SIMULATIONS OF MOTION OF PROTOTYPE RAILWAY WAGON WITH ROTATABLE LOADING FLOOR CARRIED OUT IN MSC ADAMS SOFTWARE

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Abstract

The railway wagon with a low flat rotatable loading floor was analysed in the paper. Such a structure can be used for transporting various types of vehicles such as tractors, trucks, trailers, semitrailers, cargo containers. The railway wagon allows quick and fast loading and unloading without any platform infrastructure or terminals. Only a hardened flat surface is required. Each railway wagon can be loaded-unloaded individually (no cranes needed). This construction has a wide range of application and is easy to operate. The model of a railway wagon consisted of standard carriages, undercarriages, and a rotatable loading floor was developed. The model was built of rigid solids. Between individual elements of the model, the appropriate joints and contact connections were created. The model was analysed using MSC Adams code, which allows performance of the 3D kinematic – dynamic analyses of the entire model. The analyses were carried out with use of the model of the loaded semitrailer. Passage of the railway wagon with a trailer on horizontal rails, which are the smallest standard arc with a radius 250m, was simulated at different speed. Reactions occurring in couplings of the rotatable loading floor, which are the main element of connection between the rotatable loading floor and motionless undercarriages part of the frame of the wagon, were tested. The maximum velocity at which the railway wagon can move was analysed as well. There was also examined the speed at which the wheels separate from the rails, what results in derailment of the whole wagon.

Keywords: *intermodal transport, railway wagon, simulation of motion, MSC Adams*

1. Introduction

A special wagon with a low rotatable loading floor (Fig. 1) for transportation of truck vehicles by rail was developed in Military University of Technology in the Department of Mechanics and Applied Computer science in Warsaw. The essence of such reoloading is to place the semitrailer on a special rotatable floor with the use of a truck tractor. This structure is characterised by a lowered bottom of the frame and by a rotatable floor of the body moved with the use of hydraulic engine through the gear transmission in respect to the wagon central junction, so called a swivel pin. The structure can be used for transportation of different type of vehicles such as tractors, trucks, trailers, semitrailers and cargo containers. The wagon allows quick and fast loading and unloading without any platform infrastructure or terminals. Only a hardened flat surface is required. Each railway wagon can be loaded-unloaded individually (no cranes needed).

The following constructional assumptions were made in the project of the special wagon for intermodal transport [5, 6]:

- mass of the semitrailer with load up to 40 T, wagon weight up to 45 T,
- meeting the requirements of GB 1 railway gauge,
- low- set rotatable loading floor for autonomous loading-unloading allowing individual loading-unloading of the wagon,
- application of standard biaxial bogies of Y25 type with allowed pressure on the axis 22.5 T.

Utilization of such a type of the platform allows the transport companies to reduce the time and save the funds allocated for road transport. However, the most important advantage of such a structure is reduction of a negative influence on the environment as well as the increase of safety in road traffic through reduction of the number of trucks on roads [1].

