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Procedia Engineering 134 (2016) 23 – 29

Procedia Engineering

www.elsevier.com/locate/procedia

9th International Scientific Conference Transbaltica 2015

Simulation of Railway Vehicle Dynamics in Universal Mechanism Software

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Abstract

This abstract describes the experience of a railway vehicle dynamics simulation using Universal Mechanism software. The software system Universal Mechanism (UM) was created for computer simulation of kinematic and dynamic processes of different mechanical systems, it is especially efficient for railway rolling stock simulations tasks. UM software includes different models (simplified and 3D models) of railway rolling stock and different software tools for simulation of railway vehicle dynamics. Researchers at the VGTU Railway Transport Department constantly and successfully use the UM for the educational and research purposes. For example the UM software was used for the simulation of a railway accident on the track between stations Gaižiūnai and Skaruliai. In this case six wagons derailed in very complicated circumstances. To determine the actual cause of the accident, the computer two stage model of the accident was created: at the first stage the simplified model was created and at the second stage the 3D simulation of the train dynamics was made. After creating the dynamic model of the train and analyzing the results, it was determined that the UM simulates only a single braking process of the train. That does not reliably recreate the conditions of the train and the train longitudinal conditions in the simulation process are absolutely unpredictable. That distorts the results of the simulation. Working in collaboration with the manufacturer of the UM – Laboratory of Computational Mechanics of Bryansk State Technical University, the UM software has been supplemented with the new feature which creates multibraking conditions of the train. The new version of the UM was made to re-model various train braking processes (service braking, releasing and emergency braking) with full restoration of black box tape recordings. This suggests that the results of modeling are absolutely true and can accurately determine the cause of the derailment. The simulation experience not only enhances the UM software abilities, but also created models allow to simulate lon-gitudinal dynamic processes of all train running regimes.

Peer-review under responsibility of the organizing committee of Transbaltica 2015

Keywords: railway vehicle; braking processes; dynamics simulation.

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Peer-review under responsibility of the organizing committee of Transbaltica 2015
doi:10.1016/j.proeng.2016.01.033

1. Introduction

In recent years the length and weight of freight trains in the JSC "Lithuanian Railways" significantly increased with the use of powerful new or modernized (remotorizated) diesel locomotives. In some directions the weight norm of freight trains was increased up to 8000 tons and length up to 61 relative wagons (AB "Lietuvos geležinkeliai", 2014). As a test, double connected trains appeared in railway traffic. These arrangements not just effectively increase the capacity of the railways, but also increase the probability of railway safety violations. Operation of long and heavy freight trains in the event with an unfavorable combination could create wagons derailment or rupture of coupling devices. Therefore, in case of the increase in weight and length of the trains it is necessary to define longitudinal dynamic forces of the train and understanding of the train operating conditions impact to the level of these forces.

The longitudinal dynamic of train is a complex function of wagon couplers characteristics, railway track plane and profile geometry, locomotive operation regime, train brake characteristics and other factors. The longitudinal dynamic of train can be calculated by a system of complicated differential equations and it could be solved by special commercial simulation software such as "Universal Mechanism".

A module for simulation of complex train dynamics is developed in the program package „Universal mechanism" (UM). This module automates the process of model creation and the analysis of obtained results. Every vehicle of the train in terms of "Universal mechanism" is a subsystem which can be a model of any complexity. Though in most cases it is enough to create a single-mass model of a vehicle, more precise vehicle model can be included in the train model to make more detailed analysis of a separate vehicle in the train (Laboratory… 2012).

Researchers at the Railway Transport Department of Vilnius Gediminas Technical University constantly and successfully use the UM for the educational and research purposes. For example the UM software was used for the simulation of a railway accident on the track between stations Gaižiūnai and Skaruliai (Fig. 1). In this case six wagons derailed in very complicated circumstances (Fig. 2). To determine the actual cause of the accident, the computer two stage model of the accident was created: at the first stage the simplified model was created and at the second stage the 3D simulation of the train dynamics was made (Petrenko 2013).

Fig. 1. The railway track and derailment place between stations Gaižiūnai and Skaruliai.

