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LOGI – Scientific Journal on Transport and Logistics
Vol. 10 No. 1 2019 DOI: 10.2478/logi-2019-0003

Influence of Suspension Parameters Changes of a Railway Vehicle on Output Quantities

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Abstract: This article deals with computer analyses of output quantities of a railway vehicle depending on changing of parameters of suspension system. A passenger car was chosen for dynamic analyses. An analysed passenger railway vehicle uses two stage suspension system composed of coil springs and hydraulic dampers. Stiffness of coil springs of primary and secondary suspensions were defined for two states and its influence on output values in terms of quality and quantity was evaluated. As output variables, values of forces in a wheel/rail contact and accelerations in several locations on a wagon body floor were chosen. Values of forces in a wheel/rail contact indicate dynamic response of a railway vehicle running in terms of running safety and values of accelerations serve as important input for evaluation of passenger ride comfort.

Keywords: Railway vehicle, suspension parameters, computer simulations, running properties

1. Introduction

The state of art of computer simulations and dynamic analyses have become are an important tool in a process of design and testing of railway vehicles. Engineers are able to assess and optimize performance in an early phase of a design process before a prototype creation. Typical applications of computer analyses are among others stability analyses and safety, ride comfort, wear etc. [1-3] In terms of safety, evaluation of forces in a contact of a wheel and a rail is very important. For evaluation of ride comfort, we have to know values of accelerations in desired positions [4].

2. Dynamic Analyses of Railway Vehicle by Means of Computer Simulations

Computer simulations enable engineers to focus their attention on one or more components of a railway vehicle for purposes of prediction of their dynamic behavior under various specific operation conditions [5-8]. They can retry a simulation with different parameters while results are suitable. Such a process would be more costly and more time-consuming, if it would not be performed by means of simulation computations. A dynamic analysis is way to research of behavior of a mechanical system of a railway vehicle regarding change of its motion. They evaluate behavior of individual masses of a railway vehicle, such a body of wagon, a bogie frame, wheelset etc. in relation acting forces and accelerations. For analyses of dynamics of railway vehicles various dynamic models of rigid (and/or flexible) bodies connected by viscoelastic coupling are used. Models are analyzed and assessed by various methods based on criteria and limit values [9,10].

3. Computer Simulations and Findings

For simulation computations a passenger car was chosen. Details about it are introduced in published work [11]. It is two-bogies four-axles passenger car, which is equipped with a primary and secondary suspension systems. The primary suspension connects wheelsets and axle-boxes with the bogie frame and the secondary suspension is between bogies and the body of wagon. In this work, results from simulation computations for two values of suspension stiffness are presented, i.e. original stiffness, called as Version A and “soft” stiffness, called as Version B. Parameters of both variants are listed in Table 1 and Table 2.

Table 1 Parameters of suspension, Version A. Source: authors

Springs		
	Primary suspension	
Description	Indication	Value
Stiffness	k_x	617,000 $N \cdot m^{-1}$
	k_y	617,000 $N \cdot m^{-1}$
	k_z	732,000 $N \cdot m^{-1}$
	Secondary suspension	
Stiffness	k_x	160,000 $N \cdot m^{-1}$
	k_y	160,000 $N \cdot m^{-1}$
	k_z	430,000 $N \cdot m^{-1}$

Table 2 Parameters of suspension, Version B. Source: authors

Springs		
	Primary suspension	
Description	Indication	Value
Stiffness	k_x	517,000 $N \cdot m^{-1}$
	k_y	517,000 $N \cdot m^{-1}$
	k_z	366,000 $N \cdot m^{-1}$
	Secondary suspension	
Stiffness	k_x	120,000 $N \cdot m^{-1}$
	k_y	120,000 $N \cdot m^{-1}$
	k_z	215,000 $N \cdot m^{-1}$

In addition, originally, dampers of primary and secondary suspensions have non-linear characteristics (Version A) and in the Version B damping has changed to linear characteristics. In the case of the suspension Version B the main effort was focused on experimentation with lower values of stiffnesses in the vertical direction and with linear characteristics of dampers.

