SIMULATION OF FREIGHT WAGON RUNNING ON TEST TRACK AT DIFFERENT SPEEDS AND LOAD DISTRIBUTION FROM POINT OF VIEW OF DERAILMENT SAFETY AND LATERAL FORCES

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Abstract. The paper is focused on a simulation of a railway freight wagon running on a test track with the given parameters. The railway freight wagon is running at different speeds and with different loads, at which the simulation is analysed from the point of view of derailment safety and lateral forces acting in the wheel/rail contact and individual bogies. The load distribution on the given railway freight wagon plays an important role in terms of the investigated parameters, and therefore it is compared, how the railway freight wagon behaves on the given track depending on a particular load distribution. The dynamic model was created in the SIMULIA – SIMPACK multi-body simulation commercial software. Components of a bogie were made in three-dimensional computer-aided design software and subsequently were imported into the multi-body simulation software. The theoretical foundations of the forces acting on the bogie, such as the vertical load, slip, or lateral forces of the wheelset, are covered and the test track is also described. The concept of derailment safety and the forces, that are essential for these parameters, are defined. The basic parameters of the given railway freight bogie are mentioned together with its most frequent use. The article also contains a description of a three-dimensional dynamic model of a freight railway wagon. The results are evaluated and compared for each speed and load distribution. The findings will be appropriate for advancing academic research and development.

Keywords: freight wagon, simulation, derailment safety, lateral forces.

Introduction

It is well known that the transportation of goods in Europe is dominated mostly by trucks. In fact, for distances greater than 150 kilometres, trucks move around 1.5 billion tonnes per kilometre, while freight trains move only about 0.4 billion tonnes of goods per kilometre. This greatly increases the need for fossil fuels per ton of cargo transported [1-3].

Due to ever-increasing environmental regulations which have to be fulfilled the transportation of goods by freight trains looks like a very promising form of transport that is why in the past decade the importance of railways is increasing again and it is necessary to continue in this trend. The European Union is introducing new requirements almost every year and it is therefore up to how we adapt.

The transfer of a larger amount of goods to the railway can be achieved by integrating freight trains fully into the passenger traffic because nowadays passenger trains are preferred. This slows freight trains considerably which increases the price and time needed. It will be crucial to make sure that freight wagon dynamics allow for reliable and safe track operation [4; 5].

The first step for performing a computer simulation is to create a representative model which corresponds to reality and therefore will provide as realistic results as possible, considering the computing power. Dynamic properties of a vehicle are very important because they affect a lot of forces that act during running a vehicle [6; 7].

The main goal of this research is to investigate how load distribution and speed affect the forces which act during vehicle running, especially lateral forces usually labelled as Y, and vertical loads usually labelled as Q, which are important in terms of derailment safety. The dynamic forces rise with increased vehicle speed, and therefore the focus will be on load distribution [7; 8].

Materials and methods

During a vehicle running, there are a lot of forces that act on the vehicle and these forces must be transferred into the rails. These forces can be divided into three main categories, lateral, longitudinal and vertical [9].

Lateral forces act in a direction that is perpendicular to the track axis. This axis is usually labelled as “y”. One of these forces is called the guiding force and it is marked as Y. Guiding forces are created

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while the rail vehicle is running through the curve. This force is negotiating force that acts on the bogie and inertial force, also [10-12].

Vertical forces act in the direction of gravitational acceleration. This direction is usually marked as axis "z" and a positive direction coincides with gravitational acceleration. Vertical forces are mainly dependent on the weight of cargo that is transported. A significant role plays the irregularity of the track and wheel, also. One way how vertical forces can be affected is by suspension and damping [13-15].

Derailment is one of the most common types of train accidents. It causes damage to the rolling stock, and infrastructure and usually being responsible for long distribution in passenger and freight services. That is why it is important to develop safety systems. The derailment coefficient is the quantity according to which we can determine the safety of rail vehicles running through the curve. The derailment coefficient is calculated according to formula (1) [16; 17].

$$\frac{Y}{Q}=\frac{N.\sin\beta-N.f.\cos\beta}{N.\cos\beta+N.f.\sin\beta}=\frac{\tan\beta-f}{1+f.\tan\beta}, \tag{1}$$

where N – normal force in the contact surface with the rail, N;
f – friction coefficient;
β – angle of the wheel to the horizontal axis, ◦.