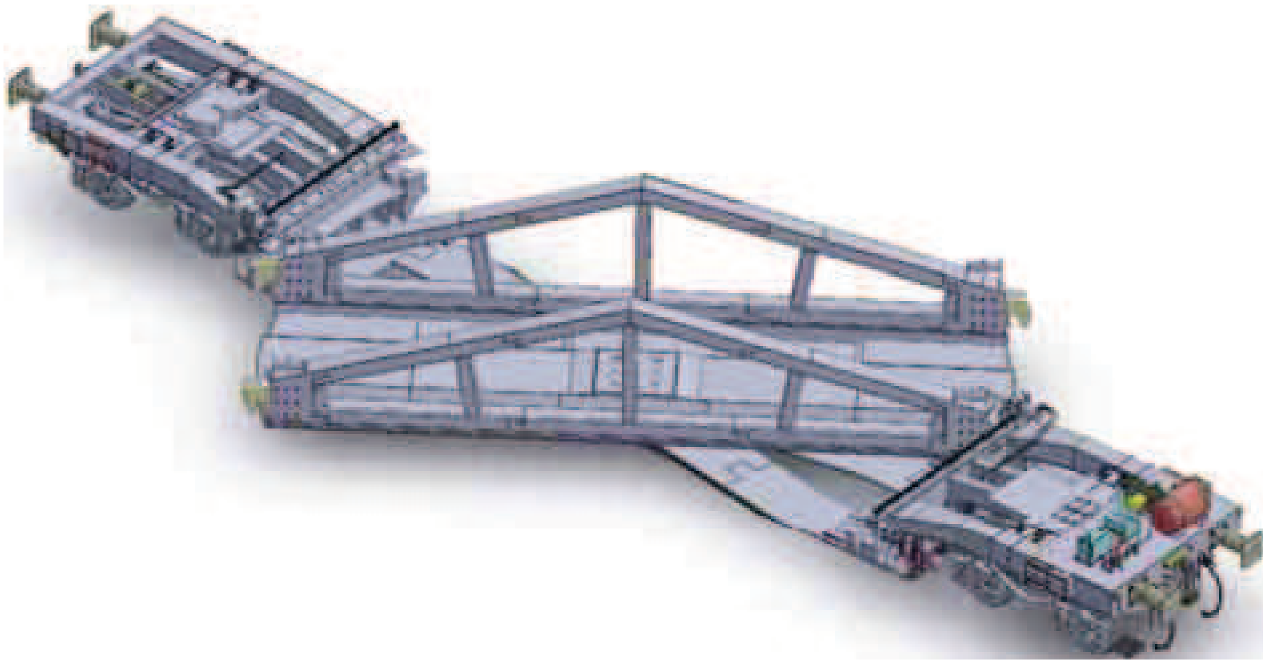

Fig. 1. Prototype version of the wagon with open loading platform

2. Wagon 3D numerical model for multibody analyses

To carry out multibody analyses with the use of MSC Adams code [3], a numerical model of the wagon and semitrailer with the load was applied. In the model, there were taken into consideration main executive subsystems of the wagon and contact joints between them (Fig. 2).

