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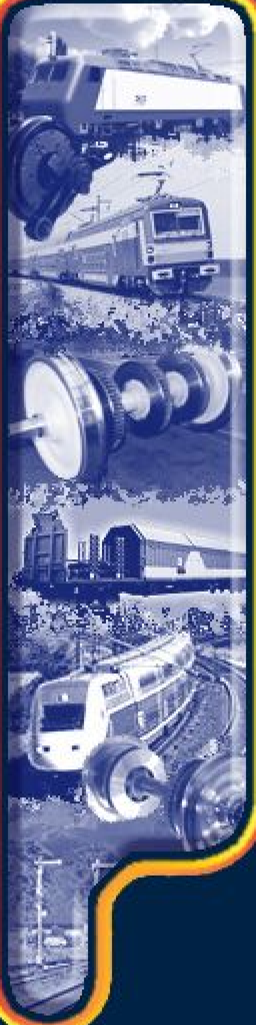

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INFLUENCE OF VERTICAL DYNAMIC OF A COACH ON WHEEL PAIR LOADING

Summary. For opportunities comparison of mathematical modeling of passenger cars dynamic by means of different software, the vertical dynamic of the coach has been investigated. The simplified 6 degrees of freedom model has been considered. Fundamental frequencies and normal modes of oscillations, and also displacements are defined at coach driving on a rough path.

1. INTRODUCTION

Now on a railway transport of many countries the tendency to a heightening of speeds of carriages observed. Thus the dynamic of their interaction with track varies. Coaches and locomotives during motion have different oscillations, each of which influences to some extent traffic safety of a train. Among these oscillations the maximal contribution to common dynamic of a train is brought with vertical oscillations or oscillations of carriage in its longitudinal plane of symmetry. These oscillations to the greatest degree influence loading of wheel pairs and rails, and also on comfort of passengers.

For research of dynamic of a rolling stock by many researchers (for example, [1, 2, 3]) modern software, which allow modeling both the whole train, and its separate elements - coaches and locomotives are used. Thus means of computer equipment allow to model mechanical systems with a many degree (more than 100) of freedoms. A disadvantage of such approach is that it in the big degree is uncontrollable, i.e. the considered mechanical model serves as though as a “black box”. Thus possible errors of model or an error of calculation may result in inadequate results, which difficultly check up.

2. PHENOMENOLOGICAL MODEL OF CARRIAGE

To remove an opportunity of getting of such results it is offered to carry out evaluations in parallel by means of several software, creating different mechanical models and comparing results of calculations among themselves. As an example of such approach the analysis of vertical dynamic of a coach of type 127 Aa (the simplified model) was carried out. Its general view is shown on fig. 1.

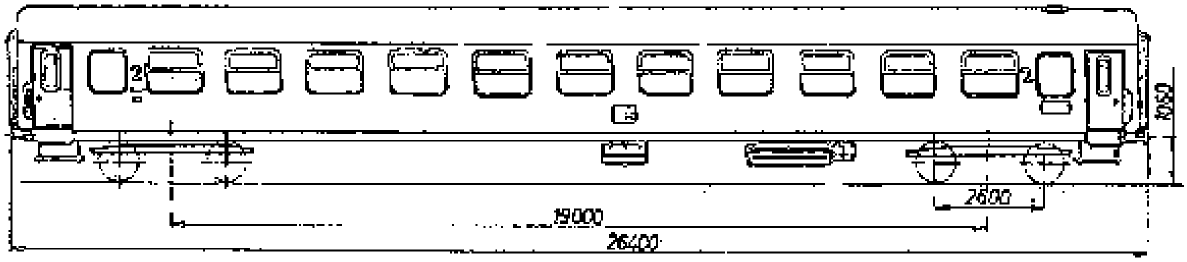


Fig. 1. A general view of a coach of type 127 Aa

The considered coach is passenger, answers the requirements of card UIC 567-2 for coaches such as Z2 which are intended for moving with the speed which is not exceeding 160 km / hour. The scheme of a coach is shown on fig. 2.

