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DYNAMICS OF A RAILWAY VEHICLE WITH TWO BOGIES ALONG DIRECT WAVED RAILWAY

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Summary: *The paper is devoted to dynamical analysis of a railway vehicle motion along a direct waved railway. A mathematical model of this discrete multibody system that consists of vehicle case and two bogies with double suspension is created. The exact time change of a wheel-rail contact point position during vehicle motion, when a wheel carries out a general spatial motion, is included into the model. The variable creep force effects between wheels and rails are supposed to be nonlinear according to Kalker's theory. The rails and vehicle wheels are interconnected through the contact creep elements. The whole vehicle is excited by rail irregularities. Numerical solution and graphical visualization of the vehicle motion with the constant forward velocity is performed.*

1. Introduction

The demand on transport safety, increasing of travel speed, comfort and reliability of railway vehicles grow continually within the development of modern high-speed railway vehicles. This tendencies lead to the analysis of the vehicle motion along the railway route and to the determining unfavourable circumstances and their influences upon the vehicle motion and its

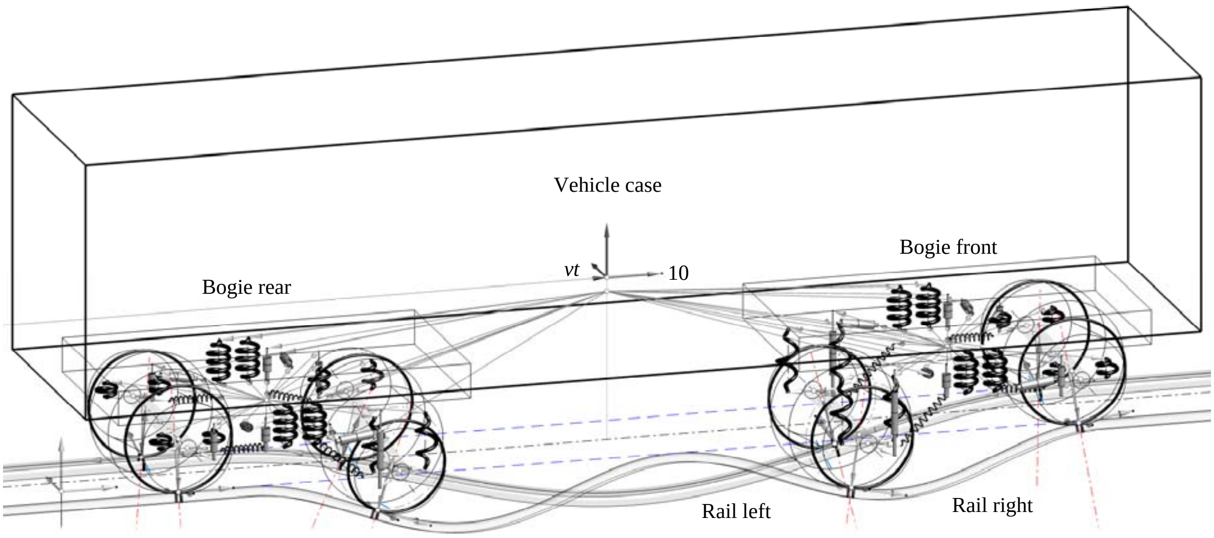

Figure 1 Geometrical visualisation of dynamic model of railway vehicle.

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stability. The main excitation sources of railway vehicles are track irregularities while the vehicle is running on the track. The next important excitation sources are caused by the flexibility and ovality of wheels. This paper is concentrated on an analyzing influence of irregularities of the railway route on the vehicle motion and follow-up to the paper Siegl & Švígler (2009) where the motion of two axled bogie along direct waved railway is analysed only.