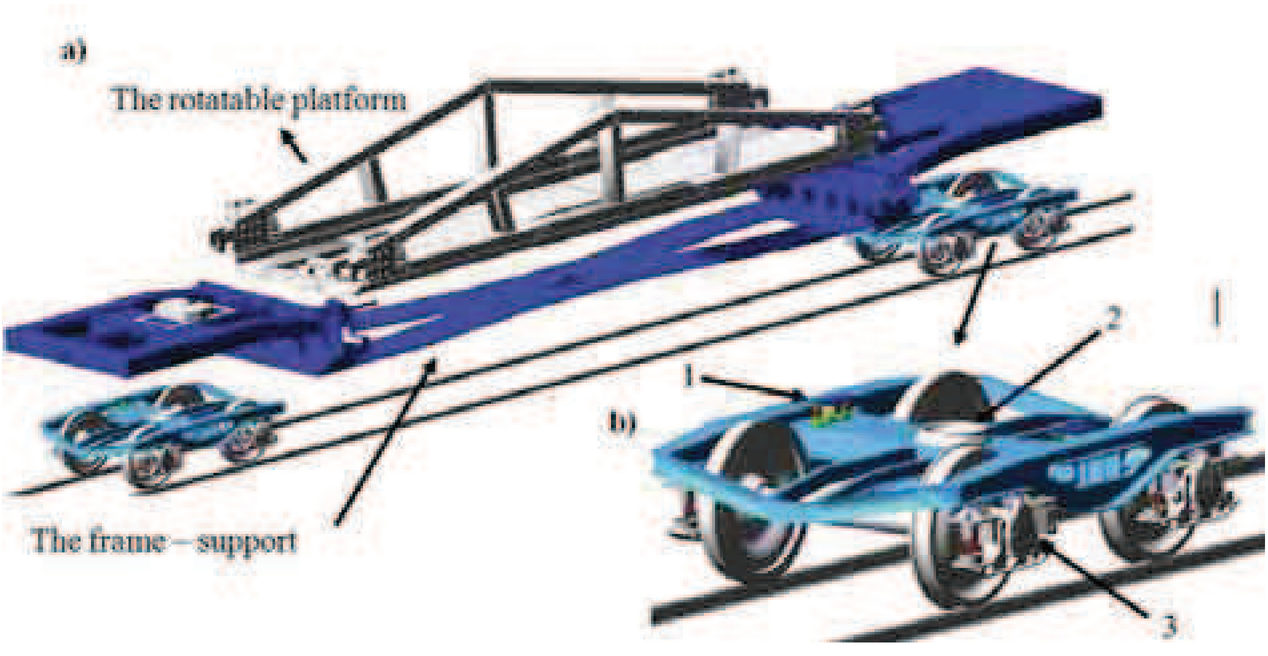

Fig. 2. a) Chart of 3D numerical model with main subsystems, b) Y25 type bogie 1- side slides, 2- swivel pin, 3 -spring element of bogie suspension

3. Initial-boundary conditions in 3D model of wagon

The following kinematic pairs and suitable constraints were introduced into the model of the frame and the bogie (Fig. 3, 4):

- bogies axes are equipped with a constraint mapping fixing of the axis in axel box and enabling the accurate rotatable motion of the axis along with the wheel,
- contact was defined between bogies wheels and tracks,
- frame-support is supported on side slides and contact conditions enabling cooperation like in a spherical pin joint were mapped in the bogie swivel pivot,
- bogie frame can perform independent vertical movements, in respect to axel boxes slides and bogies sets (axis with wheels), limited by contacts conditions in axel boxes slides and springs with accurate stiffness modelling the suspension of the bogie,
- movement of the frame-support is limited by side slides supported on the bogie frame and on the transverse beam.

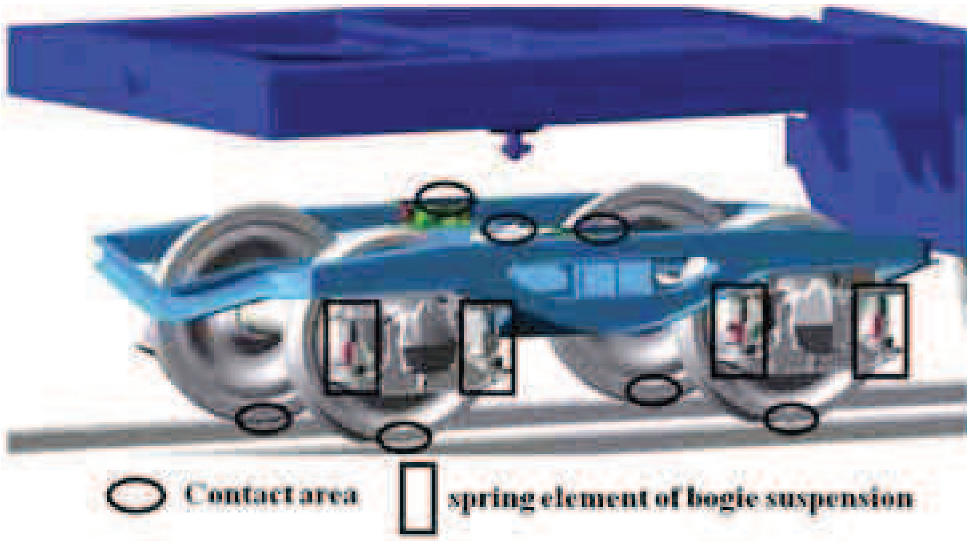

Fig. 3. Charts illustrating constraints and conditions of cooperation (contact) in connections of subsystems of bogies, frame-support and central junction