In the model of a railway vehicle and a track, a standard non-linear wheel/rail contact known was defined. This model assures sufficient accuracy of calculation together with acceptable computing time [12-16].

For purposes of dynamic analyses, a model of a railway track was created, which distance was 6,075 m with higher number of curves of various radii in order to investigate behavior of the tested railway vehicle in severe operational conditions and at various running speeds. The track was defined in the vertical and in the horizontal profile. Outputs quantities are evaluated for two chosen running speeds, namely for 80 km·h^{-1} and for 120 km·h^{-1}.

3.1 Analysis of Running Properties of the Tested Railway Vehicle

Vertical wheel forces, lateral wheel forces and derailment quotient were chosen as the criteria for evaluation of running properties of a railway vehicle. In this section, results for running speed of 120 km·h^{-1} are shown.

For the vertical wheel force the limit value of 145 kN for quasi-static value is valid. For dynamic value of the vertical wheel force Q the limit value depends on its static value and on running speed and it varies from 160 kN to 200 kN [17].

Vertical wheel forces, lateral wheel forces and derailment quotient were chosen as the criteria for evaluation of running properties of a railway vehicle. In this section, results for running speed of 120 km·h^{-1} are shown.

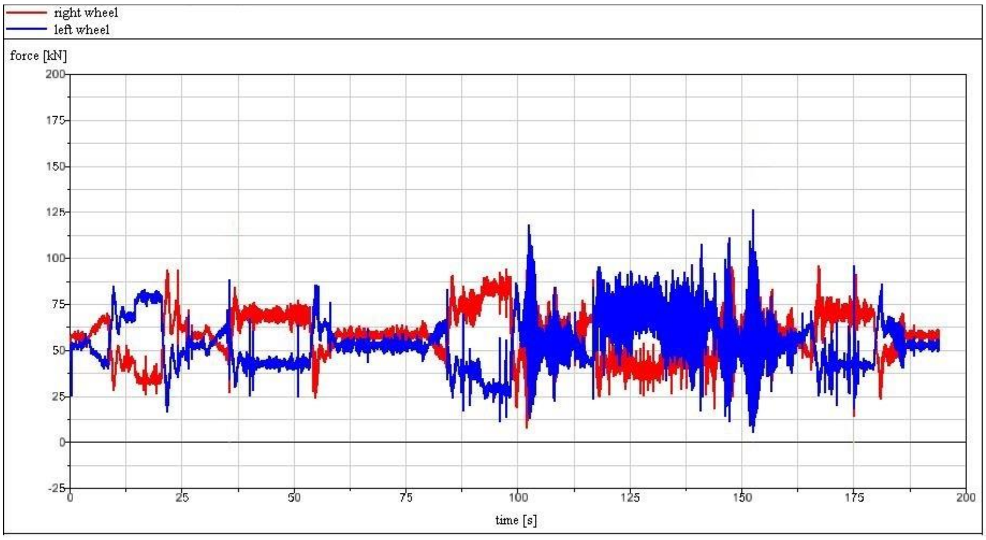

Fig. 1 Waveform of vertical wheel forces of the right wheel (red) and left wheel (blue), Version A. Source: authors