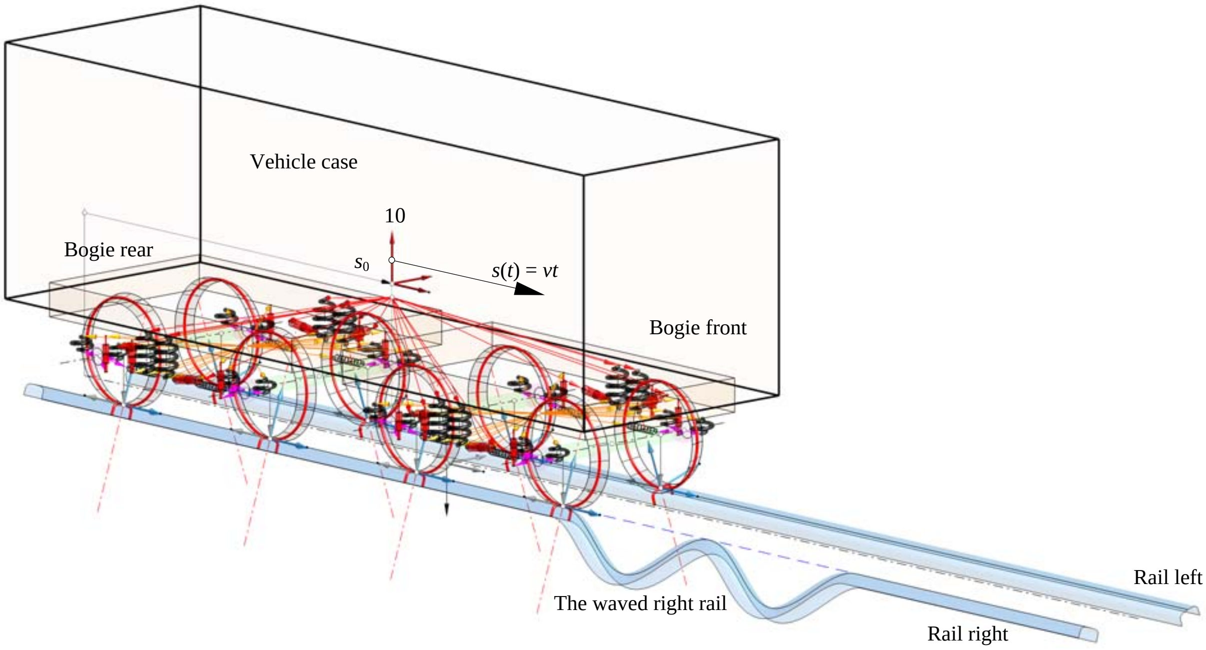

Figure 2 Railway vehicle in the start position

2. Vehicle model

The railway vehicle is considered as a closed kinematical chain that creates the multibody system with 23 bodies and 30 degrees of freedom, see Fig. 1. Each body of this system is considered perfectly rigid with immaterial link elements, which can be connected to arbitrary other body. Two node link elements with 6 degrees of freedom are designed and with nonlinear characteristics. The bogies have not individual wheel set drive. The railway, which is considered infinitely material and perfectly rigid, is connected to the vehicle wheels by contact creep elements. The rail head profile is modeled exactly in accordance with the profile UIC 60 and the rails waviness in the vertical longitudinal plane has a form of harmonic function. Vehicle primary and secondary suspension is modeled by spring and damper elements. The following assumptions are considered for motion equations developing of the vehicle system. The wheel sets run freely in the journal bearings without bearing friction and do not generate either tractive or braking force effects. Displacements in suspension elements are considered great. The wheel-flange contact and nonlinearities in adhesion limits between the wheel and rail are neglected. The simplified wheel contact geometry and the linear creep theory is used. The gyroscope moments of the wheel sets are neglected. There is no wheel lift and the wheels are always in contact with the rails. Mathematical model of the vehicle is created by the decomposition method. The force effect in a contact creep element is described by the Kalker's linear theory of rolling contact, Kalker (1967). The contacting bodies are considered finite rigid for rolling contact analyses.

2.1. *Vehicle building*

The railway vehicle is understood as a multibody system. The model is assembled by structural elements of types mass body and link elements whose parameters are given in Siegl & Švígler (2009). The list of original bodies is shown in the Tab. 1, however, ballast and a sleeper are not considered in this model yet.

