RTU
ZINĀTNISKIE
RAKSTI

SCIENTIFIC
PROCEEDINGS
OF RIGA
TECHNICAL
UNIVERSITY

MAŠĪNZINĀTNE UN TRANSPORTS

TRANSPORT AND ENGINEERING

SĒRIJA 6
SĒJUMS 12

RĪGA 2003

CONTENTS

SIMPLIFIED MODEL OF VERTICAL VIBRATION FOR PASSENGER CAR DURING ITS MOVING ON IRREGULAR TRACK

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Simplified Model of Wagon, Irregular Track, ADAMS modeling

Introduction

Computer program are used for the modeling of dynamic phenomenon which take place during the movement of the train. Among them there are such program as ADAMS, VAMPIRE, DADS, SIMPACK, ERDE, MEDYNA and Visual NASTRAN 4D Desktop.

The use of programs for the analysis of dynamics of a train plays an important role in the field of research and development of modern conception of the trains. The reason of the use of computer models for the prior stages of trains research is the high price of the prototype research. Such programs make it possible to model not only the influence of construction carriage parameters and the influence of outside phenomena connected with motion (e.g. irregularities of tracks) on the dynamic characteristics, as separate elements of a train, so trains as a whole or groups of carriages.

The research of different railway transport (locomotives, carriages, special cars, trains consisting of locomotive and few carriages) includes:

- analysis of the forces which appear between the wheel and the rail;
- analysis of the influence of the construction of wheels, bogies and other parts of the construction on the dynamics of a carriage;
- analysis of the movement of a carriage along the irregular track;
- determination of amplitude – frequency characteristics for the elements of a carriage;
- analysis of the sensitivity of the railway carriage.

Analysis of the sensitivity of the railway carriage motion (fig. 1) includes the sensitivity of structure and sensitivity of parameters. Analyzing structural sensitivity first of all we consider the influence of the type of a carriage and its technical parameters on its movement. Analysis of parametric sensitivity consider parameters connected with track (irregularities), wheel – rail pair as well as with the element influencing the behavior of the carriage while moving (spring).

A lot of scientists in Poland and all over the world carried out the research of the dynamic phenomena of the railway carriage motion. They were interested not only in separate carriage (e.g. locomotives, box-cars, etc.) but also in a set of carriages (e.g. set of several carriages and locomotive). Not only new constructions are under research but also those which have been used for several years. Research of new constructions makes it possible to model their behavior in different situations. Modeling of the behavior of the used carriages makes it possible to optimize the construction of the railway carriage for the improvement of their dynamic characteristics.

The research can not include the whole carriage, but only its elements (wheel set, bogies). W. Gąsowski and Z. Marciniak [1] researched the bogie with a primary suspension. One of the aims was the analysis of bogie construction parameters influence on its stability. The equations of the bogie motion were developed, under the condition of regular track. The article consider the interaction of wheel and rail. Also two computer programs for the determination of the criti-