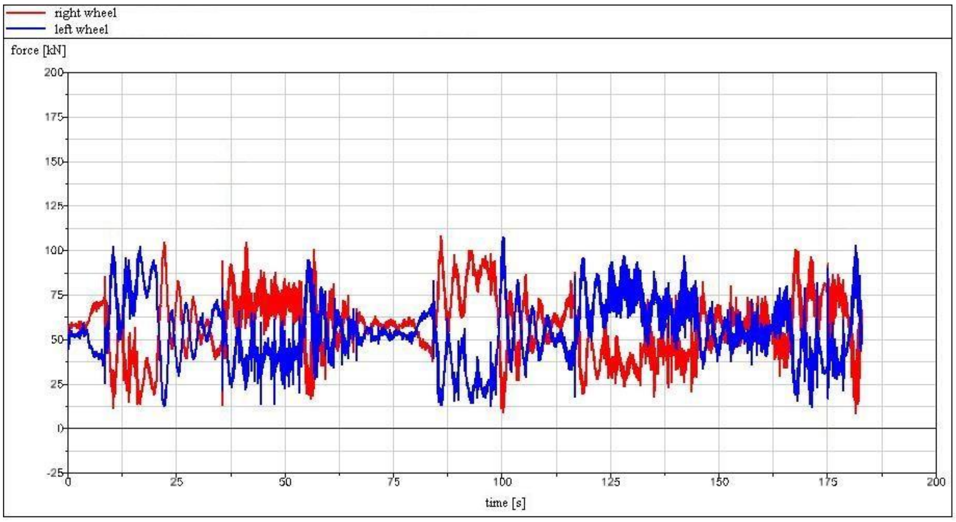

Fig. 2 Waveform of vertical wheel forces of the right wheel (red) and left wheel (blue), Version B.
Source: authors

The waveform of vertical wheel forces (see Fig. 1) shows, which values of the load act on wheels of a closing-up wheelset, while the load of the external wheel is being increased and in the opposite, the internal wheel is being relieved, when a railway vehicle is entering a curve and it is running in a curve. In Fig. 2 we can see, the mechanical system of the railway vehicle is excited by track irregularities, which results to higher amplitudes of observed vertical wheel forces. Values of the vertical wheel force do not exceed the value of 120 kN expect of a peak value.

When parameters of suspensions are set in compliance with Tab. 2, Version B, we can observe higher values of vertical forces in comparison with Version A, mainly in first half of a track, where the difference of forces in some moments reaches the value of 15 kN, but at different frequency of vibration. In straight sections of the track the average value of wheel forces on the left and right wheel corresponds to the weight belonging to individual wheels.

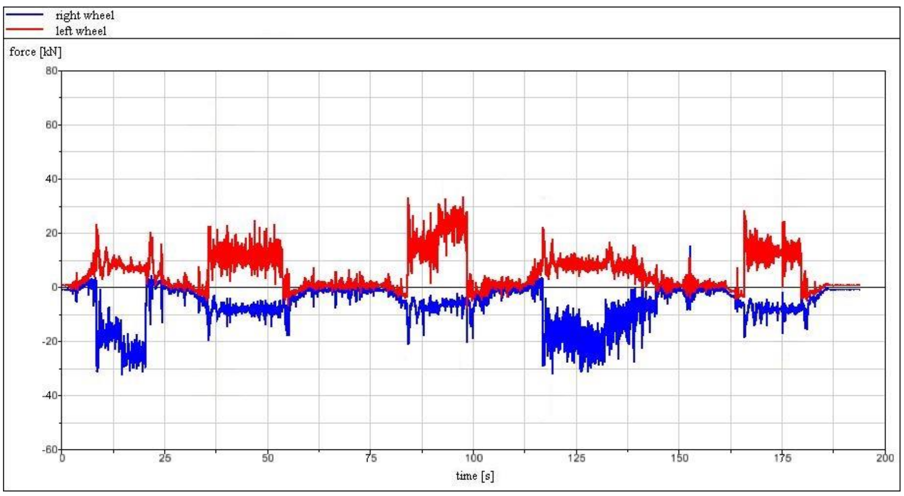

Fig. 3 Waveform of lateral wheel forces of the right wheel (red) and left wheel (blue), Version A.
Source: authors