The critical value Y/Q is 1.2 [18]. The dynamical model was created in multi-body simulation (MBS) software called SIMULIA-SIMPACK. This software allows engineers and researchers to model the motion of any mechanical or mechatronical system. To predict and depict dynamic motion, coupling forces, and stresses, it is possible to create and solve virtual 3-dimensional models [19; 20].

The model consists of two bogies which were created in CAD software and were imported into SIMPACK. The links between components of these bogies were then created in MBS software. On the top of the bogies the superstructure of the platform wagon is located. On the platform are three blocks which represent the transported cargo. The model is shown in Fig. 1.

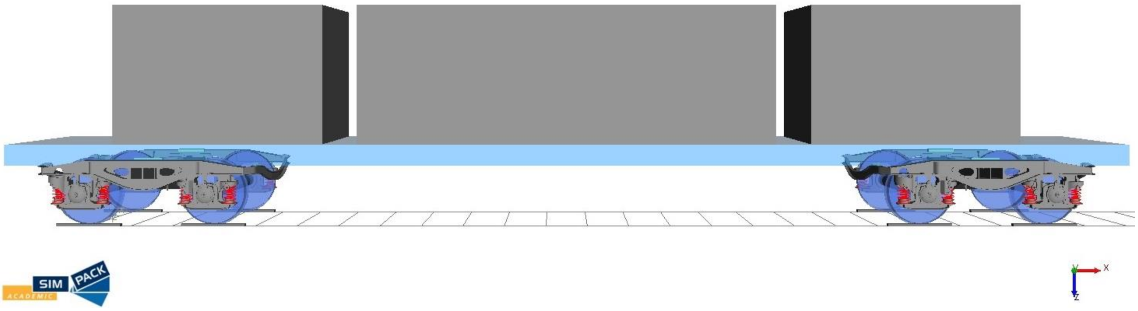

Fig. 1. **MBS model**

The bogie is a model of TVP2007, which is a derivate of Y25, which is more "track friendly". The Y25 and its derivates are one of the most used freight bogies in central and western Europe. The bogie is shown in Fig. 2. The bogie has a standard gauge of 1435 mm, standard profile S1002 and a wheel diameter is 460 mm. Also, there are used two Lenoir friction dampers for each wheel, which means there are eight of these dampers in total in the model of the bogie.

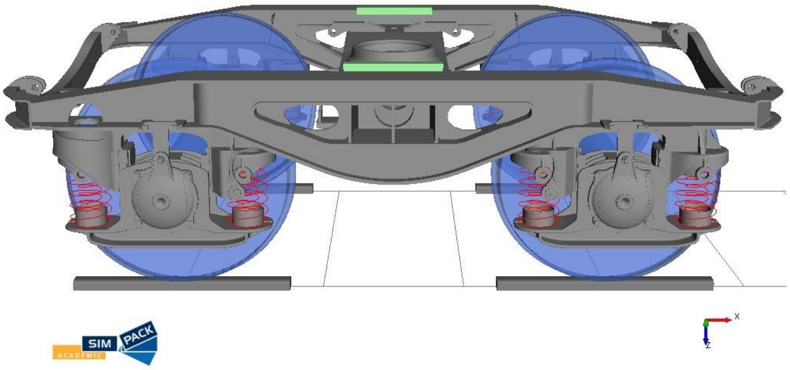

Fig. 2. **TVP2007 bogie MBS model**

The simulation was done for the speed of 25 km·h^{-1} and 50 km·h^{-1}. In the first simulation, the load distribution was equal. In the second run, the load distribution was changed to 60% on the front bogie. These terms apply to both speeds.

The track uses a standard gauge of 143 5 mm. The rail profile is UIC 60 on both rails. The track consists of two curves with a diameter of 250 m and a length of 100 m. Clothoid transitions have a length of 50 m and go from a radius of 0 m to 250 m or vice versa from 250 m to 0 m radius. A straight line in front and after these curves. The front straight has a length of 100 m. The straight between the curves has a length of 100 m, too. The third straight has a length of 1000 m. Superelevation is not used on the track.

The sample rate of 100 Hz was used, and the time changed depending on the speed of the vehicle. The SODASRT 2 integration method was used, and the wheel-rail contact is determined by the FASTSIM method. The track parameters are shown in Fig. 3.