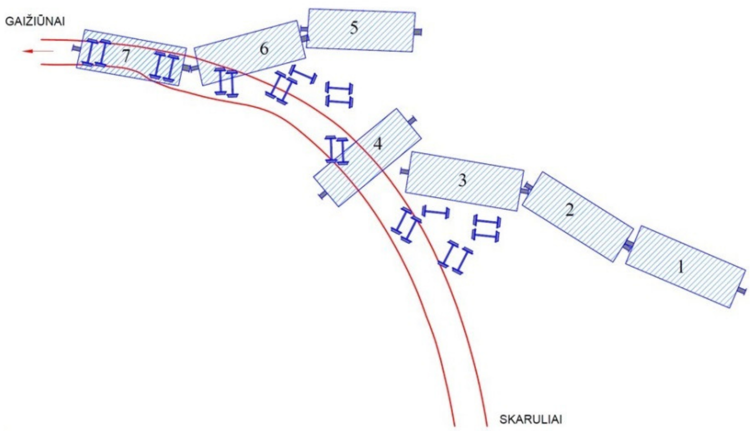

Fig. 2. Cistern cars displacement during derailment on railway track between Gaižiūnai and Skaruliai stations.

After creating the dynamic model of the train and analyzing the results, it was determined that the UM software simulates only a single braking process of the train. That does not reliably recreate the conditions of the train and the train longitudinal conditions in the simulation process are absolutely unpredictable. That distorts the results of the simulation. Working in collaboration with the manufacturer of the UM – Laboratory of Computational Mechanics of

Bryansk State Technical University, the UM software has been supplemented with the new feature which creates multi-braking conditions of the train.

The new version of the UM was made to re-model various train braking processes (service braking, releasing and emergency braking) with full restoration of black box tape recordings. This suggests that the results of modeling are absolutely true and can accurately determine the cause of the derailment.

This article describes the simulation of longitudinal dynamics of a freight train during a derailment of wagons using the new features of UM software.

2. Determination of the longitudinal dynamic forces

Obviously, in this case, to identify the cause of the wagons derailment, it is necessary to determine the level of the longitudinal dynamic forces in the train. Application of emergency braking during a descent form the slope, in the curve with a small radius, with the loaded wagons at the end of the train, the level of longitudinal forces in the train could reach a critical level, which could cause a derailment of wagons.

To determine the longitudinal forces of the train traditionally a simplified model of the train was used, in which vertical and lateral dynamics were neglected and railway vehicles connected by elastic and dissipative elements. In the case of cistern wagons (which were derailed from the track) two mass model was used of the wagon in which the longitudinal motion of the fluid is simulated with the additional elastic and dissipative connections. This train model simplifies and speeds up the calculations, but allows precisely calculate the level of longitudinal forces.

Using the simplified train's model, railway track profile and plan can also be simplified, but it must be prepared for certain simulation conditions. Presented in Fig. 3 and Fig. 4 macro geometry of the plan and profile path consists of three parts:

- The first part (0‰ slope, straight) is intended for the initial simulation of the train, this is required by conditions of the software;
- The second part (slope 6‰, straight) is used to create a certain state of longitudinal train forces (compressed/ tensed);
- The third part simulates a real plan and profile of the track, where derailment accrued, also the conditions of the accident.

Fig. 3. Track's profile macro geometry.

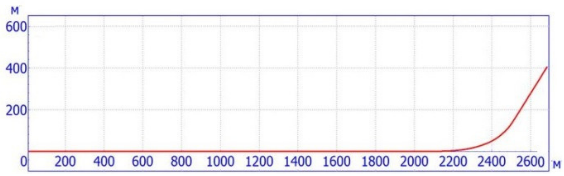

Fig. 4. Track's plane macro geometry.

New software features of UM allow to simulate any control train mode with any number of different braking regimes and, therefore, may recreate the exact conditions of the accident. In this case, based on the description of the accident and analyzing the black box recordings, there are two possible accident scenarios. In a first scenario, the derailment of wagons occurred after testing the brakes during free moving regime. In the second case, the derailment of wagons could be due to the use of emergency brake by the train diver.