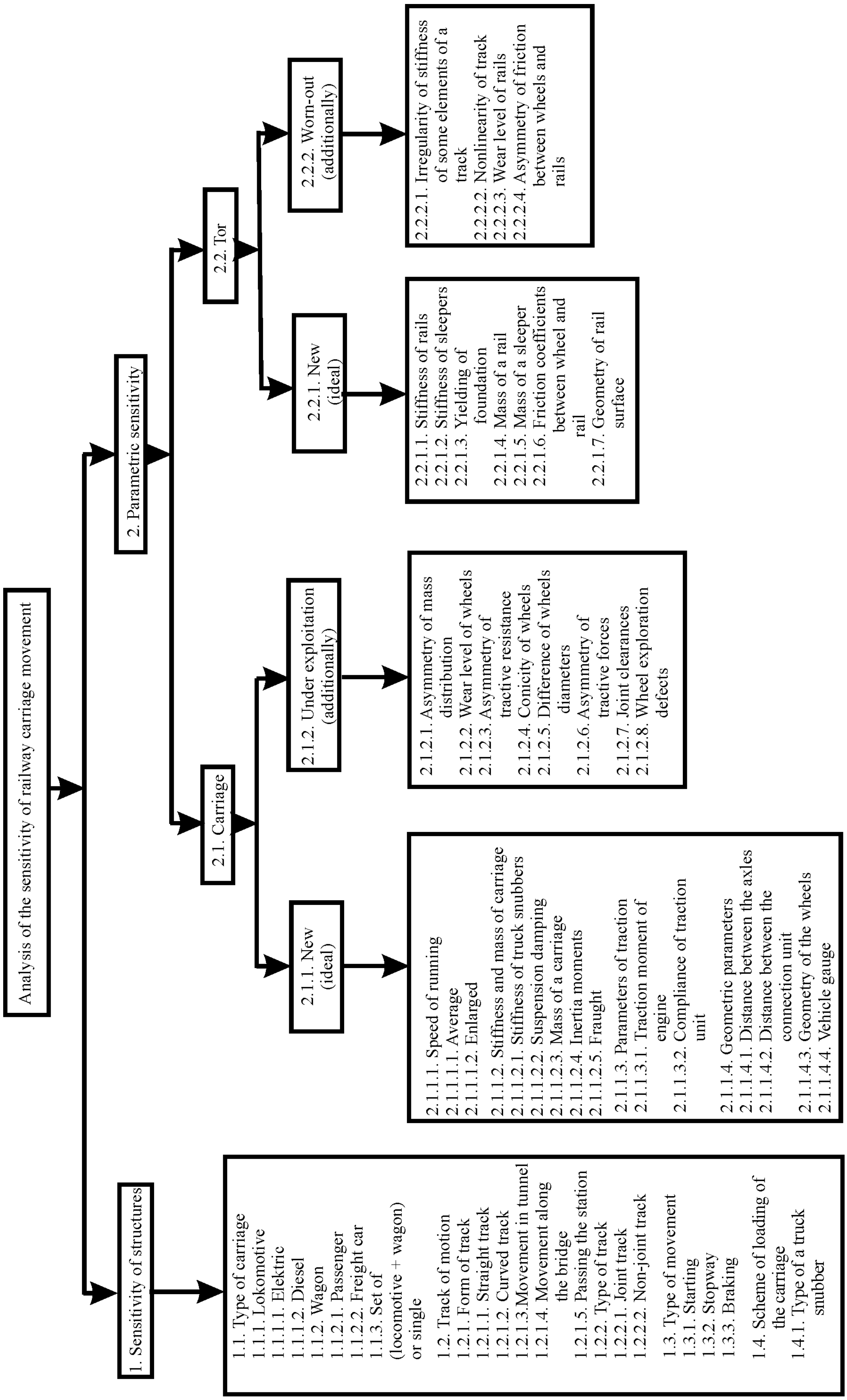


Fig. 1. Analysis of the sensitivity of railway carriage movement

cal speed of a bogie were worked out and the results were described. The authors describe those parameters of bogie, which have the main influence on its stability during movement. The model movement of the bogie is going along the ideal track. The article doesn't give the description of the movement along real track.

J. Kisilowski [2] gave the analysis of the dynamics of the whole railway train. Analysis of the behavior of the train is given for the motion along arbitrary track. Mathematical models of the motion of the separate elements of carriage (wheel sets, bogies) as well as the model of track were given. The article also gives the description of experimental research of the train - track interaction for determination of some magnitudes which influence the dynamics of railway train. Mathematical model is given, but, at the same time, there is no description of model train movement along real track. The author also doesn't try to describe the irregularities of the track. The experimental research is carried out on the real track, but there id no its description (irregularities including).

J. Matej in his article [3] described the model of bimodal train consisting of two tanks and one semi-trailer. The research was carried out in the ADAMS RAIL program. The article deals with the analysis of the stability of the model movement as well as describes the displacement and acceleration in defined points of bimodal train. The magnitudes of the forces which act on the side slippers are also given. The article doesn't describe the type of the track. The author also doesn't mention if the experimental track was ideal or it was with some defined irregularities.