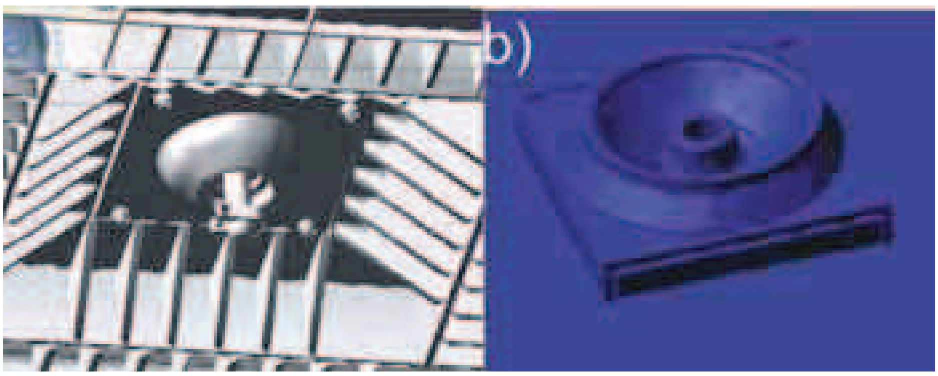

Fig. 4. Model of swivel pin used as central junction of floor rotation a) loading floor – down view, b) support – top view

Separate kinematic pairs and constraints were defined in the locks connecting tailboards of rotatable platform and a part of frame-support (Fig. 5). A single lock of type the hook built up in the platform tailboard is connected with the part of the frame – support, and its transversal motion is blocked with the use of a hydraulically moved wedge. A contact joint was applied between a wedge and a hook. There are four sets of locks.

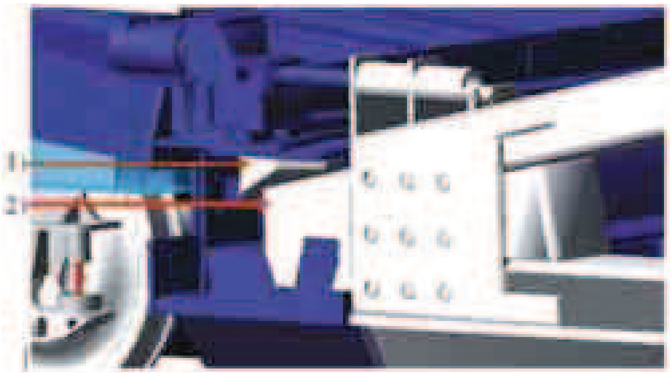

Fig. 5. Lock connecting tailboards of rotatable platform and a part of frame: 1) wedge, 2) lock-hook

A numerical model of the truck semitrailer (Fig. 6) was also applied for analyses. This model was built with the real dimensions taken into account. The mass of the semitrailer is 40 T and it is the weight with the full load – additional external load. The model of the semitrailer was placed on the wagon and fixed in the saddle thus defining a junctions set (Fig. 6). A contact between semitrailer wheels and bottom plate of a loading floor was taken into consideration in the wagon model, as it is shown in Fig. 6.

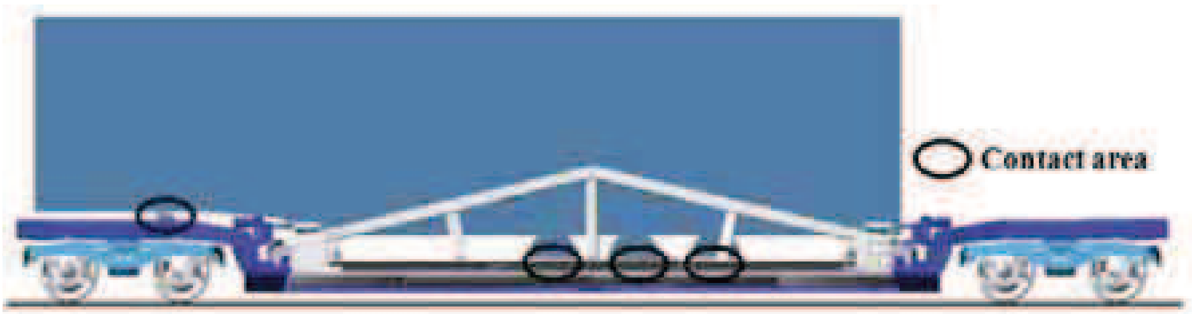

Fig. 6. Constraints mapping fixing of the semitrailer in the saddle and additional contact areas of semitrailer wheels with wagon model

The following initial conditions were considered in simulations:

- classical gravity (wagon dead weight) was taken into consideration in all analyses,
- wagon moves on the 1000m straight railway track and next it enter the horizontal arc of 250 m radius (minimal radius according to standard PN-EN 13232-1:2004-[4]),which is proceeded by an accurately selected transition curve - Fig. 7a,
- the wagon movement was obtained through defining an accurate characteristic of angular velocity on bogies axes (Fig. 8),
- on the line segment of 1000m railway track, the wagon accelerates to the appropriate velocities, then it moves on the arc at constant velocity (Fig. 8b),
- S49 type rails were used in analyses – Fig. 7b.