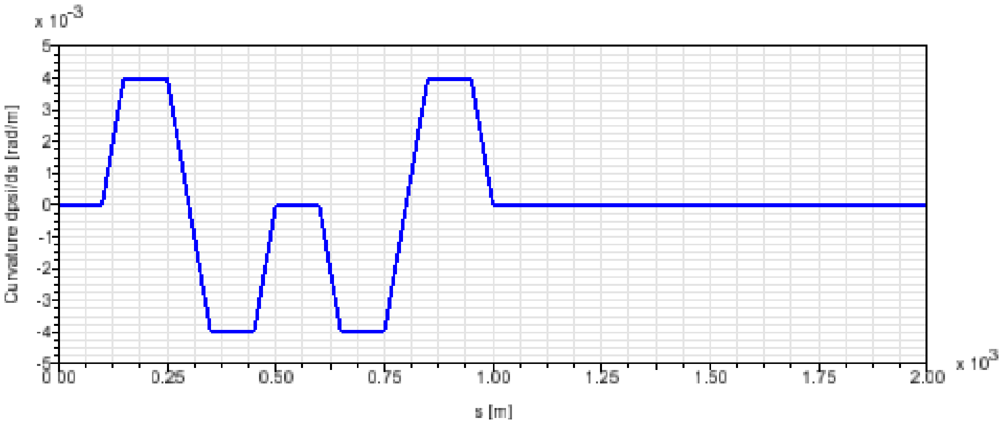

Fig. 3. **Track parameters**

Results and discussion

The derailment coefficient of the front guiding wheelset for a speed of 25 km·h^{-1} and evenly distributed load is shown in Fig. 4. As we can see, the derailment coefficient for a speed of 25 km·h^{-1} or 6.95 m·s^{-1} reaches the maximum value of 0.46. As mentioned above, the critical value for the derailment coefficient is 1.2. Because of that it is possible to say that the vehicle is able to pass the track with given parameters and evenly distributed cargo with a weight of 60 tons.

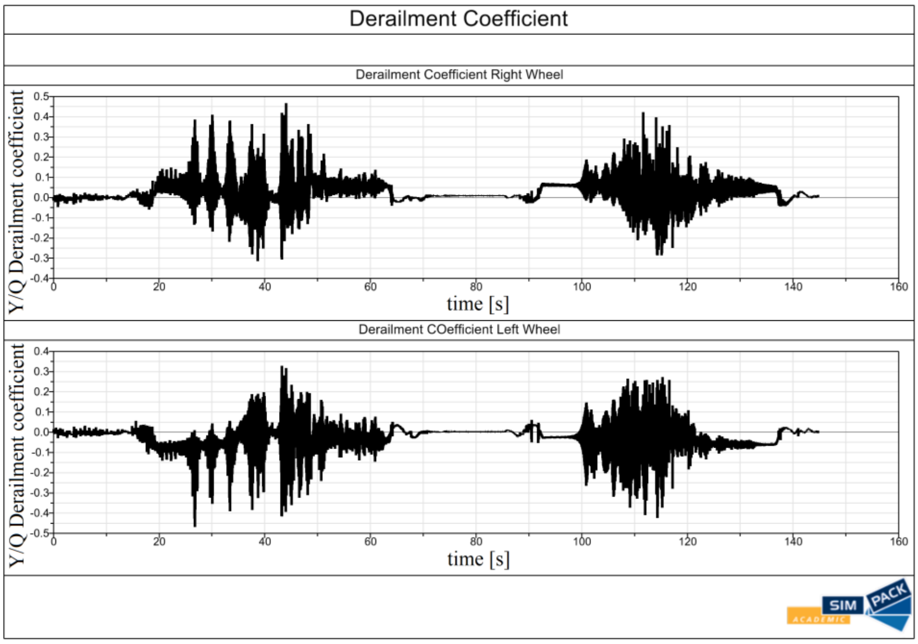

Fig. 4. **Derailment coefficient 25 km·h^{-1}, evenly distributed load**

The derailment coefficient of the front guiding wheelset for a speed of 25 km·h^{-1} with 60% load on the front bogie is shown in Fig. 5. From Fig. 5 we can assume that the derailment coefficient for the front load reaches a maximum peak at 0.7, which is slightly higher than it was with evenly distributed load. The vehicle is still able to pass the track with the given conditions as the value of the derailment coefficient is below the given critical value.