In their article W. Gąsowski and M. Szymański [4] deal with the problem of the influence of the increase of loading on the axle and on the dynamics of the carriage under research. The experimental carriage was a dump-car type 424V. The article also analyzed the influence of increase of axle loading on the safety of movement along the wavy track. But the authors don't give the magnitude and the type of the irregularities, the parameters which describe the track (stiffness of rail, sleepers, beds, etc.) are also not given.

The authors in their works [5], [6] dealt with the problems described before. None of the works is the continuation of the carried research.

The aim of this work is to work out a computer model of a carriage dynamics for further defining of the influence of the carriage characteristics on the dynamic loading of the wheel sets. Such model had to be worked out by analytical method.

Description of the model under research

The passenger wagon of type 127Aa with the bogies of type 4Anc was under simulation research in program ADAMS. Physical model of the research wagon is shown on fig. 2. Coordinates x_1 and x_2 describe the vertical movement of bogies. Coordinates x_3 and φ describe the behavior of car body during the movement along the irregular track.

Body of a wagon is modeled as a stiff one, which is connected with bogies with a help of spring and truck snubbers (k_2' and c_2') with linear characteristics. Bogie frame is modeled as a stiff body. It is connected with the wheel sets (k_1' and c_1') by the spring-damper unit. Such connection is of a linear type.

Coefficients of stiffness k_1' and k_2' as well as the coefficients of damping were determined during reduction of modeling wagon up to model with four degrees of freedom.

The model of the wagon created by means of the program ADAMS is shown on fig. 3.

Parameters chosen for the modeled wagon and its movement are submitted in table 1.