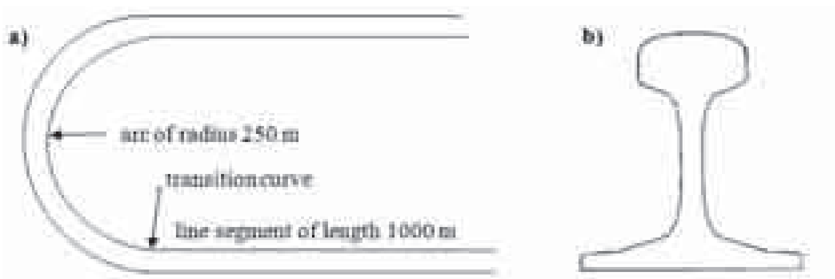

Fig. 7. a) The chart of test section of railway track, b) mapped model of S49 rail

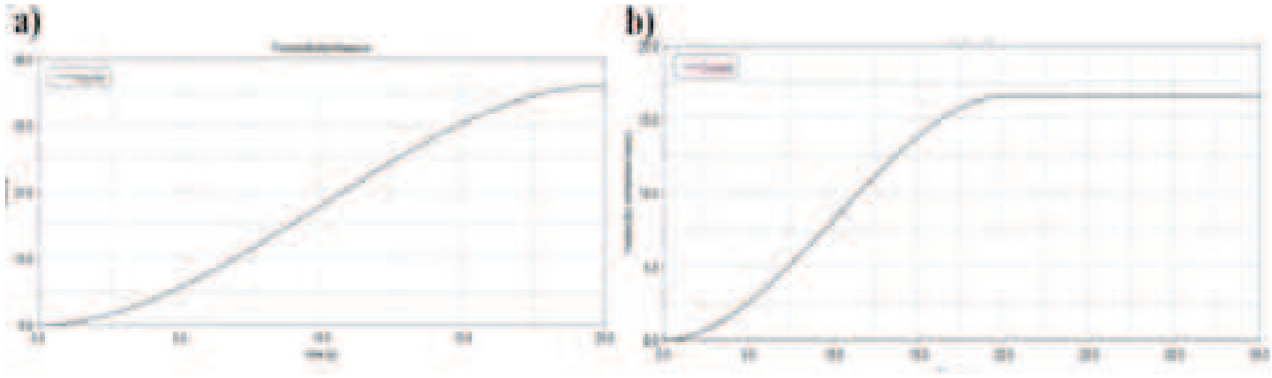

Fig. 8. a) Phase of wagon accelerating, maximum fixed velocity 36rad/s was obtained after 20 seconds, b) change of linear velocity of the wagon during simulation (maximum velocity of fixed motion 60 km/h)

4. Analyses results

4.1. Analysis of reaction force in joints

Numerical analyses carried out in MSC Adam were composed of a few following one after other phases. The initial phase of acceleration, in which the wagon with a semitrailer starts moving and in which the contact of all cooperating kinematic pairs is identified, lasts to the second of the simulation. From the second there occurs the growth of wagon acceleration, what causes the increase of the value of contact forces between individual elements of the construction. The phase of acceleration lasts to the thirty-fifth second of simulation, after that the wagon moves at maximal fixed velocity and enters the transition curve and then the arc of 250m radius. Owing to the equipment limitations, (a lot of calculation memory is required), all the simulation was ended at the moment when the wagon reached the quarter of the covered arc. On the basis of the analyses, results there were defined the changes in time of contact forces values in individual pairs: wheel-rail (forces values were recorded on all the wheels), wedge-hook (blocking lock), bogie-support, rotatable platform-support. There was also determined the maximum velocity at which the wagon can move on the considered arc. The values of contact forces were recorded during the duration time of the whole simulation.