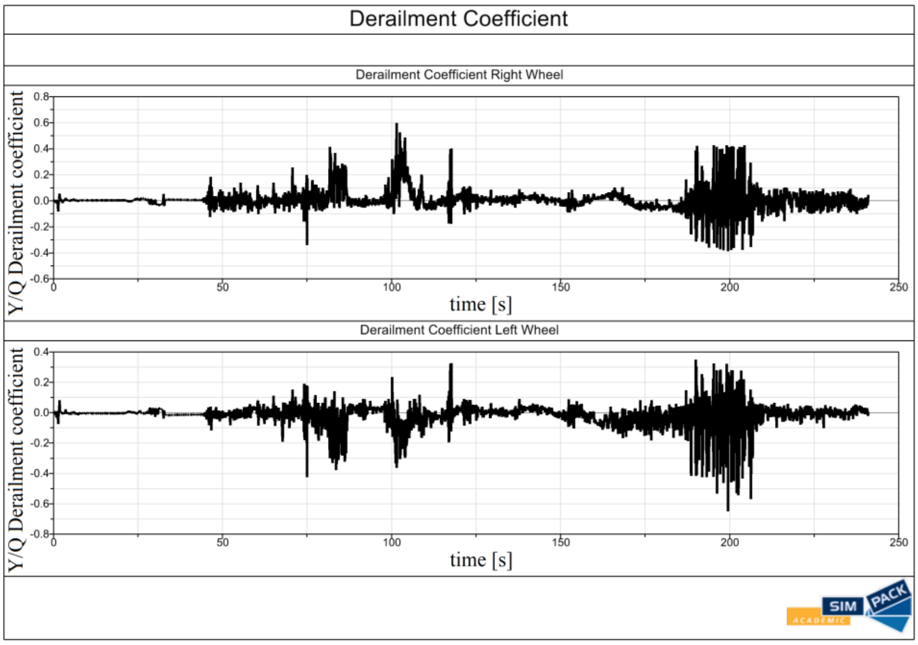

Fig. 5. **Derailment coefficient 25 km·h^{-1}, 60% load in front**

The derailment coefficient of the guiding wheelset for a speed of 50 km·h^{-1} with evenly distributed load is shown in Fig. 6. The derailment coefficient reaches the maximum value of 0.65 for the speed of 50 km·h^{-1} or 13.89 m·s^{-1} and evenly distributed cargo with a weight of 60 tons. The maximum value of the derailment coefficient is below the critical value and the vehicle is able to pass the track with the given condition. As we can see, the maximum value is higher than it was for the speed of 25 km·h^{-1} and evenly distributed load.

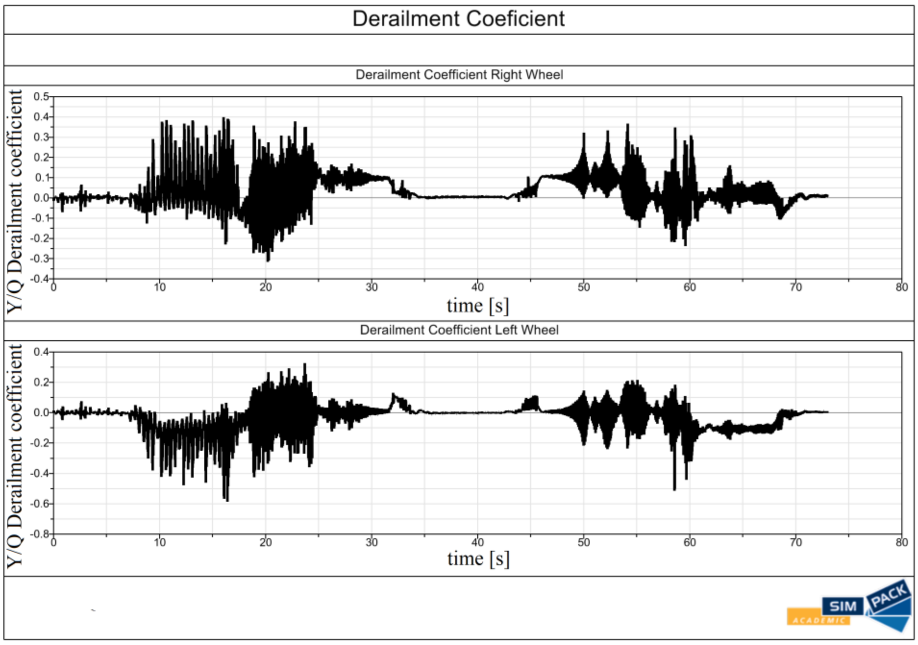

Fig. 6. **Derailment coefficient 50 km·h^{-1}, evenly distributed load**

The derailment coefficient for a speed of 50 km·h^{-1} with 60% load on the front bogie is shown in Fig. 7.