Part *i*	Name of body
1	Case of vehicle
2	Frame of bogie
3	Axle shaft
4	Axle box left
5	Axle box right
6	Wheel
10	Rail
11	Sleeper
12	Ballast
13	Earth

Table 1 List of parts

The *j*-th copy of the *i*-th body is marked *ij* and the unique identifying number of this body *ij* is marked *m*, see Tab. 2. The bodies of this multibody system are connected by link elements of types spring, damper and joint. The equilibrium space 10 of the vehicle case is used for vehicle moving along railway. Because the multibody system of the vehicle has a *finite tree structure* there is created a builder with the *recursive* algorithm of a whole vehicle system. A list of the bodies is shown in the Tab. 2.

Absolute number *m*	Name	Part *i*	Parent *p*	Tree level *L*	Degrees of freedom	Asolute copy *j*	Relative copy	Note
1	Case of vehicle	1	1	1	6	1	1	
2	Frame of bogie	2	1	2	6	1	1	Front bogie
3	Axle Shaft	3	2	3	3	1	1	
4	Axle Box Left	4	3	4	0	1	1	
5	Axle Box Right	5	3	4	0	1	1	
6	Wheel	6	3	4	0	1	1	Left
7	Wheel	6	3	4	0	2	2	Right
8	Axle Shaft	3	2	3	3	2	2	
9	Axle Box Left	4	8	4	0	2	1	
10	Axle Box Right	5	8	4	0	2	1	
11	Wheel	6	8	4	0	3	1	Right
12	Wheel	6	8	4	0	4	2	Left
13	Frame of bogie	2	1	2	6	2	2	Back bogie
14	Axle Shaft	3	13	3	3	3	1	
15	Axle Box Left	4	14	4	0	3	1	
16	Axle Box Right	5	14	4	0	3	1	
17	Wheel	6	14	4	0	5	1	Left
18	Wheel	6	14	4	0	6	2	Right
19	Axle Shaft	3	13	3	3	4	2	
20	Axle Box Left	4	19	4	0	4	1	
21	Axle Box Right	5	19	4	0	4	1	
22	Wheel	6	19	4	0	7	1	Right
23	Wheel	6	19	4	0	8	2	Left
					30			

Table 2 Bodies list – Relational matrix

Note 1. The wheels and axle boxes are connected to the axle shaft by joints with zero degrees of freedom.

3. Motion equations

The condition of the *m*-th body dynamical equilibrium in the actual space *m* is

$$\mathsf{Q}_m(t) = \mathsf{Q}_m\left(\frac{\partial^2 \mathsf{q}_m}{\partial t^2},\ \frac{\partial \mathsf{q}_m}{\partial t},\ \frac{\partial \mathsf{q}_r}{\partial t},\ \mathsf{q}_m,\ \mathsf{q}_r\right) = \mathsf{Q}_{Im} + \mathsf{Q}_{Em} + \mathsf{Q}_{Gm} = 0_{8\times 1} \tag{1}$$

where Q_{Im}, Q_{Em}, Q_{Gm} is inertia, link elements and gravity force effect, respectively, *r* is a body number that is linked with the *m*-th body by link elements. The Eq. 1 represents a system of ordinary second-order nonlinear differential equations which are solved numericaly.