It was noticed that in the first stage of simulation, in which the model starts movement with insignificant acceleration, the contact forces are small. However, in the second stage of simulation, in which a significant growth of velocity occur, the increase of contact forces value, caused by the appropriate dynamic response of the construction modelled in the form of rigid solids, takes place. Fig 10 presents the changes of the resultant contact forces occurring between the wheels and outer railway track (wheel – rail pair) at the velocity of 60km/h (Fig. 9). It was found that from the forty-eighth second, when the wagon enters the arc at the fix velocity, the contact force increases, what is caused by tilting of the structure resulting from the centrifugal force. It causes the increase of the pressure on the wheels moving on the outer railway track. Averaging the results of the results obtained during the ride on the line segment (from 0 to the 48^{th} s of simulation), it was observed that the value of contact force in this variant amounts to approximately 100kN (the red part of the graph), what corresponds to the weight of a rotatable platform. On the arc (from the 48^{th} s of simulation), this value increases to 250kN (blue line – Fig. 10).

It was observed that contact forces in joints interact only at the moment when the wagon enters the turning. The centrifugal force interacting on the construction tries to open the rotatable platform. Due to the fact that analyses are carried out on the rigid solids, it is not possible to find what forces occur in the joints at the moment of moving on the line segment. In this movement, there occur the forces stretching the joins, however, owing to the multibody analysis, there is no possibility to read them since further analyses with the use of a finite element method are required [2]. Fig. 11, 12, 13 presents graphs of resultant contact force in the joint for velocities of 60, 90, 115km/h, respectively.

It was noticed that these values change along with the increase of velocity at which the wagon covers the arc. For velocity of 60km/h, the averaged resultant contact force is equal to 30kN, for velocity of 90km/h, it is equal to 75kN and for velocity of 115km/h, it is equal to 100kN.