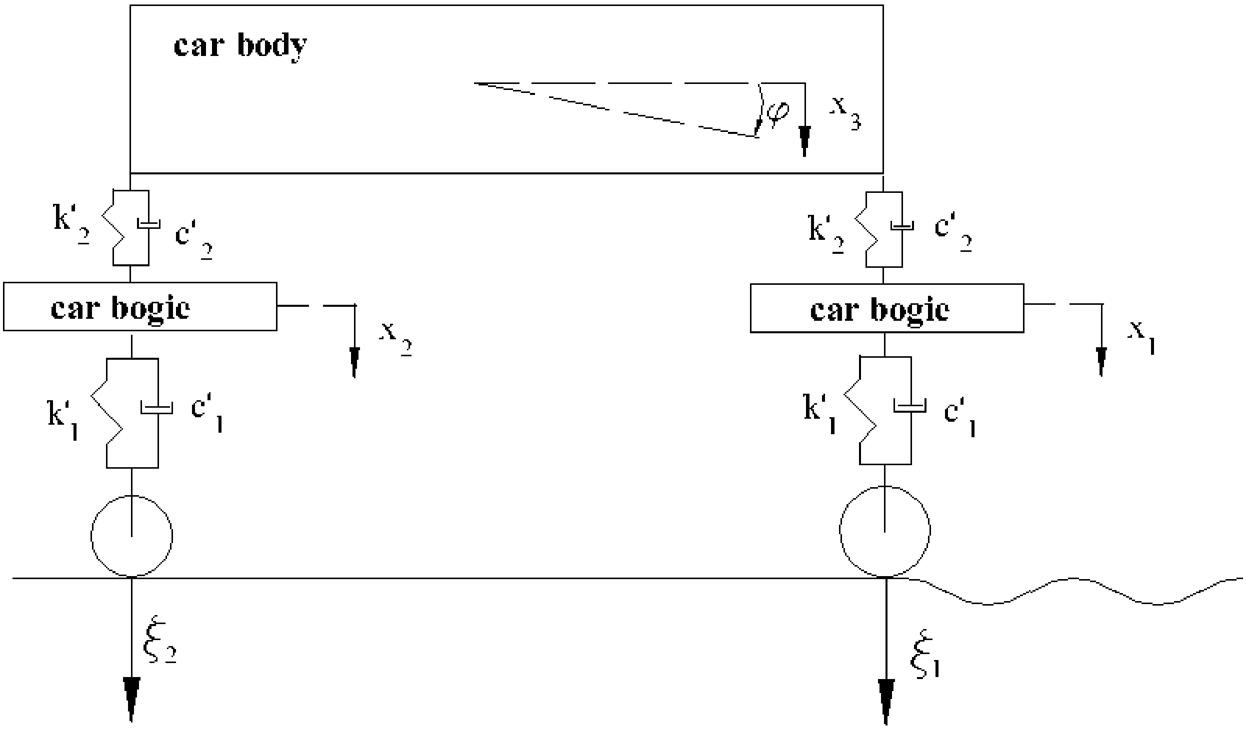


Fig. 2. Simplified model of wagon under research

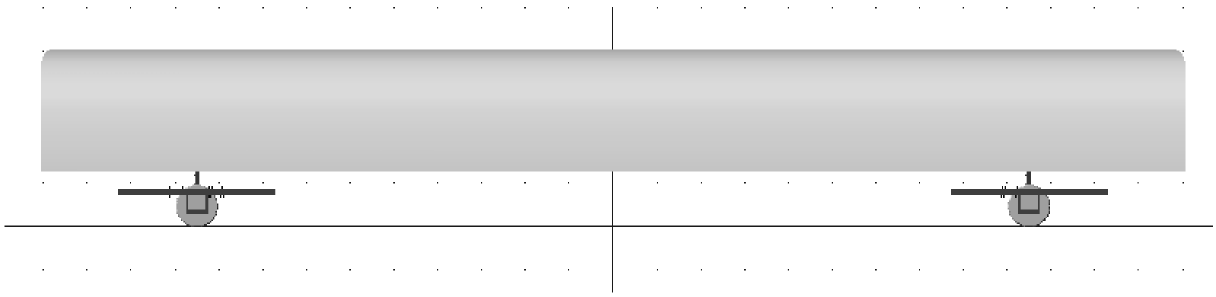


Fig. 3. Model of wagon on program ADAMS

Table 1.

Some technical data of the wagon under research

N	Data	Quantity
1	Mass of a wagon body	28530 [kg]
2	Mass of a bogie frame	3000 [kg]
3	Mass of a wheel set	1500 [kg]
4	Diameter of wheels	920 [mm]
5	Vertical stiffness for first level spring	$3{,}6\cdot10^6$ [N/m]
6	Vertical stiffness for second level spring	$7{,}6\cdot10^5$ [N/m]
7	Vertical damping for first level spring	$6{,}4\cdot10^4$ [Ns/m]
8	Vertical damping for second level spring	$5\cdot10^4$ [Ns/m]
9	Distance between connection units	19 [m]
10	Speed of running	60 [km/h]

Modeled wagon runs with the speed of 60 km/h along the straight track, irregularities in which are modeled as changes in vertical positions of a wheel in time (function $\xi_1(t)$ and $\xi_2(t)$ for first and second wheel sets).

Formulated mathematical model was given later.

$$m_w \cdot \ddot{x}_1 + \left(c_1' + c_2'\right) \cdot \dot{x}_1 - c_2' \cdot \dot{x}_3 - \frac{l}{2} \cdot c_2' \cdot \dot{\varphi} + \left(k_1' + k_2'\right) \cdot x_1 - k_2' \cdot x_3 - \frac{l}{2} \cdot k_2' \cdot \varphi = c_1' \dot{\xi}_1 + k_1' \xi_1$$

$$m_w \cdot \ddot{x}_2 + \left(c_1' + c_2'\right) \cdot \dot{x}_2 - c_2' \cdot \dot{x}_3 - \frac{l}{2} \cdot c_2' \cdot \dot{\varphi} + \left(k_1' + k_2'\right) \cdot x_2 - k_2' \cdot x_3 - \frac{l}{2} \cdot k_2' \cdot \varphi = c_1' \dot{\xi}_2 + k_1' \xi_2$$

$$m_p \cdot \ddot{x}_3 + 2 \cdot c_2' \cdot \dot{x}_3 - c_2' \cdot \dot{x}_1 - c_2' \cdot \dot{x}_2 + 2 \cdot k_2' \cdot x_3 - k_2' \cdot x_1 - k_2' \cdot x_2 = 0 \quad (1)$$