Using new features of the UM program, has become possible to create two exact accident scenarios. For example, in the case of the first scenario, without the use of emergency braking (Fig. 5), the train driver tests the brakes (one breaking step) after reaching desired braking effect, the train driver releases the brakes. The results of the black box decoding show, that in only 2 km from the Gaižiūnai station at the speed of 38 km/h (10,6 m/s) the train driver tested the brakes, the train speed decreased to 18 km/h (5 m/s). After brake release train speed increased up to 24 km/h (6.7 m/s). Fig. 6 shows the distribution of the speed of the train from the beginning of the simulation to the place of wagons derailment and proves identity of black box recordings and simulation conditions.

As a result, the computer simulation of the first scenario the level of longitudinal forces in the train was defined. Fig. 7 shows the level of longitudinal forces of all wagons and locomotive. As you can see, the maximum level of the longitudinal compressive forces reached 636 kN for the 40-th wagon during a brake test. Fig. 8 shows the level of the longitudinal forces of the first six wagons (which had derailed) which does not exceed 452 kN same during brake testing, but not at the derailment place.

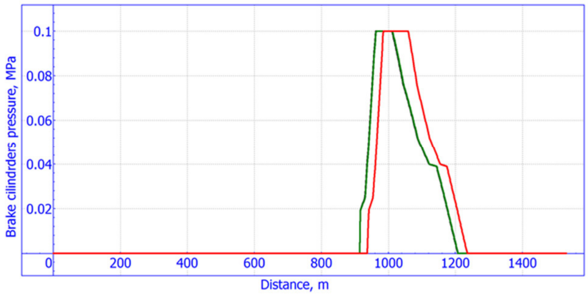

Fig. 5. Train brake cylinders pressure (green line – locomotive, red line – last wagon).

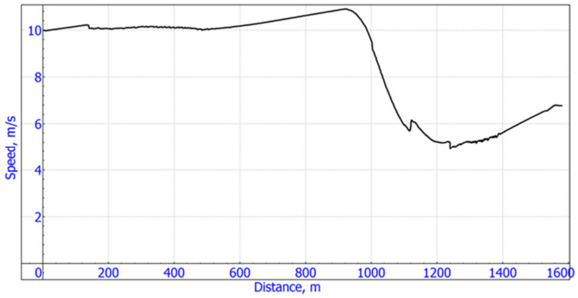

Fig. 6. Train (locomotive) speed distribution.

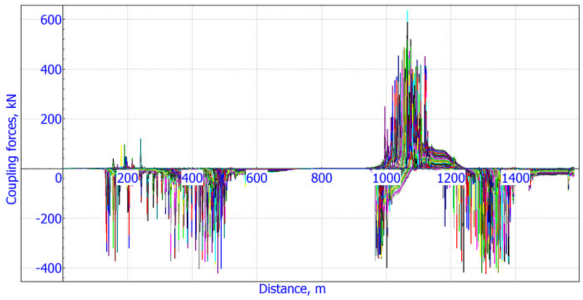

Fig. 7. Dependence of the longitudinal forces on the coupler and simulation distance (free running regime).

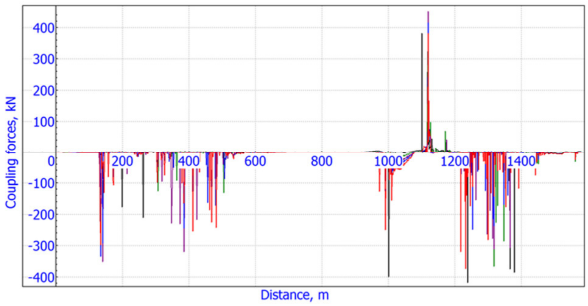

Fig. 8. Dependence of the longitudinal forces on the coupler of the first six wagons and simulation distance (free running regime).

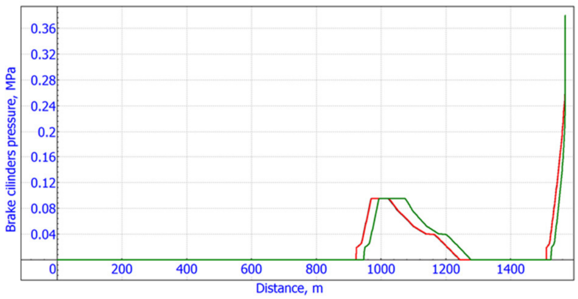

Fig. 9. Train brake cylinders pressure (green line – locomotive, red line – last wagon).