The body of a coach 1 rests on bogie bolsters 2, which by means of packages of springs 3 rested on frames of carriages 4. In turn frames of carriages through axle springs 5 rested on axle units (wheel pairs) 6. Thus, double suspension of a body of a coach is realized, that it is typical of carriages.

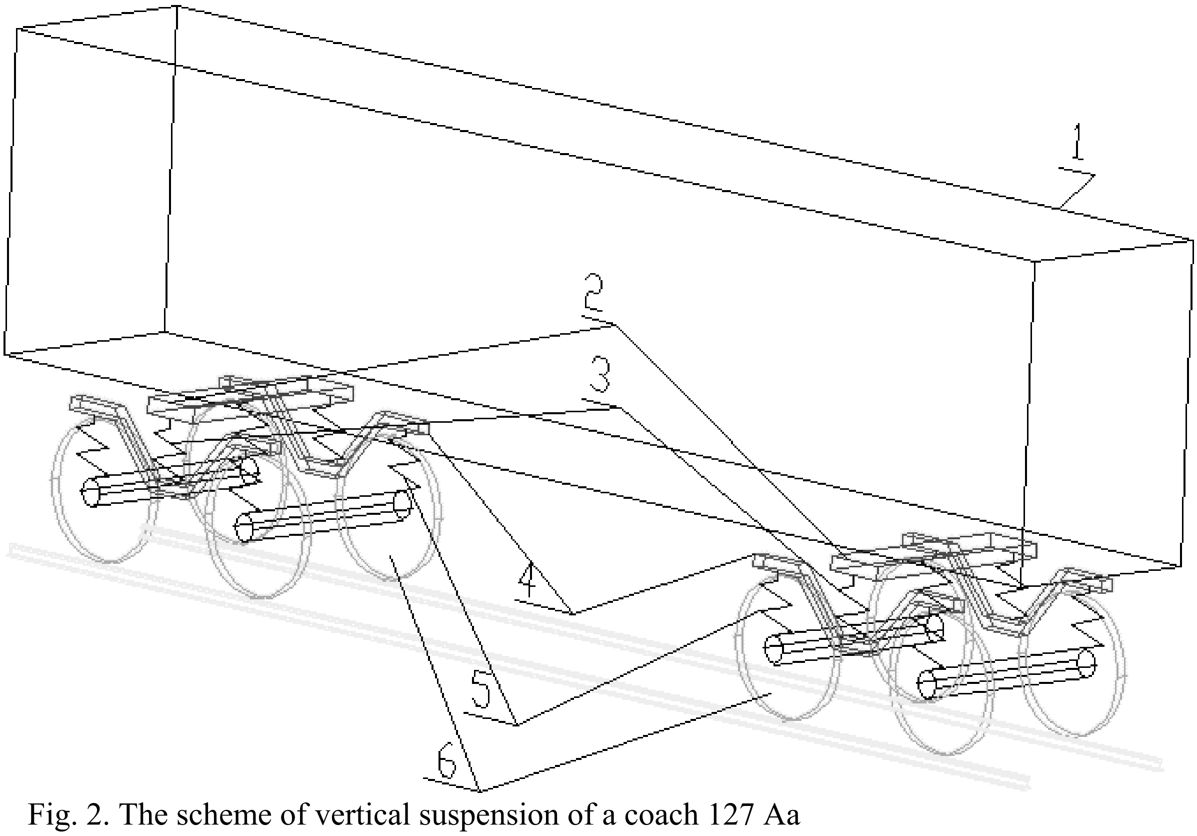


Fig. 2. The scheme of vertical suspension of a coach 127 Aa

The following inertial parameters of considered model are accepted: a mass of a body of a coach mp=28530 kg; a moment of inertia of a body concerning central transversal axis J_p=650000 kg·m^2; a mass of the carriage m_w=3000 kg; a moment of inertia of the carriage concerning central transversal axis J_w=1540 kg·m^2. Rigidities of spring packages are accepted the following: springs 3 (each of four packages) $k^*_2=3{,}8\cdot10^5$ N/m; springs 5 (each of 8 packages) $k^*_1=0{,}9\cdot10^6$ N/m. It is supposed also, that vertical shock absorbers work in parallel with each package of springs, which force of resistance linearly depends on speed. The appropriate factors of a viscous resistance of the dampers parallel to springs 3, $c^*_2=2{,}5\cdot10^4$ N·s/m; factors of a viscous resistance of the dampers parallel to springs 5, $c^*_1=1{,}6\cdot10^4$ N·s/m.