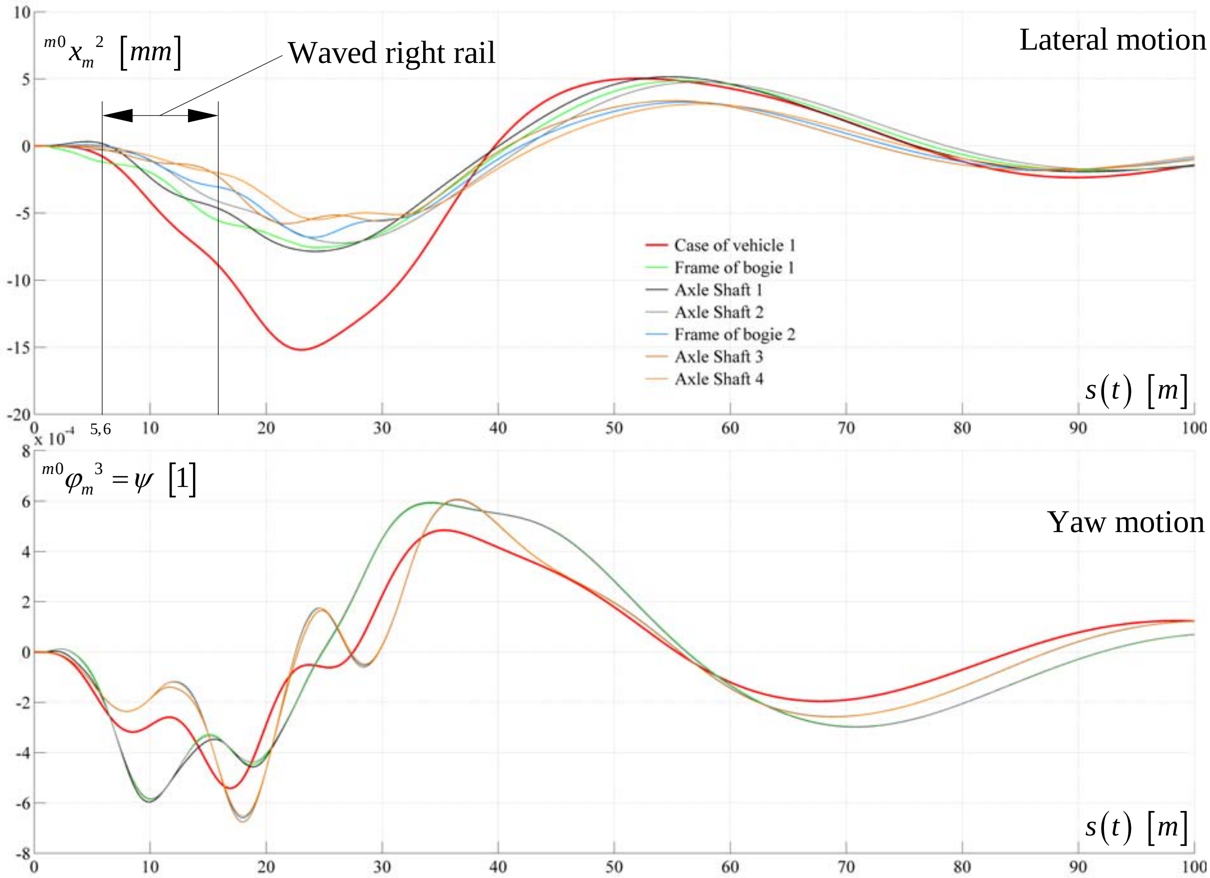

Figure 4 Motion of the railway vehicle by forward velocity *v* = 100 [*km*/*h*]

4. Numerical simulation

The numerical simulation is made with zero initial values without vertical position of the vehicle case $^{10}q_{10}{}^3 \cong -159{,}05\ [mm]$ and vertical positions of bogies $^{20}q_{20}{}^3 = {}^{20}q_{13,0}{}^3 \cong -32{,}54\ [mm]$ on the direct railway with length 100 [*m*], Fig. 4, 5. Two forward velocities *v* are chosen for comparison. The following deformed railway is chosen for illustrative visualisation of dynamical response of the vehicle, Fig. 2. The right rail in the second railway segment with length 20 [*m*] has two cosinusoidal downthrows with minimum 12 [*mm*]. The bodies names used in the legends in the Fig. 4 and 5 are shown in the Fig. 3.