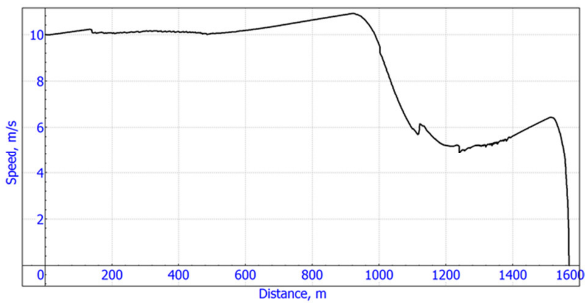

Fig. 10. Train (locomotive) speed distribution.

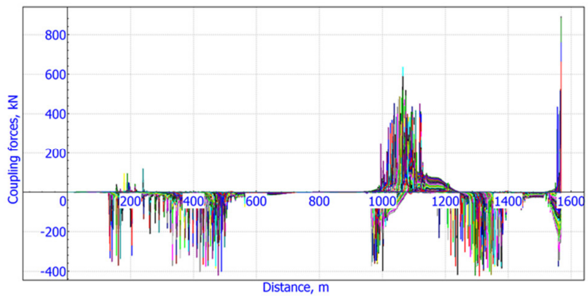

Fig. 11. Dependence of the longitudinal forces on the coupler and simulation distance (emergency braking regime).

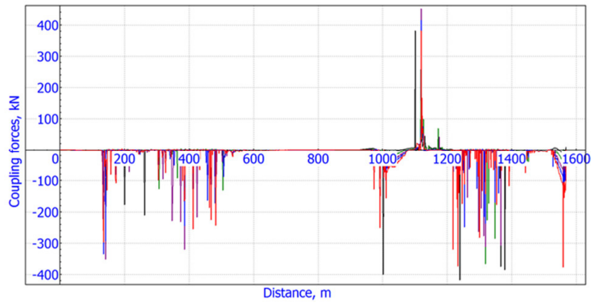

Fig. 12. Dependence of the longitudinal forces on the coupler of the first six wagons and simulation distance (emergency braking regime).

Simulation of the second scenario shown in Fig. 9 and Fig. 10. The driver of the train after testing the brakes with pressure 0,1 MPa and a full brake release, applied emergency braking, after that the pressure in the brake cylinders of the locomotive increased to 0,39 MPa, while the wagons to 0,24 MPa, and the train stopped. During the emergency braking the highest level of the longitudinal compressive forces of the train has been achieved. For example, 46-th wagon longitudinal compressive force was 892 kN (Fig. 11). In the first six wagons the level of maximum tension longitudinal forces did not exceed 377 kN (Fig. 12).

3. Train longitudinal dynamics simulation results

The obtained results of computer simulation must be compared with the safety standards for the level of the longitudinal forces of the train. In this case, you can use the Technical specifications Rail transport infrastructure with freight trains with increased weight and length (РЖД, 2010). The technical specifications describe requirements for the railway infrastructure design, rolling stock and to the maximum longitudinal dynamic forces of the train.

In this case, derailed wagons loaded with a mass of about 60 t., and on the site of the accident was the curve of small radius (about 250 m), the level of the longitudinal tension forces (1 table):

- track's stability must not exceed 1275 kN;
- automatic coupler strength during start and electric braking should not reach 932 kN.

And the level of longitudinal compressive force (2 table):

- track's stability must not exceed 981 kN;
- automatic coupler strength shall not exceed 932 kN.

Table 1. Maximal tension longitudinal forces (kN), in a freight trains (РЖД, 2010).

