doi: 10.21495/71-0-177

25th International Conference
ENGINEERING MECHANICS 2019
Svratka, Czech Republic, 13 – 16 May 2019

SIMULATION OF SAFETY AGAINST DERAILMENT TESTS OF AN ELECTRIC LOCOMOTIVE

J. Kalivoda*, L. Neduzha**

Abstract: *European standards define the conditions for stationary and track tests that each new type of rolling stock has to pass within its approval process. Because those tests are demanding and their results are influenced by weather conditions and other random factors, there is an attempt to replace them by computer simulations. The paper deals with simulations of stationary tests for proving safety against derailment. The multibody simulation model of Ukrainian electric locomotive DS3 has been built. This model was used to simulate all three methods defined in the European standard EN 14363 for proving safety against derailment. The results of the simulations are shown in the paper.*

Keywords: railway vehicle, safety against derailment, testing for acceptance, simulation.

1. Introduction

Safety against derailment must be assured for each railway vehicle. In the European Union the requirements for the safety against derailment are specified in the Technical Specifications for Interoperability (TSI) and related European standards especially in EN 14363. Prove of safety against derailment is required in two stages:

1. stationary tests,
2. dynamic performance assessment.

The first stage tests are to prove the safety against derailment under quasi-static conditions. To perform those tests, special test benches (Kalivoda & Bauer, 2013, Myamlin et al., 2017) or specific track sections negotiated at very low speed are utilized. In the second stage a dynamic performance assessment is performed while running a vehicle in a real track. The range and parameters of the test runs are defined to cover various conditions that occur in the operation of the vehicle. Quasi-static safety against derailment must be proven before the track tests begin.

Both stationary and track tests are expensive and time-consuming. Moreover, the results of track tests are influenced by several random factors such as the state of the railway infrastructure, weather conditions, etc. Therefore, there is an attempt to replace those tests, or some of their parts, by simulations.

The paper deals with the simulations of stationary tests of safety against the derailment. Those simulations were performed with the model of four axle high-speed electric locomotive DS3. This locomotive was designed in Ukraine Dnipropetrovsk research-and-production association for electric locomotive engineering jointly with Siemens Company (Klimenko et al., 2018). Its maximum speed is 160 km/h, weight 90 ton and output power 4800 kW. A detailed description of the locomotive can be found at (Sokolov, 2011). The goal of performed simulations is:

- to assess the compliance of DS3 locomotive running characteristics with European legislation,

* Ing. Jan Kalivoda, PhD.: Czech Technical University in Prague, Faculty of Mechanical Engineering; Technická 4, 166 07 Praha 6 CZ, jan.kalivoda@fs.cvut.cz

** Doc. Larysa Neduzha: Dnipropetrovsk National University of Railway Transport named after Academician V. Lazaryan, Dep. «Theoretical and Structural Mechanics», Lazaryan St. 2, 49010, Dnipro, Ukraine, nlorhen@i.ua

- to assess the possibility of replacing vehicle tests with simulations,
- to create simulation models for individual tests. Those models can be used for simulations with other types of railway vehicles and for the teaching of experimental methods and testing of rolling stock.

2. Vehicle model

The simulation model of locomotive DS3 was built using multibody software Simpack. It consists of fifteen solid bodies (car body, two bogie frames, four intermediate beams, four wheel set and four ballasts representing the inertia properties of the track under each wheelset). The model has 66 degrees of freedom in total. It respects the spatial and inertia arrangement of the vehicle including non-linear characteristics of suspension elements, clearances, friction and the non-linear wheel-rail contact geometry. For the calculation of wheel-rail contact tangential forces the method FASTSIM was used. The model parameters are based on the nominal values of vehicle dimensions, mass properties and suspension characteristics. The model was not validated by experiments, because the experimental are not available.