$$J_p \cdot \ddot{\varphi} + \frac{l^2}{2} \cdot c_2' \cdot \dot{\varphi} - \frac{l}{2} \cdot c_2' \cdot \dot{x}_1 + \frac{l}{2} \cdot c_2' \cdot \dot{x}_2 + \frac{l^2}{2} \cdot k_2' \cdot \varphi - \frac{l}{2} \cdot k_2' \cdot x_1 + \frac{l}{2} \cdot k_2' \cdot x_2 = 0$$

where m_w - mass of wagon bogie, m_p - mass of wagon body, J_p - inertia moment of body.

On base of charts of vertical irregularities of track were obtained as a result of the research of the track state on the way Katowice – Częstochowa the function describing vertical displacement of wheel set was as follows:

$$\xi(t) = \frac{a}{2}\left(\cos\frac{2\pi}{\lambda} \cdot t - \alpha\right) \quad (2)$$

where t - time of movement, a - amplitude of a function ($a = 0{,}02$ m), λ - distance between the tops of irregularities, α - phase of driving function.

Program MathCAD was used for the solving of equations obtained as a result of analytical method. The solution of the equations in this program is not simple. System of four differential equations of the second order must be changed for system of eight differential equations of the first order. System of equation for MathCAD solving must be as following:

$$\frac{d}{dt}X_0 = X_4$$

$$\frac{d}{dt}X_1 = X_5$$

$$\frac{d}{dt}X_2 = X_6 \quad (3)$$

$$\frac{d}{dt}X_3 = X_7$$

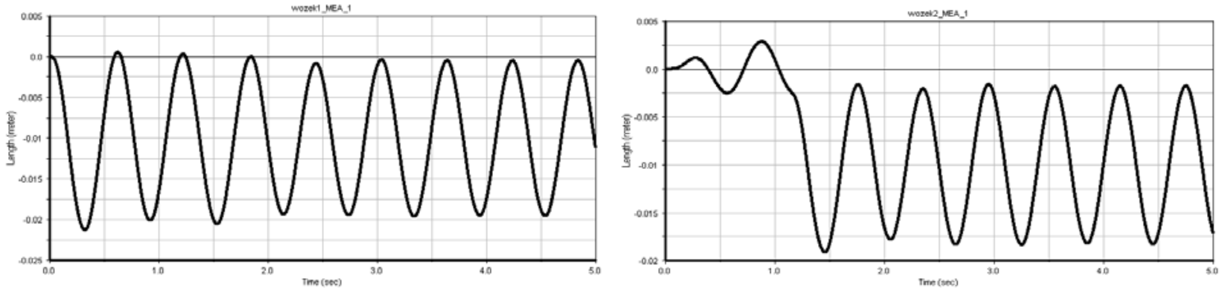
$$\frac{d}{dt}X_4 = \frac{\left[c_{z2} \cdot \left(X_6 + \frac{1}{2}X_7\right) - (c_{z1} + c_{z2}) \cdot X_4 + k_{z2} \cdot \left(X_2 + \frac{1}{2}X_3\right) - (k_{z1} + k_{z2}) \cdot X_0 + c_{z1} \cdot \varepsilon_1(t) + k_{z1} \cdot \xi_1(t)\right]}{m_w}$$

$$\frac{d}{dt}X_5 = \frac{\left[c_{z2} \cdot \left(X_6 - \frac{1}{2}X_7\right) - (c_{z1} + c_{z2}) \cdot X_5 + k_{z2} \cdot \left(X_2 + \frac{1}{2}X_3\right) - (k_{z1} - k_{z2}) \cdot X_1 + c_{z1} \cdot \varepsilon_2(t) + k_{z1} \cdot \xi_2(t)\right]}{m_w}$$

$$\frac{d}{dt}X_6 = \frac{(c_{z2} \cdot X_4 + c_{z2} \cdot X_5 - 2 \cdot c_{z2} \cdot X_6 + k_{z2} \cdot X_0 + k_{z2} \cdot X_1 - 2 \cdot k_{z2} \cdot X_2)}{m_p}$$

