at three different workplaces (Jan Perner Transport Faculty of the University of Pardubice, VÚKV a.s. and ŠKODA Transportation a.s.). The simulation results allow comparison of these different models as well as revelation and clarification of problematic aspects of the individual models.*

Keywords: Rail vehicle dynamics, Comparative simulations, Guiding behaviour, Model validation.

1. Introduction

Nowadays, computer simulations are commonly used for the assessment of rail vehicle dynamics in the design stage of new vehicles and allow investigation of influence of many parameters on the dynamic behaviour of the vehicles (as it is shown e.g. in the paper by Michálek and Zelenka (2013)). It is possible to optimize e.g. characteristics of joints (springs, dampers, wheelset guiding etc.) and improve the running and guiding behaviour of the vehicle in this way. In the future, the next field of using the computer simulations could be the replacement of a certain part of track tests realized in the framework of certification process by the simulation results because new drafts of relevant standards (especially a new version of the EN 14363) permit such approach which could make the certification process shorter and less expensive. During the process of investigation of rail vehicle dynamics by means of computer simulations, the question of model validation is very important. Only if a validated computational model is used, the simulation results can reliably prove about the dynamic properties of a real vehicle. And in case of using the simulation results as a proof of the safety in the certification process, this question becomes more important than ever before.

The model validation is a very demanding process (see e.g. the paper by Polách et al. (2013)) at which it is necessary to know how the computational model works. However, a detailed knowledge of algorithms, on which the model is based, could be a problem, especially in case of commercial simulation tools. This is also the reason why an important part of solving the R&D project "Competence Centre of Rail Vehicles" in the work package WP5 is focused on the comparative simulations of rail vehicle running performance. More detailed knowledge of different simulation tools, which are being used by the project partners, together with clarification of problematic aspects, which occur during the realization of computer simulations, should enable easier validation of the models.

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2. Computational Models

For purposes of the comparative simulations of vehicle running performance, results of four different simulation tools, which are being used by three project partners nowadays, were taken into account:

- SJKV-L3A, i.e. a version of the original multi-body simulation software SJKV, which has being developed at the Detached Branch of the Jan Perner Transport Faculty of the University of Pardubice in Česká Třebová, which is intended for simulations of a four-axle electric locomotive (more detailed information about this software can be found e.g. in the paper by Michálek and Zelenka (2011)).
- SIMPACK 8900, i.e. an older version of the commercial simulation tool by SIMPACK AG which is also being used at the Jan Perner Transport Faculty of the University of Pardubice.
- SIMPACK 9.4-build65 64 bit, i.e. a newer version of the commercial simulation tool by SIMPACK AG which is being used by the company VÚKV a.s.
- ADAMS/VI-Rail, i.e. the commercial simulation tool by VI-Grade built upon the MSC Software product MSC ADAMS which is being used by the company ŠKODA Transportation a.s.

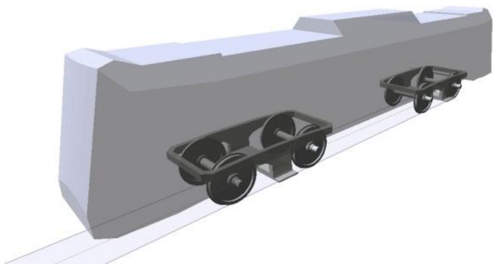

Fig. 1: Model of the locomotive in SJKV-L3A by the Jan Perner Transport Faculty.

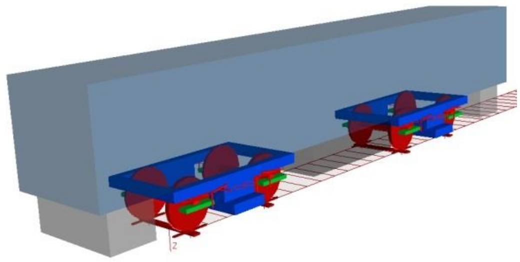

Fig. 2: Model of the locomotive in SIMPACK 8900 by the Jan Perner Transport Faculty.

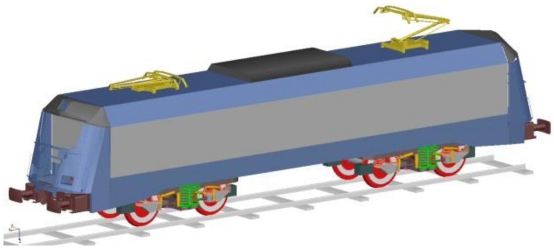

Fig. 3: Model of the locomotive in ADAMS/VI-Rail by ŠKODA Transportation.