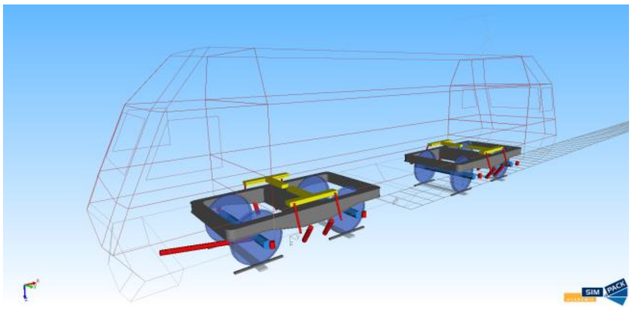

Fig. 1: Model of locomotive DS3 in the environment of Simpack software.

3. Safety against derailment stationary tests

Assessment of quasi-static safety against derailment s based on evaluating of the ratio between the vertical and lateral components of forces acting in the wheel-rail contact. The limit value of this ratio, at which the derailing process starts, was expressed by Nadal (Nadal, 1896).

$$\frac{Y}{Q} = \frac{\tan\beta - \mu}{1 + \mu \tan\beta} \qquad (1)$$

where: Y is the lateral component, called guiding force, and Q the vertical component, called vertical wheel force, of the force in the wheel rail contact, β is flange angle and μ friction coefficient.

The assessment methods for proving safety against derailment create an artificial and extreme situation for the vehicles. Currently, the standard EN 14363 specifies three stationary testing methods to investigate the derailment performance of vehicles while negotiating twisted track.

3.1 Method 1

The Method 1 represents a vehicle negotiating curved track with a 150 m radius and defined twist. If the actual twist of the test track is smaller than the required test twist, the missing twist is included within the vehicle by adding shims in the springs of both suspension levels. The objective is to apply the correct test twist to the vehicle and thus to achieve the corresponding vertical unloading on the guiding wheel. The influence of longitudinal forces in the train set shall be minimized. The speed shall be constant during the test and not to exceed 10 km/h. The assessment criteria are the wheel lift Δz and the ratio Y/Q. The limit value of the wheel lift Δz_{lim} = 5 mm. The limit value of Y/Q is given in dependence on the flange angle β by Nadal formula. The value of the friction coefficient μ = 0,36 is considered. For the flange angle β = 70° the limit value $(Y/Q)_{lim}$ = 1.2. The figure *Fig. 2* shows the Y/Q ratio on all wheels obtained by the simulation of the test according Method 1. The first index of the wheel designation represents the axle number, the second index determines the side of the vehicle (1 … right side, 2 … left side). The investigated twisted track section is in distance from 55 to 85 m. The maximum value of ratio Y/Q = 0.675 was obtained, no wheel lifts occurred.

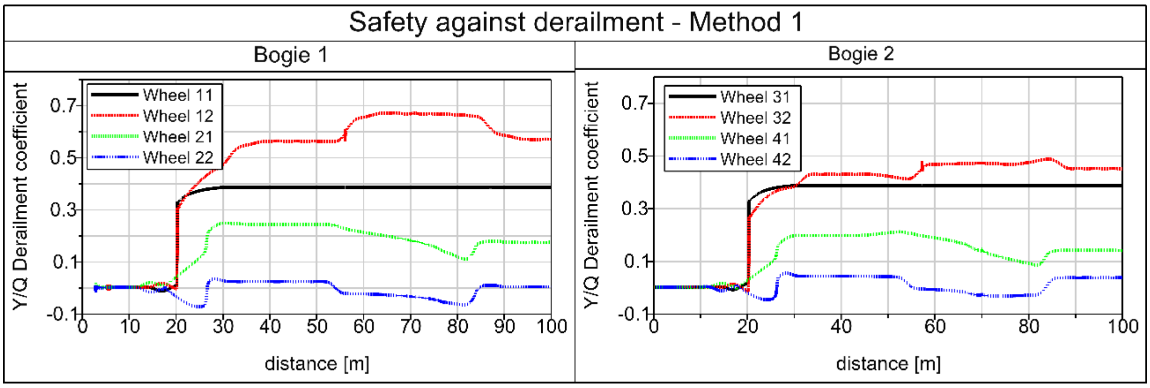

Fig. 2: Simulation of Method 1 - Y/Q ratio.