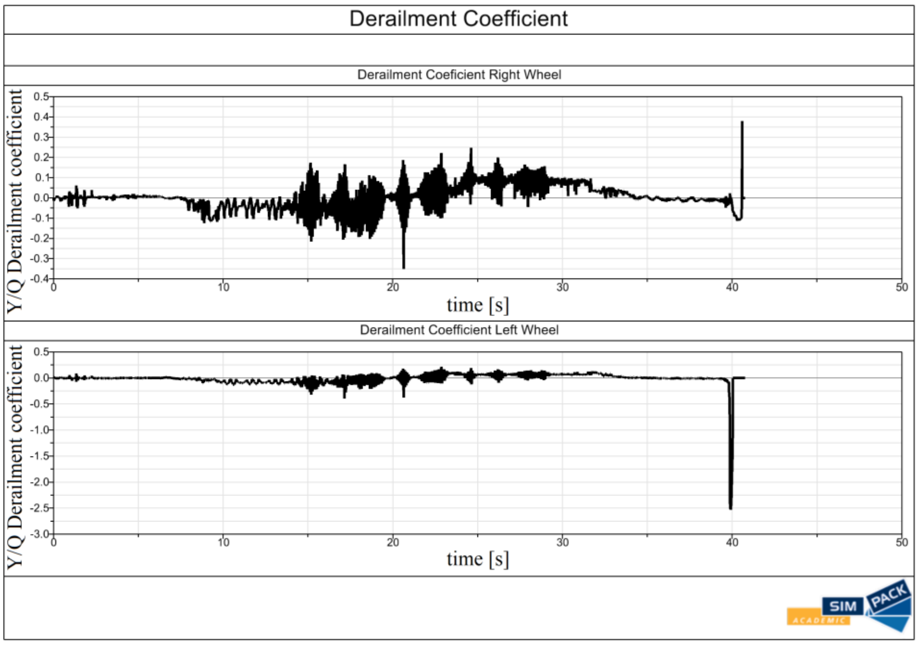

Fig. 7. **Derailment coefficient 50 km·h^{-1}, 60% load in front**

Fig. 7. shows that the maximal derailment coefficient on the front bogie reaches the maximum value of 2.5. The maximum value was reached on the left wheel after 40 seconds of the ride. As it was mentioned above, the critical value of the derailment coefficient is 1.2. The maximum value is more than 2 times higher. We can say that with 60% of the load on the front bogie and given condition on the track the vehicle is not able to pass the track and after the derailment coefficient hit the top the vehicle derailed.

According to the simulation results we can say that the speed and load distribution play a role in the value of the derailment coefficient. If the numbers are compared for evenly distributed load, the maximum value for 25 km·h^{-1} was 0.46, and for 50 km·h^{-1} it was 0.65 for the given track and its parameters. The maximum value with 60% load distribution on the front bogie for the speed of

25 km·h^{-1} was 0.7 and for the speed of 50 km·h^{-1}, the derailment coefficient was 2.5 for the given parameters of the track.

As we can see, with the increased speed of the vehicle the value of the derailment coefficient also increases but the vehicle was able to pass the track with evenly distributed load. If we compare the values with unevenly distributed load, they are much higher and unevenly distributed load for the higher speed may cause derailment of the vehicle.

Conclusions

The derailment coefficient was analysed in the paper from the point of view of load distribution for different speeds, specifically for 25 km·h^{-1} and 50 km·h^{-1}. Even distribution and 60% of the load on the front bogie were used for both speeds. The weight of the cargo was 60 tons, and the superstructure was located on the most common freight bogie. Evaluation of the results was made by SIMPACK Post. From the simulation, as we compare the found results for each speed and load distribution, we can say that load distribution and speed can play a significant role in derailment safety. For the speed of 25 km·h^{-1} the difference is not so significant and the vehicle can pass the track with both load distributions. For the speed of 50 km·h^{-1} and evenly distributed load, the derailment coefficient is slightly higher but still under the critical value. But for the load distribution on the front bogie the derailment coefficient jumps to 2.5. This value is over the limit and the vehicle derailed.

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