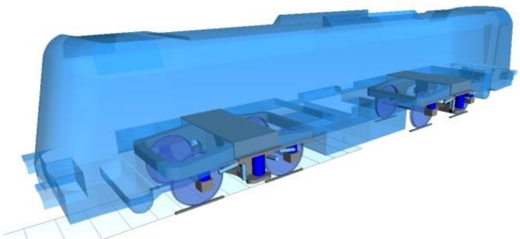

Fig. 4: Model of the locomotive in SIMPACK 9.4-build65 64 bit by VÚKV.

A model of a modern four-axle electric locomotive was chosen as a reference vehicle. All the project partners had the same input data (parameters of the locomotive, i.e. masses and inertia moments of individual constructional parts, characteristics of joints etc.) at their disposal to apply them into their models. All the computational models, which were used for the comparative simulations, are depicted in Fig. 1 up to Fig. 4.

In the first stage of realization of comparative simulations, the attention was paid to the guiding behaviour of the locomotive. The term "guiding behaviour of a rail vehicle" covers dynamic properties of the vehicle during its run through a curve (see the paper Michálek and Zelenka (2011), for example). Parameters of the track as well as parameters of the wheel/rail contact and vehicle speed were defined uniformly again. Specifically, following parameters of simulations were taken into account:

- Track with curves with 5 different radii from a range of 250 m up to 1500 m.
- Ideal track without irregularities.
- Friction coefficient in wheel/rail contact 0.4.
- Vehicle speed corresponding to cant deficiency of 130 mm and 165 mm.
- Wheel/rail contact geometry corresponding to wheelsets with theoretical wheel profiles ORE S1002 and track with theoretical rail profiles 60E1 with rail inclination 1:20 and 1:40.

3. Simulation Results

The complete simulation results including their assessment are presented in the report by Zelenka et al. (2013). In this stage, only the stable (quasistatic) values of chosen quantities observed during the run of the vehicle in full curve were compared. The following quantities were observed:

- Quasistatic guiding forces acting on each of wheels.
- Quasistatic wheel forces (wheel loads) acting on each of wheels.
- Angles of attack of each of wheelsets.
- Angles of bogie rotation to the vehicle body about the vertical axis.
- Lateral acceleration on the vehicle body (in its centre of mass).
- Roll angle of the vehicle body (about its longitudinal axis).

In Fig. 5, there is shown an example of results of the comparative simulations. There are presented the quasistatic values of guiding forces, angles of attack and angles of bogie rotation to the vehicle body about the vertical axis in the graphs. These results correspond to the simulations of run through a right hand curve with radius of 300 m at cant deficiency of 165 mm (i.e. at speed of ca. 90 km/h); wheel/rail contact geometry is determined with the rails 60E1 with inclination of 1:40. It is evident that the computational models of all involved project partners provide relatively close results of all the depicted quantities in this case.