Type of rolling stock		Railway curve radius, m									
		150		200		250		400		700*	
Freight wagon weight, t	0	392 u		490 u		490 u		490 u		490 u	
	10	685 u		785 u		883 u		1177 u		1275 p	932 t
	20	981 p	932 t	1079 p	932 t	1177 p	932 t	1275 p	932 t	1275 p	932 t
	30	1275 p	932 t	1275 p	932 t	1275 p	932 t	1275 p	932 t	1275 p	932 t
	40	1275 p	932 t	1275 p	932 t	1275 p	932 t	1275 p	932 t	1275 p	932 t
	50	1275 p	932 t	1275 p	932 t	1275 p	932 t	1275 p	932 t	1275 p	932 t
	60	1275 p	932 t	1275 p	932 t	1275 p	932 t	1275 p	932 t	1275 p	932 t
	70	1275 p	932 t	1275 p	932 t	1275 p	932 t	1275 p	932 t	1275 p	932 t

Notes: u – stability of the wheels on the rails;
p – track's stability with R50 type rails and not stabilized ballast;
t – automatic coupler strength during start and dynamic electric braking;

p – automatic coupler strength during acceleration;
* – 700 m and more.

The final step is, to compare the results of computer modelling and technical requirements.

During the first scenario (free moving) the level longitudinal tension forces in the first six cars (Fig. 7), which derailed does not exceed restriction limits in 1275 kN and 932 kN. The level longitudinal compressive forces did not exceed the maximum limits in the 981 kN and 932 kN. This means that the derailment of the first six wagons, due to adverse longitudinal forces of the train is unlikely.

Table 2. Maximal compressive longitudinal forces (kN), in a freight trains (РЖД 2010).

Type of rolling stock		Railway curve radius, m				
		150	200	250	400	700*
Freight wagon weight, t	0	392 u	441 u	490 u	490 u	490 u
	10	588 u	638 u	687 u	736 u	785 u
	20	785 u	833 u	883 u	932 u	981 u 932 a
	30	981 u 932 a	1030 u 981 p 932 a	1078 u 981 p 932 a	1128 u 981 p 932 a	1176 u 981 p 932 a
	40	1176 u 981 p 932 a	1226 u 981 p 932 a	981 p 932 a	981 p 932 a	981 p 932 a
	50	981 p 932 a	981 p 932 a	981 p 932 a	981 p 932 a	981 p 932 a
	60	981 p 932 a	981 p 932 a	981 p 932 a	981 p 932 a	981 p 932 a
	70	981 p 932 a	981 p 932 a	981 p 932 a	981 p 932 a	981 p 932 a

Notes:
u – stability of the wheels on the rails;
p – track's stability with R50 type rails and not stabilized ballast;
a – automatic coupler strength, with speed limits of 60 km/h, the maximum compressive strength should not exceed 392 kN;
* – 700 m and more.

In the case of a second possible scenario (braking) the level of the longitudinal tension forces in the first six cars at the scene of the accident (Fig. 12), reaching a maximum value at 377 kN, but again, this level of force is not critical.

This means that in the first six wagons the level of longitudinal compressive and tension forces did not exceed the maximum permissible level. So in these driving conditions with and without the use of emergency braking the derailment of the first six wagons is not possible.

Analyzing longitudinal dynamic forces in the application of emergency braking in all freight wagons couplers, you will notice that in the end of the train compressive dynamic impact appeared. This impact could lead to a derailment of wagons in the end of the train, as the level of the longitudinal compressive force (892 kN) approached the critical level for the railway track's stability.

4. Conclusions

1. Working in collaboration with the manufacturer of the program package "Universal mechanism" – Laboratory of Computational Mechanics of Bryansk State Technical University, the UM software has been supplemented with the new feature which creates multi-braking conditions of the train.
2. The new version of the program package "Universal mechanism" was made to re-model various train braking processes (service braking, releasing and emergency braking) with full restoration of black box tape recordings. This suggests that the results of modelling are absolutely true and can accurately determine the cause of the derailment.
3. To determine the actual cause of derailment, the computer model of the accident between stations Gayzunai and Skaruliai was created. The simplified models of locomotive and wagons are used for train dynamics simulation.

4. During railway accident investigation using computer simulation the maximum values of the longitudinal forces in derailed six cars were calculated and the biggest longitudinal forces did not exceed 377 kN;
5. The first six wagons levels of longitudinal compression and tensione forces did not exceed the maximum permissible level.

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