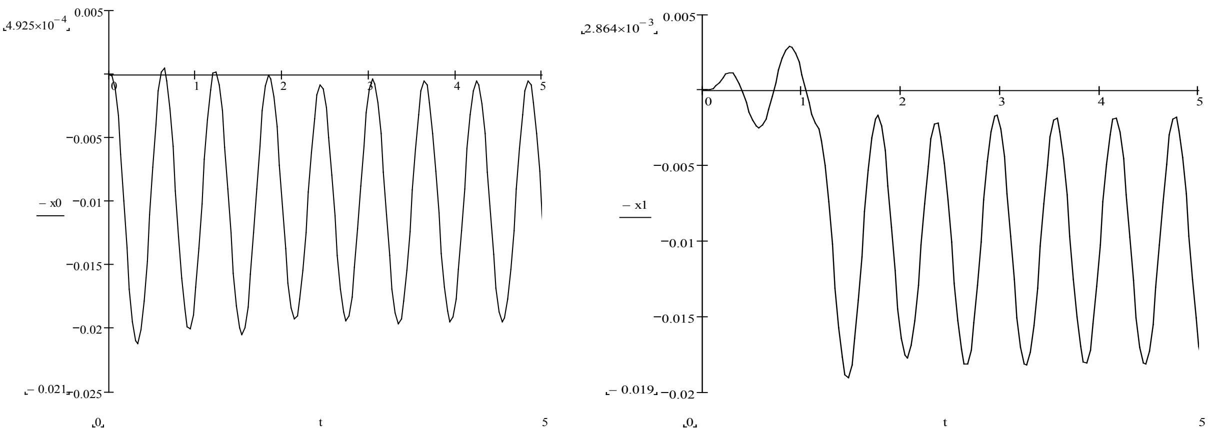
$$\frac{d}{dt}X_7 = \frac{\left(\frac{l}{2} \cdot c_{z2} \cdot X_4 - \frac{l^2}{2} \cdot c_{z2} \cdot X_7 - \frac{l}{2} \cdot c_{z2} \cdot X_5 + \frac{l}{2} \cdot k_{z2} \cdot X_0 - \frac{l^2}{2} \cdot k_{z2} \cdot X_3 - \frac{l}{2} \cdot k_{z2} \cdot X_1\right)}{I_p}$$

where X_0 - vector of vertical displacements of the first bogie, X_1 - vector of vertical displacements of the second bogie, X_2 - vector of vertical displacements of the body of wagon, X_3 - vector of angular displacements of the body of wagon, $\varepsilon_1(t) = \dot{\xi}_1(t)$, $\varepsilon_2(t) = \dot{\xi}_2(t)$. In the following figures (fig. 4 – 9) schedules of vertical moving of elements of the considered car are shown.



a b

Fig. 4. Vertical displacement of the bogie of wagon modeling in program ADAMS:
a) the first bogie, b) the second bogie



a b

Fig. 5. Vertical displacement of the bogie of wagon modeling in program MathCAD:
a) the first bogie, b) the second bogie