3.2 Method 2

Also in the Method 2 assesses the risk of flange climbing by the ratio of the horizontal guiding force Y and vertical wheel force Q. The testing is carried out in two stages:

1. The measurement of the vertical wheel force Q is performed on a test rig that simulates twisted track. The individual wheels of the vehicle are gradually lifted in order to achieve the required twist. The minimum value of force Q is considered.

2. The measurement of the guiding force Y on a test track. The test track is a curved track of 150 m radius without twist. Other test conditions are analogous to the Method 1.

The calculation of the ratio (Y/Q) is based on the test results. The evaluation is analogous to the Method 1.

Figure *Fig. 3* shows the results of simulations of safety against derailment tests by Method 2. The values of Q forces obtained by simulation of vehicle twisting are on the left, the guiding forces Y obtained in the test track are in the middle and resulting derailment coefficient Y/Q is depicted on the right. The test curved track segment begins at the distance 20 m. Maximal value of derailment coefficient obtained by simulation of Method 2 is $Y/Q = 0.63$.

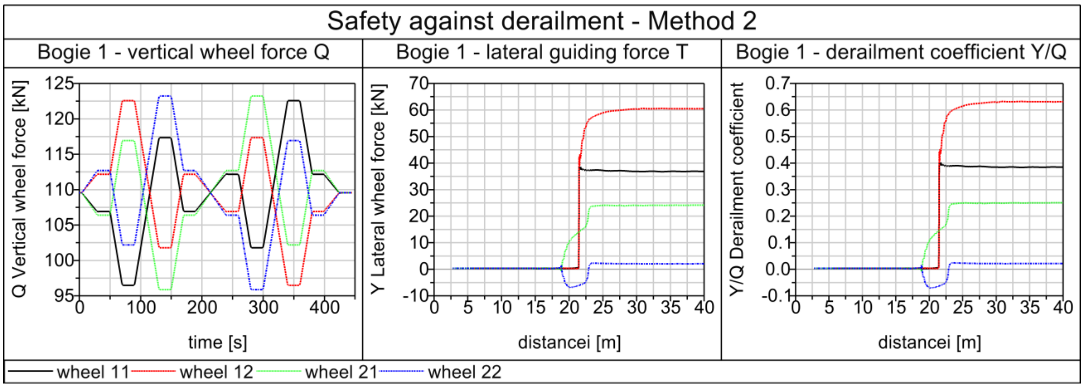

Fig. 3: Results of the simulation of Method 2.

3.3 Method 3

According the Method 3 is the risk of flange climbing assessed by two separate tests.

1. The measurement of the reduction of the vertical wheel force Q on a test rig which simulates twisted track. The test conditions are analogues to Method 2, however the required vehicle twist is different.

2. The measurement of bogie yaw resistance generated as a vehicle negotiates the smallest radius of curvature that the vehicle is designed to go through. This test is carried out on a test rig that is capable to rotate the bogie relative to the car-body whilst determine the required torque.

Two criteria are used for the evaluation:

1. $\Delta Q / Q_0 \leq 0.6$, where Q_0 is the average vertical wheel force for the tested wheelset on a horizontal track, ΔQ is the deviation from Q_0 at maximum twist condition.

2. $X \leq 0{,}1$, where factor X depends on the results of the measurement of bogie yaw resistance.

$$X = \frac{M_{z,R\min}}{2a^{+}P_{F0}} \tag{2}$$

$M_{z,R\min}$ is the yaw moment required to rotate the bogie during yaw resistance test, $2a^{+}$ is the bogie wheel base in m and P_{F0} is the nominal static vertical wheelset force in kN.

Both criteria should be fulfilled.