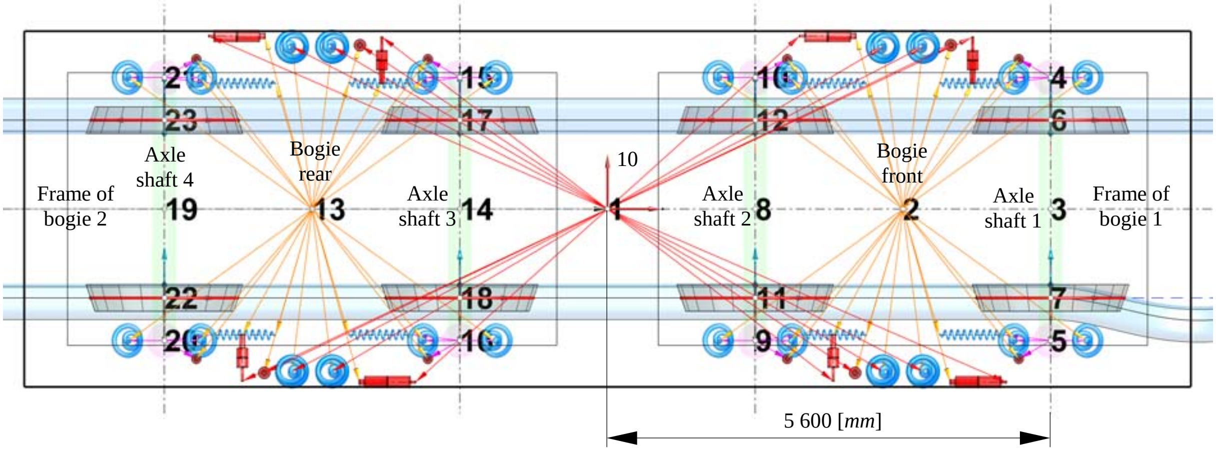

Figure 3 Railway vehicle in the start position
with bodies identification numbers m – Top view