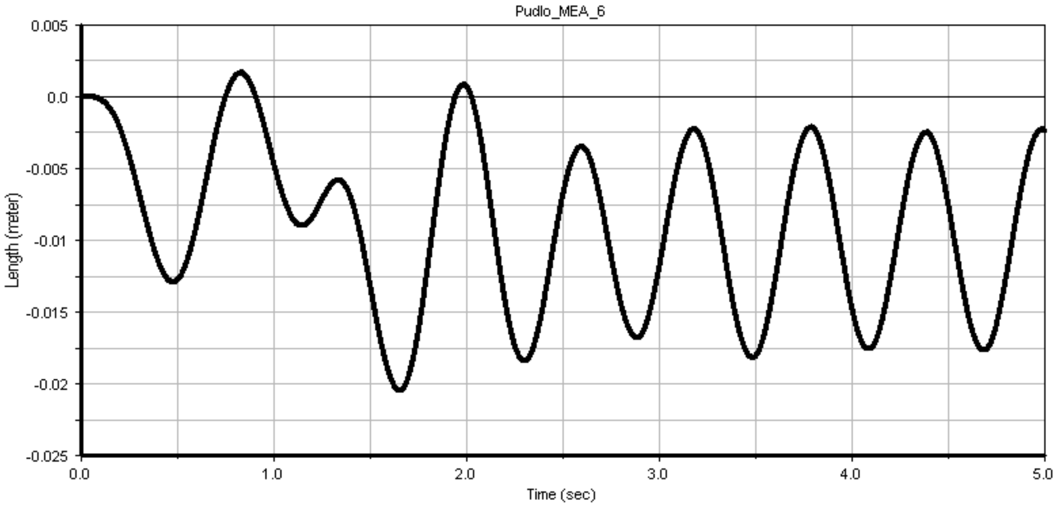


Fig. 6. Vertical displacement of the body of wagon modeling in program ADAMS

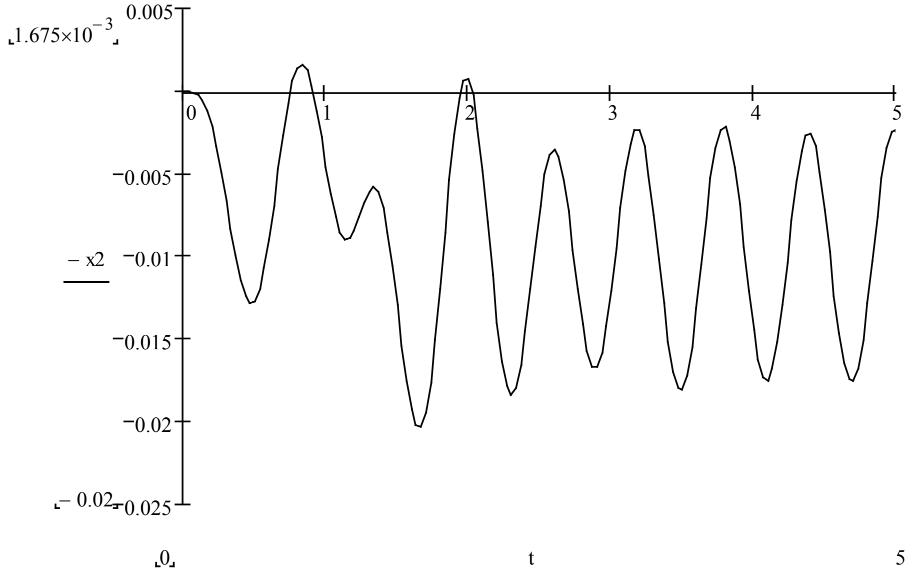


Fig. 7. Vertical displacement of the body of wagon modeling in program MathCAD

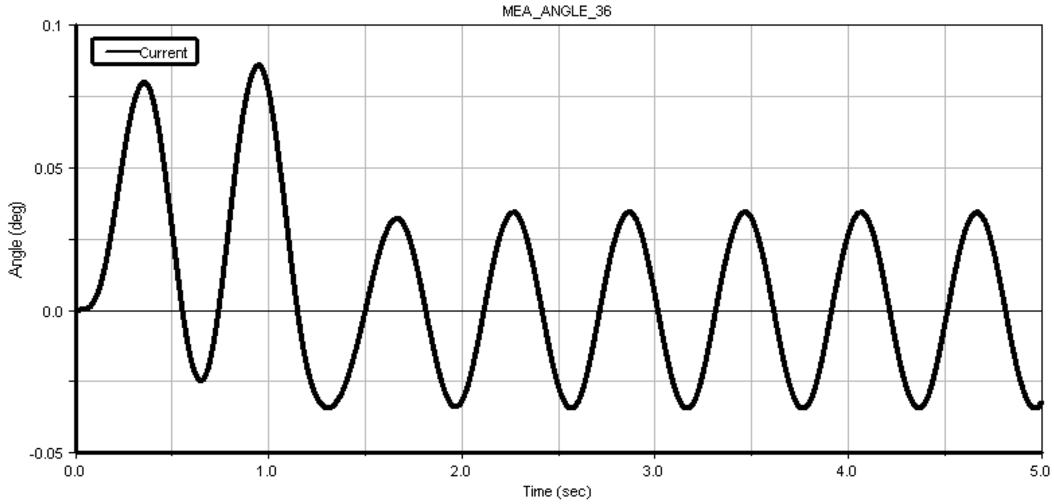


Fig. 8. Rotation angle of a wagon body around the transverse axis modeling in program ADAMS