Figure *Fig. 3* shows the results of simulations of safety against derailment tests by Method 3. Maximal value of wheel unloading factor $\Delta Q/Q_0 = 0.17$, yaw torque required for bogie twist $M_{z,Rmin} = 10.7$ kNm. According the formula (2) the factor $X = 0.018$. Both criteria of Method 3 are thus met.

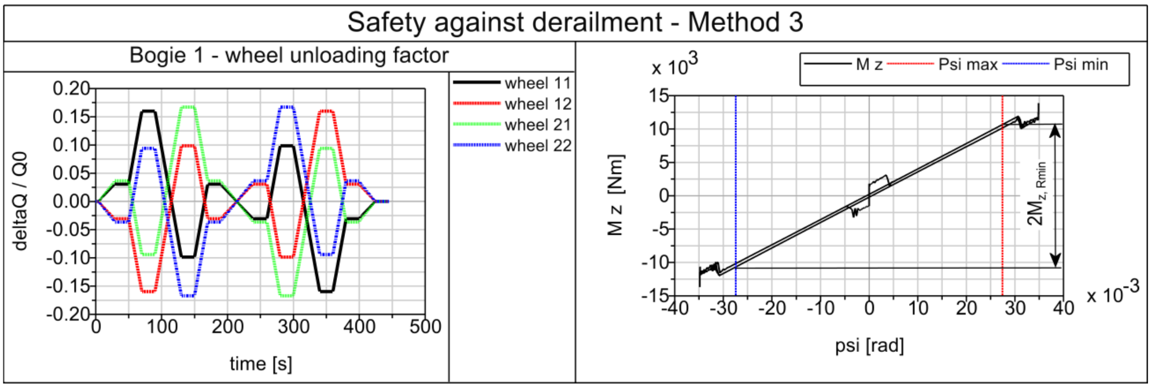

Fig. 4: Results of the simulation of Method 3.

4. Conclusions

The article presents an introductory study which maps the first stage of rolling stock approval process according EN 14363. The long-term goal in this topic is to propose the methodology of simulations that allow to avoid some of the demanding tests in the vehicle certification process. The MBS model of Ukrainian electric locomotive DS3 has been built and computer simulations of stationary tests of safety against derailment have been performed. The second phase of vehicle approval involves track tests. During track tests the running safety, the track loading and the ride characteristics of the vehicle are evaluated. The simulations of the track tests and vehicle dynamic performance assessment will be next steps of the authors' work.

Acknowledgement

This research has been realized using the support of Technological Agency, Czech Republic, programme National Competence Centres, project # TN01000026 Josef Bozek National Center of Competence for Surface Vehicles. This support is gratefully acknowledged.

References

Nadal, M. J. (1896) Theorie de la Stabilite des locomotives, Part II:mouvement de lacet", *Annales des Mines*, 10, 232.

Sokolov, Yu (2011) Конспект для локомотивных бригад электровоз ДС3, изд. Юго-Западной железной дороги Kiev, (in Russian).

Kalivoda, J., Bauer, P. (2013) Experimental Research of Railway Vehicles Running Behaviour on Roller Rigs. In: In: *Současné problémy v kolejových vozidlech: XXI. konference s mezinárodní účastí. Pardubice: Univerzita Pardubice, Dopravní fakulta Jana Pernera*, pp. 49-60, (in Czech).

Klimenko, I., Černiauskaite, L., Neduzha, L., Ochkasov, O. (2018) Mathematical Simulation of Spatial Oscillations of the "Underframe-Track" System Interaction, In: *Proc. of 12th Intern. Conf. «Intelligent Technologies in Logistics and Mechatronics Systems – ITELMS'2018*, pp. 105-114.

Klimenko, I., Kalivoda, J., Neduzha, L. (2018) Parameter Optimization of the Locomotive Running Gear. *Proc. of 22nd Intern. Scientific Conf. «Transport Means. 2018»*, pp. 1095-1098.

Myamlin, S., Kalivoda, J., Neduzha, L. (2017) Testing of Railway Vehicles Using Roller Rigs, In: *Procedia Engineering*, Volume 187, pp. 688-695.