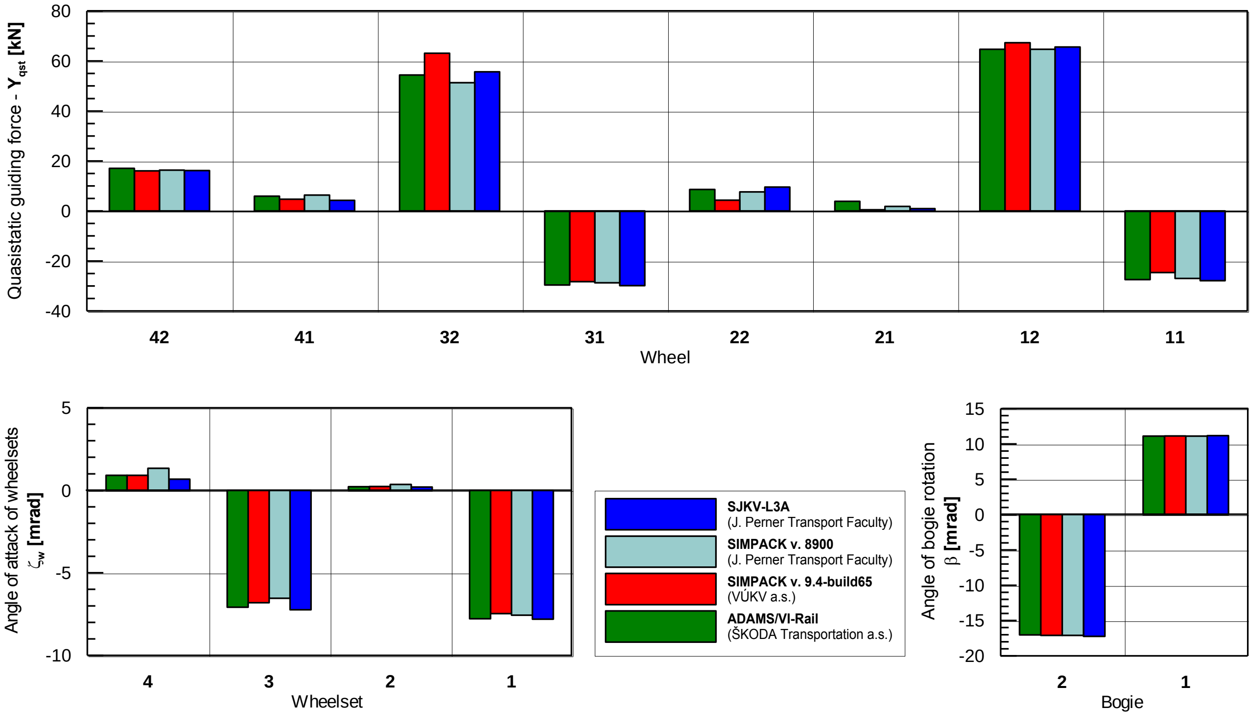

Fig. 5: Example of results of comparative simulations – quasistatic guiding forces, angles of attack and angles of bogie rotation to the vehicle body about the vertical axis during the run through a 300 m curve (cant deficiency: I = 165 mm; wheel/rail contact: ORE S1002 – 60E1/1:40).

On basis of the realized comparative simulations of guiding behaviour of the investigated electric locomotive, following observations can be stated:

- From the point of view of dependency of the observed quantities on the curve radius, all used computational models provide similar trends in dynamic behaviour of the locomotive.
- On the “structural level” (i.e. the behaviour of the vehicle body, whole wheelsets and bogies assessed by means of angles of attack and angles of bogie rotation to the vehicle body about the vertical axis), all computational models show good agreement in all investigated cases.
- Generally, the agreement of results of the used computational models is better in case of smaller curve radii and the wheel/rail contact geometry corresponding to the rails with inclination of 1:20.

4. Conclusions

This work is focused on results of the comparative simulations of dynamic behaviour of an electric locomotive which were performed by means of four different multi-body simulation tools at three workplaces in Czech Republic. In the described stage, the attention was paid only to the simulations of vehicle running performance in curves on ideal track without irregularities. Regardless, the gained data represent a large set of simulation results and show that all the used computational models provide similar results which can prove about the dynamic behaviour of a real vehicle.

However, some differences between the simulation results also occurred, especially in the values of quasistatic guiding forces in curves with larger radius. Because all the models show similar dynamic properties on the "structural level", the reason of the different results can rather lie in the mode of wheel/rail contact modelling (i.e. processing of the wheel/rail contact geometry, consideration of one-point vs. multi-point contact, used theory of tangential forces etc.) than e.g. in the modelling of individual bodies or joints (springs, dampers etc.). Clarification of these problematic points should create the next part of the verification process of the computational models.

Besides to that, the next work will be focused on comparative simulations of vehicle running performance on a real track, i.e. on a track with irregularities. In this way, the rail vehicle dynamics (or more precisely: the dynamic behaviour of the computational models) can be assessed more complexly than in case of evaluation of the steady (quasistatic) values of observed quantities in curves as it was performed in this first stage. Then, the next target will be an investigation of the dynamic behaviour of the computational models at higher speeds, i.e. the question of stability of run.

The general aim of this work is a validation of the computational multi-body models of rail vehicles. The last draft of the European standard EN 14363 as well as the UIC Code No. 518:2009 and also e.g. the Technical Specification for Interoperability (TSI) of freight wagons (i.e. the Commission Regulation (EU) No. 321/2013) permit a substitution of a certain part of the track tests, which have to be performed in the framework of the certification process of new or modernized vehicles nowadays, by the computer simulations under certain conditions. This so-called "virtual certification" could have a potential to make the railway vehicles less expensive and more competitive. However, the model validation, which is based on comparison of results of track tests and simulation results, creates an essential condition for the use of simulation results in the certification process. Besides to that, all the problems of the model validation have not been fully solved yet. Therefore, the comparative simulations realized in the framework of activities of the WP5 of the "Competence Centre of Rail Vehicles" and their results should help with the model validation by means of clarification of functioning of different computational models at a wide range of various conditions.

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