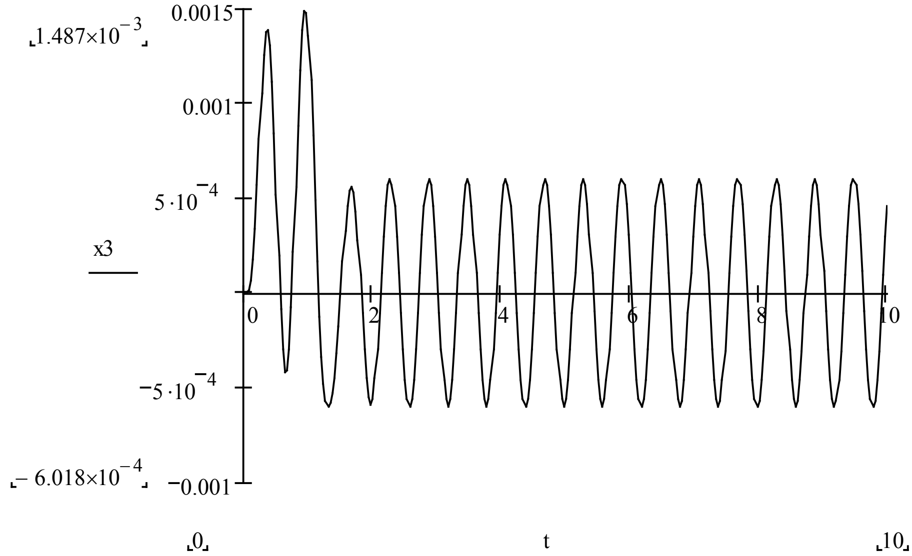


Fig. 9. Rotation angle of a wagon body around the transverse axis modeling in program MathCAD

Table 2 shows maximum research values of angular and vertical displacements obtained by semi analytical (MathCAD) method and by full numerical (ADAMS) method.

Table 2

Maximum values of the research of vertical and angular displacements

Displacements	ADAMS		MathCAD		Error
	t_1	X_n	t_2	X_a	ΔX [%]
Bogie 1 – vertical	0.312	0.0212	0.3333	0.021195	0.024
Bogie 2 – vertical	1.458	0.0191	1.4667	0.019061	0.205
Body – vertical	1.639	0.0204	1.6667	0.020352	0.236
Body – angular	0.942	0.0015	0.9333	0.001487	0.605

Resume

1. The research made by semi analytical method and by the program ADAMS for model of wagon of four degrees of freedom showed very big similarity of the obtained results.
2. The further research of the wagon dynamics will include:
   - research of the dynamic of a wagon by modeling different types of the irregularities of track with the help of analytical and numerical methods;
   - comparison of the results obtained by different computer programs (ADAMS, VISUAL NASTRAN for Windows, etc.)

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Sładkowski A., Wojdyła T. Simplified model of vertical vibration for passenger car during its moving on irregular track

Modeling vertical vibrations of the carriage is carried out. Its simplified model with four degrees of freedom is developed. The differential equations of vibrations are written out. Their solution is found by means of program MathCAD. Comparison of the received solution with the similar solution for the model created by means of program ADAMS is carried out.

Сладковский А., Войдыла Т. Упрощенная модель вертикальных колебаний пассажирского вагона при его движении по неровному пути

Проведено моделирование вертикальных колебаний пассажирского вагона. Разработана его упрощенная модель с четырьмя степенями свободы. Выписаны дифференциальные уравнения колебаний. Найдено их решение при помощи программы MathCAD. Проведено сравнение полученного решения с аналогичным решением для модели, созданной при помощи программы ADAMS.