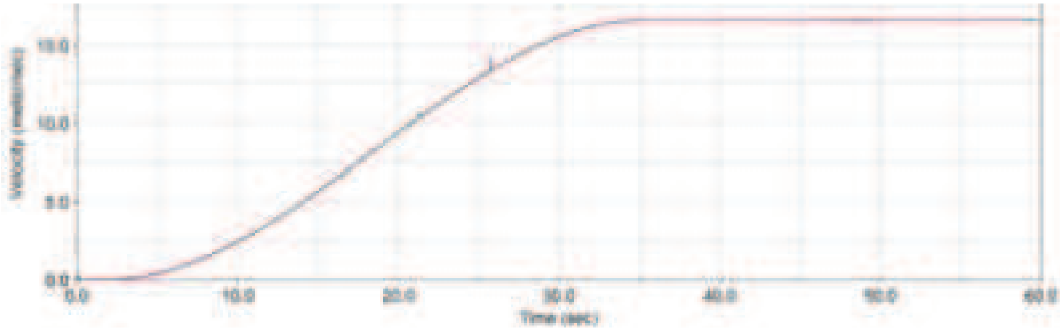

Fig. 9. The change of wagon velocity during simulation – V_{max}=60 km/h

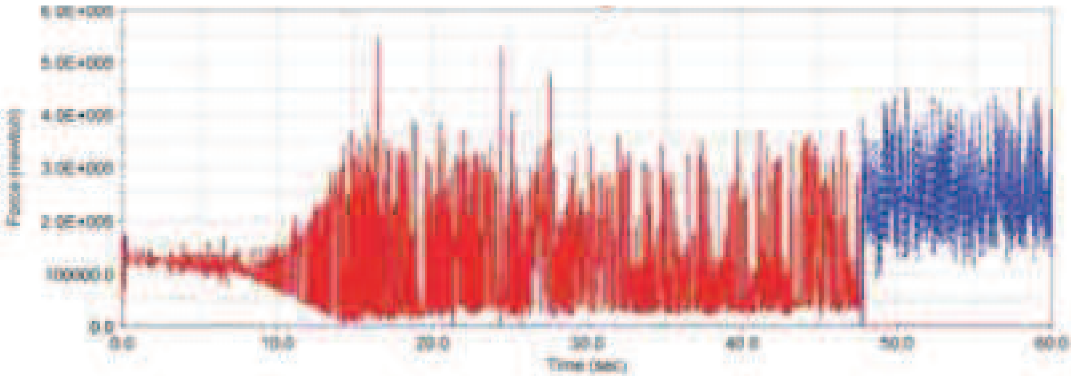

Fig. 10. The resultant change of force value of wheel – rail contact during the transit at 60 km/h velocity