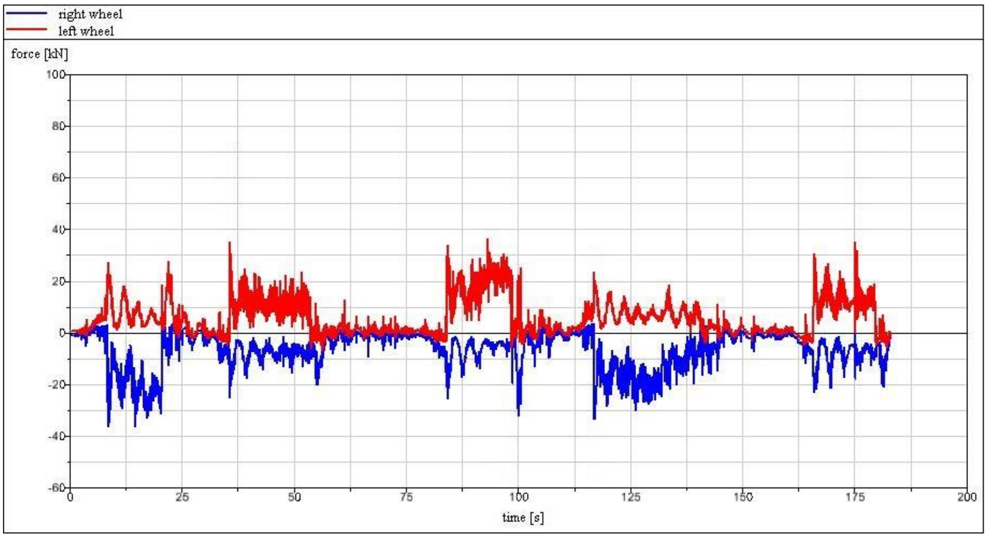

Fig. 4 Waveform of lateral wheel forces of the right wheel (red) and left wheel (blue), Version A.

Source: authors

Lateral wheel forces are other evaluated parameters from simulation computations. Results are shown in Fig. 3 and Fig. 4. Values of lateral forces reach during the railway vehicle running maximum values about 40 kN, which are formed, when the first wheelset is entering a curve. There are also sporadic values, which reach in some moments the value of 60 kN. These values are caused by a numerical error in calculation at that moment. Fig. 4 shows waveform of the lateral force of the same wheelset, but for version B. We can observe, results almost not differ from Version A.

A criterion for safety of a railway vehicle is the derailment quotient and it is given by the ratio of a lateral (Y) and a vertical force (Q), i.e. Y/Q. Results from simulations for derailment quotient are shown in Fig. 5 and Fig. 6.

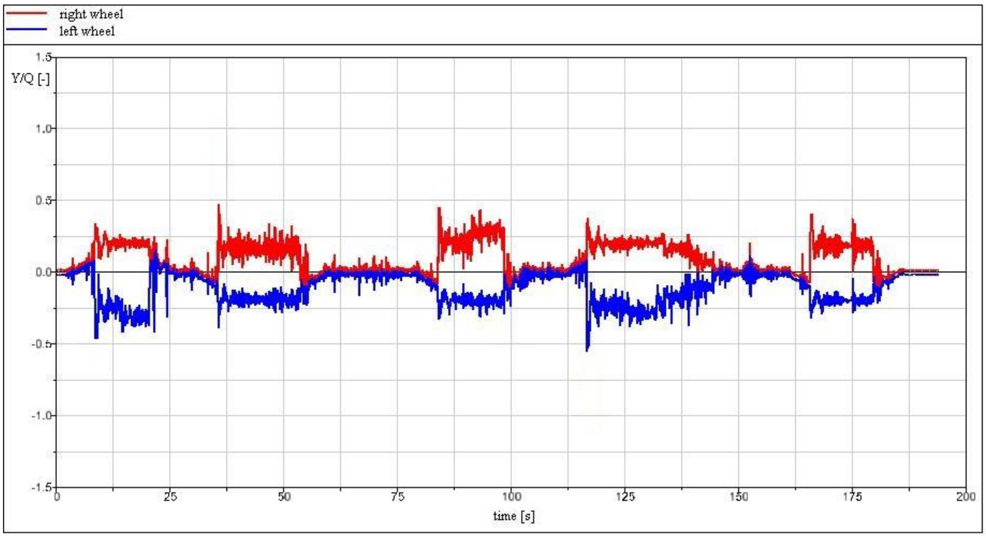

Fig. 5 Waveform of lateral wheel forces of the right wheel (red) and left wheel (blue), Version A.