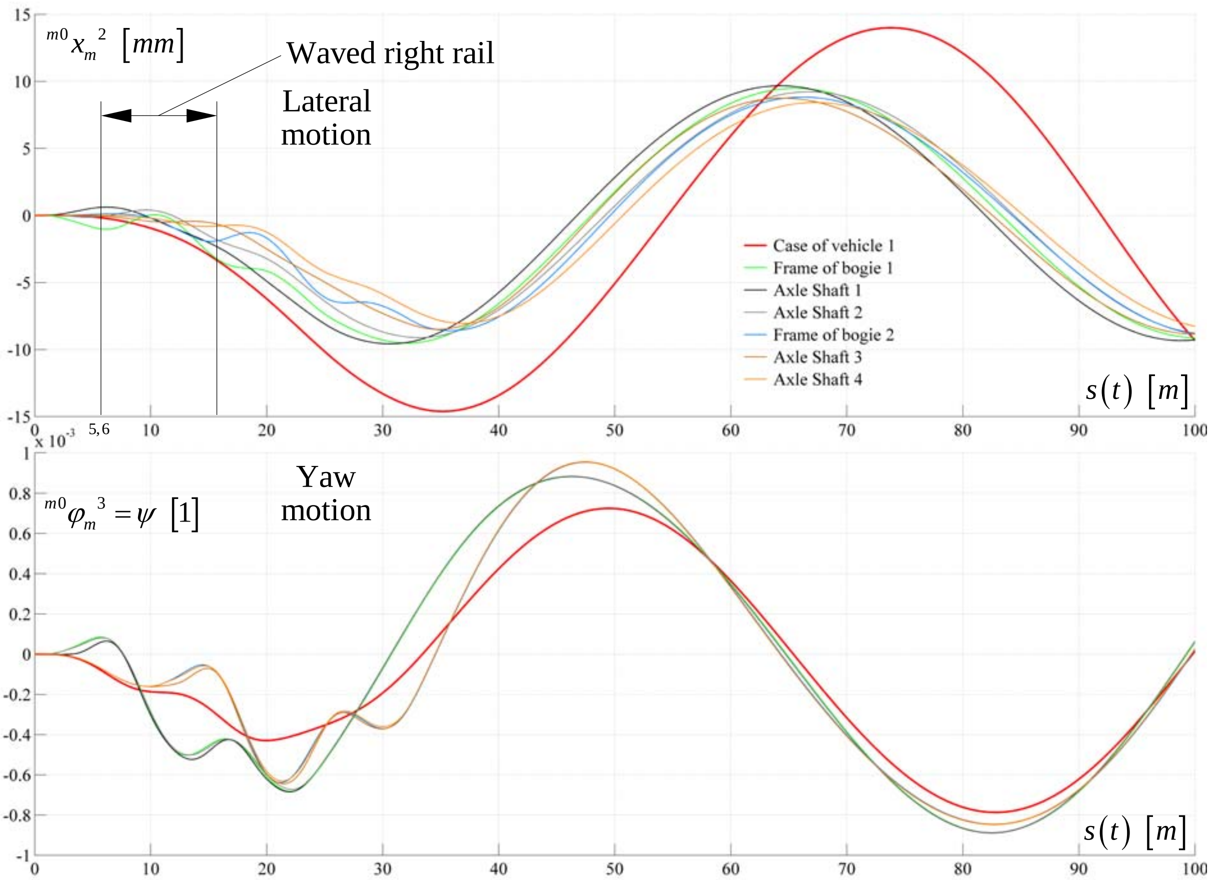

Figure 5 Motion of the railway vehicle by forward velocity v = 160 [km/h]

5. Conclusions

The mathematical model of the railway vehicle and the numerical solution of this mathematical model is made by own computational software which allows to simulate a multibody system oscillation in dependence on initial values. An influence of railway waviness to the vehicle motion stability is shown. The performed numerical simulation for given input data indicates that vehicle motion is steady approximately up to the forward velocity $v = 158$ [*km*/*h*], see Fig. 6. The next work will be oriented to the model extension with a finite stiffness of the rail with subsoil. The own software gives very good preconditions for performance of targetly oriented analyses.

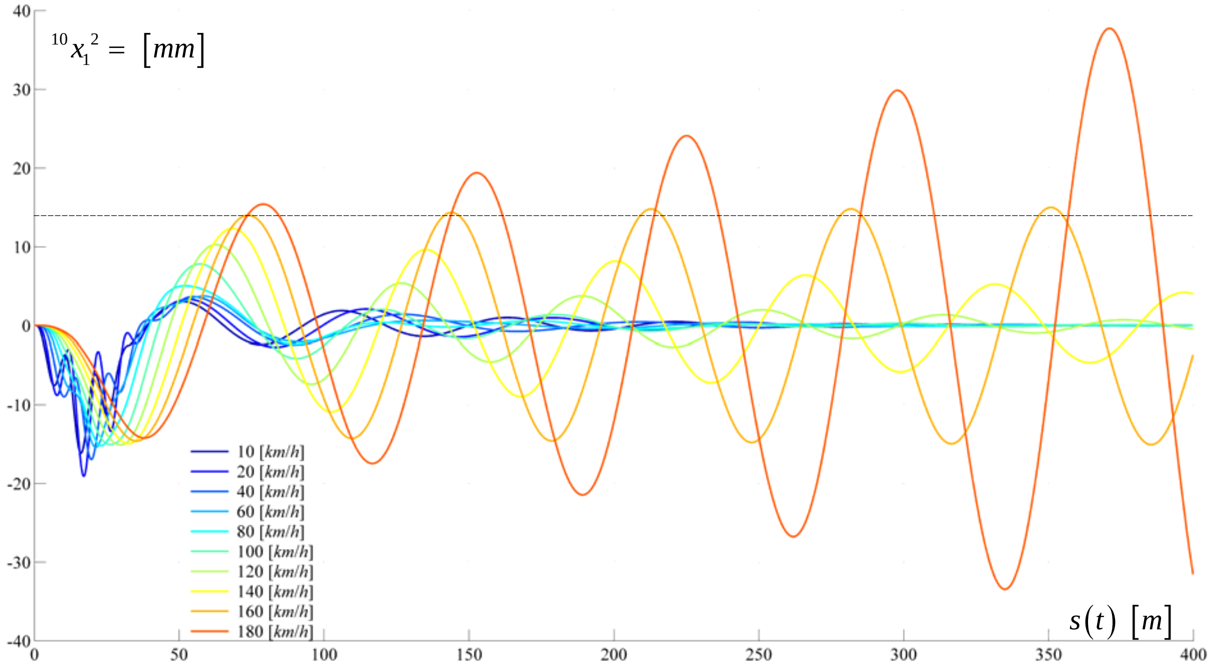

Figure 6 Lateral motion of the vehicle case in dependence of time and forward velocity *v*

6. Acknowledgement

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