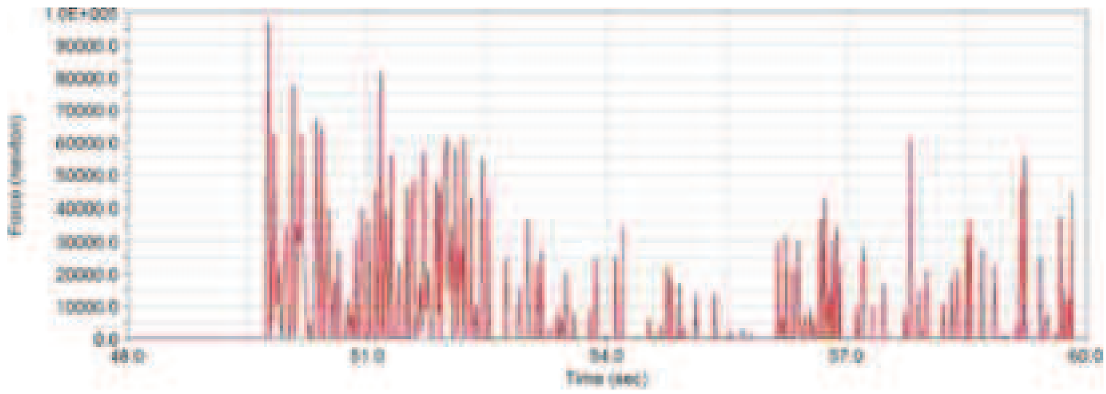

Fig. 11. The change of the contact force in the tailboard joint – velocity 60 km

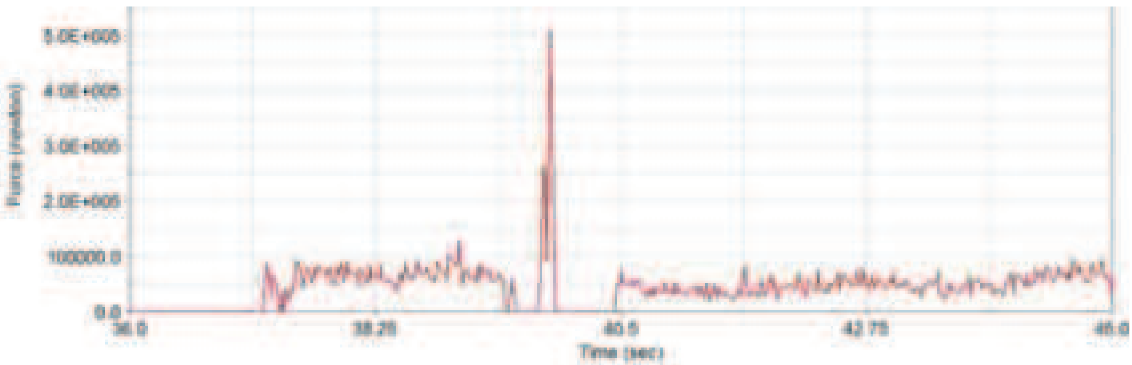

Fig. 12. The change of the contact force in the tailboard joint – velocity 90 km

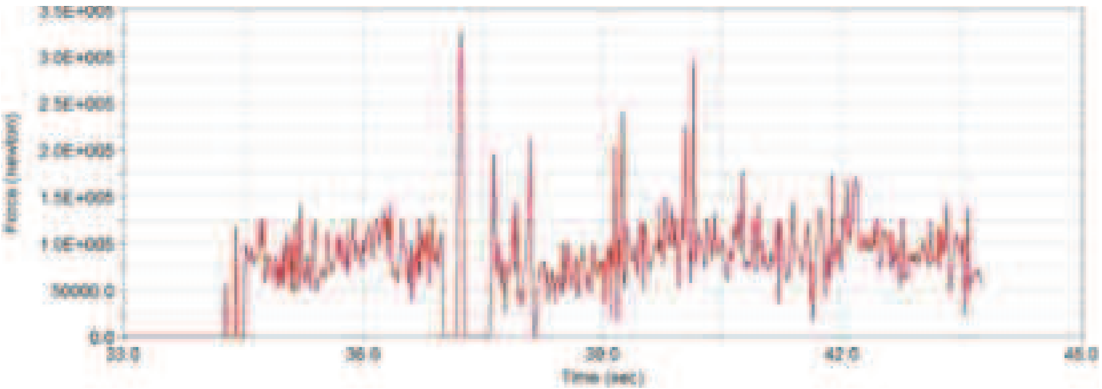

Fig. 13. The change of the contact force in the tailboard joint – velocity 115 km

4.2. Analysis of kinematic parameters of wagon movements

Based on the realized simulations of the transit of the special wagon at different velocities on the standard section of the track, there was determined the boundary – maximum velocity of the wagon at which it can move on the arc of 250 m radius. After conducting a number of analyses, it was found that at velocity of 120 km/h a wagon with a loaded semitrailer tilts to the side after entering the arc, what results in derailment of a whole structure (Fig. 14). The centre of gravity of the semitrailer is located halfway of its height, what causes that the structure is more susceptible to interaction of centrifugal force and loss of stability. Lowering of the gravity centre of the semitrailer, due to a different type of load (for example, the load with reduced volume occupying the semitrailer), enables transit at higher velocity, however, it is not allowed from the point of arc characteristic and railway standards. The allowed standard velocity for this type of transit is 80 km/h. The boundary – maximal velocity at which a wagon can move on this type of arc with a gravity centre located halfway of semitrailer height without danger of derailment is 115 km/h.

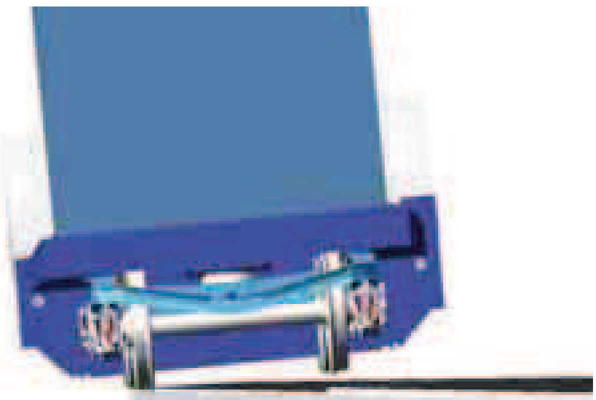

Fig. 14. Wagon moving at velocity of 120km/h on the arc of 250m radius with a view of detachment of wheels from the rails on the inner side of the arc

5. Summary

The simulation with the use of multibody methodology enables the investigation of kinematic and dynamic values describing the motion of a complete wagon on the track selected test section. In such numerical investigations, the conditions of cooperation of rigid bodies mapping accurate geometry of the main subsystem of the prototype wagon are taken into consideration. The conditions of cooperation in all contact connections were described and substitute characteristics of bogies springs were mapped. The results presented in the graphs correspond to the simulation of wagon transit on the test track at different velocities. Contact forces occurring in joints of the individual elements of structure change non-uniformly. It can result from simplifications in the numerical model requiring geometrical adjustment in the boundaries of the assumed fits. Evaluation of distributions and changes of reaction forces is rated since it does not take into consideration adaptive possibilities of a real deformable system of the wagon rotatable platform and the frame.

Acknowledgements

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