Source: authors

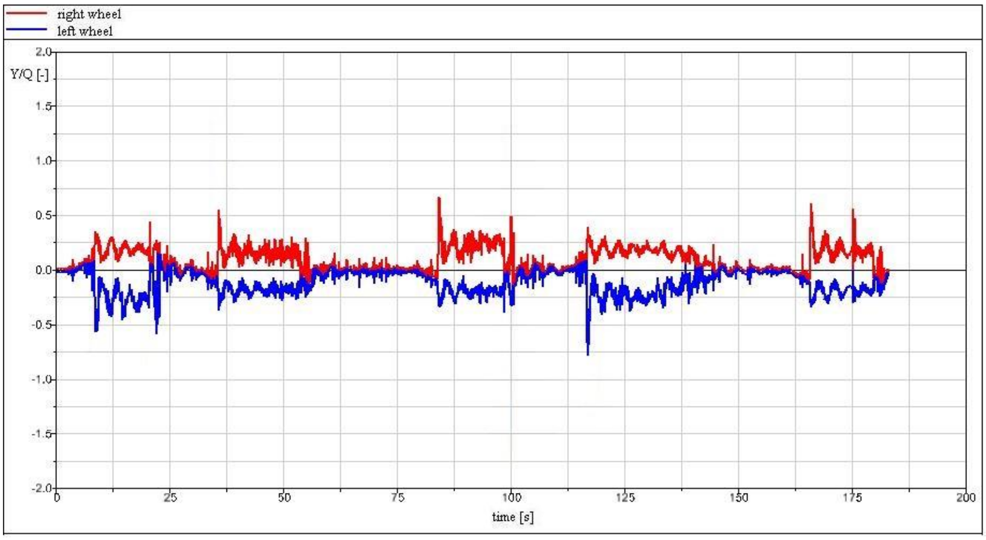

Fig. 6 Waveform of lateral wheel forces of the right wheel (red) and left wheel (blue), Version A. Source: authors

Values of the derailment quotient for the first wheelset vary about a value of 0.5 on both wheels of a wheelset. The greatest values of Y/Q are reached on the external wheels in curves. At this moment, the value oscillates about the value of 0.6. In some moments, sporadic values appear, which reach the limit value of 0.8. These values come from numerical errors during calculation. For Version B we observe similar values of ratio Y/Q as for Version A, but with higher number of sporadic values, which overcome the limit value.

3.2 Analysis of Passengers' Ride Comfort of the Tested Railway Vehicle

This section contains results from simulation analyses, which are focused on evaluation of passengers ride comfort. Generally, ride comfort for passengers express the sensitivity of a human body on vibration and movements. The level of discomfort is assessed based on vibrations, which are found out in defined positions. As key physical quantity, values of acceleration are crucial [18-20]. In related standard [21], there are defined more positions, where accelerations are measured.

In this work, the index for ride comfort measured on the body floor were calculated and evaluated. It is marked as N_{MV} ride comfort index.

For evaluation of ride comfort we can know values of accelerations in measured positions. In our case of study, measured positions are chosen in compliance with Fig. 7. Subsequently, these accelerations were input for calculation of the N_{MV} comfort index. Presented results are for running speeds of 80 $km{\cdot}h^{-1}$ and 120 $km{\cdot}h^{-1}$ and for both Version A and Version B.

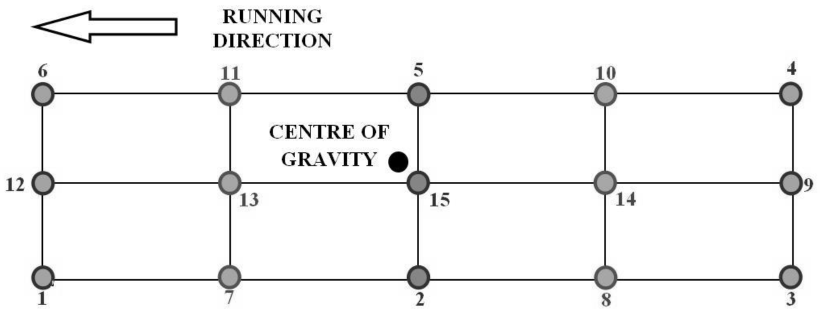

Fig. 7 Positions of acceleration sensors on the body floor. Source: authors

Results of calculated indices of ride comfort for passengers are arranged in Tables 3 to 6.

Table 3 N_{MV} index for Version A, 80 km·h^{-1}. Source: authors

Point	N_{MV} index	Point	N_{MV} index	Point	N_{MV} index	Point	N_{MV} index	Point	N_{MV} index
1	1.202	4	0.847	7	0.652	10	0.809	13	1.162
2	1.212	5	0.836	8	0.624	11	0.788	14	1.150
3	1.221	6	0.853	9	0.648	12	0.788	15	1.165

Table 4 N_{MV} index for Version A, 120 km·h^{-1}. Source: authors

Point	N_{MV} index	Point	N_{MV} index	Point	N_{MV} index	Point	N_{MV} index	Point	N_{MV} index
1	3.740	4	2.613	7	1.763	10	1.640	13	2.345
2	3.719	5	2.558	8	1.691	11	1.573	14	2.329
3	3.726	6	2.593	9	1.781	12	1.573	15	2.359

Table 5 N_{MV} index for Version B, 80 km·h^{-1}. Source: authors

Point	N_{MV} index	Point	N_{MV} index	Point	N_{MV} index	Point	N_{MV} index	Point	N_{MV} index
1	1.075	4	0.726	7	0.582	10	0.604	13	0.869
2	1.060	5	0.713	8	0.565	11	0.588	14	0.859
3	1.066	6	0.731	9	0.585	12	0.588	15	0.874

Table 6 N_{MV} index for Version B, 120 km·h^{-1}. Source: authors

Point	N_{MV} index	Point	N_{MV} index	Point	N_{MV} index	Point	N_{MV} index	Point	N_{MV} index
1	3.326	4	2.207	7	1.666	10	1.712	13	2.352
2	3.228	5	2.120	8	1.632	11	1.680	14	2.329
3	3.183	6	2.142	9	1.708	12	1.680	15	2.408

From calculated values comfort index we can assess, that with increased running speed, at which the railway vehicle runs on a track, mainly in curves, higher accelerations act on passengers and cause worse level of ride comfort. The highest values of comfort index are measured in ends of the body of wagon and towards to the centre of gravity values are being decreased. For running speed of 80 km·h^{-1} we can see, values of the N_{MV} index comfort do not exceed value of 1.5, which indicate very comfortable running for passengers. For running speed of 120 km·h^{-1} (see Table 4 and Table 6) we observe, the values of the N_{MV} comfort index are in the range of $1.5 \leq N_{MV} \leq 2.5$ [18], which belong to the comfortable running for passengers except for points 1, 2 and 3, which locate in rear part of the body of wagon. In these positions, we have calculated values over 3.5, which class them to the evaluation of uncomfortable running for passengers. For Version B, values of N_{MV} index are in the range of $2.5 \leq N_{MV} \leq 3.5$ [18], which is the range for average comfortable running for passengers. When we have compared values of N_{MV} comfort index for Version A and Version B we have observed, that the using of system of suspension with parameters of Version B ("soft" stiffness, linear damping) gives an account of better values of ride comfort for passengers then Version A for both described values of running speeds of 80 km·h^{-1} and 120 km·h^{-1}.

4. Conclusion

The computer simulations of railway vehicles will remain in existence even will be used much more. Low cost of simulation computations in comparison with production and testing of real vehicles on tracks represent essential advantage connected with increasing productivity and efficiency. By means of these analyses we can quite easy obtain various output parameters, based on we can evaluate and assess all fundamental and advanced properties of a railway vehicle, which are necessary from the ride safety, ride comfort and load of a track.

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