Using reduction of rigidities and viscosities, assuming, that they work at considered oscillations in parallel, we shall receive the simplified model of a coach (fig. 3). The specified model has 6 degree of freedoms. The displacements appropriate to them and angles of rotation are shown in figure.

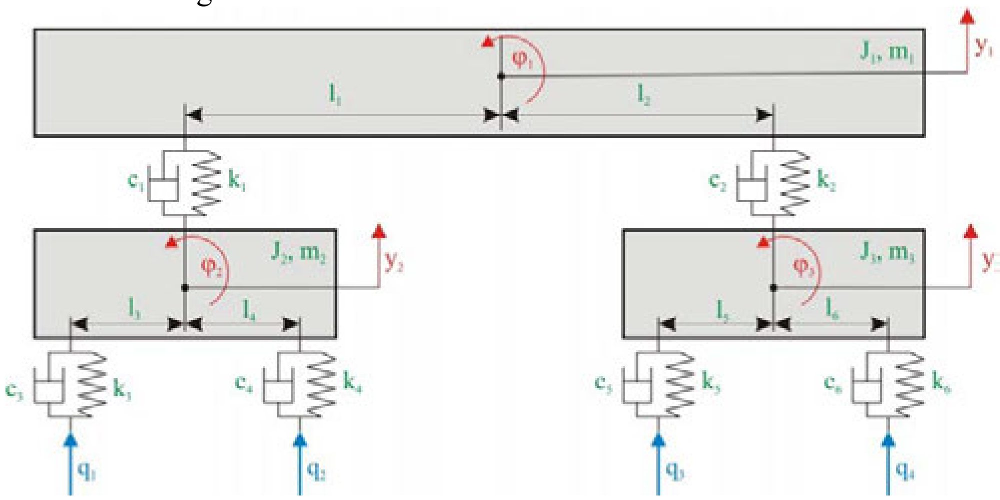


Fig. 3. The simplified model of a coach

3. APPLICATION OF GRAPH THEORY TO SIMULATION OF DYNAMIC OF THE COACH

The graph method was developed H. Paynter in the beginning of 60th years of 20 centuries for the analysis of electric systems. D.Karnopp and R. Rosenberg have expanded application of a method for mechanical and hydraulic systems. Expansion of opportunities of a graph method has appeared from observation, that it is possible to select elements with different properties on the basis of transfer (transformation) of energy and to assign it conventional symbolical notations [4, 5, 6]. In the points of view of graph simulation is the most compact way recording of links between separate elements of dynamic system. Simulation of dynamic systems with a different engineering construction assumes application of a uniform terminology for titles of variables in a graph method. The following titles of the variables used in the graph conventional: ***effort*** - e(t) and ***flow*** – f(t). As an effort variable e(t) we understand force, the moment, pressure; while as a flow variable f (t) it is understood, for example, linear or angular velocity.

В методе графов ребро (узел) связей описывается двумя переменными, в отличие от других топологических методов. Скалярное произведение питающей и питающейся переменных равно мощности переносимой через ребро графа. Направление потока мощности обозначаются при помощи половинных стрелок (рис. 4).

In a graph method the edge of links is described by two variables, as against other topological methods. Scalar product effort and flow variable is equal to power transferable through an edge of a graph. Stream directions of power are meant with the help half arrows (fig. 4).

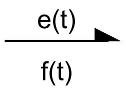


Fig. 4. A designation of an edge of a graph of links

Half arrow direct so that was to write down the differential equations in an obvious aspect. For univalent drawing up of mathematical model on the basis of the graph of links should assign to edges causally - consequence links. These links called also as a causality, describe ratios between effort and flow variables. The designation of a causality is represented by means of a line on one of the ends of an edge of a graph (fig. 5).

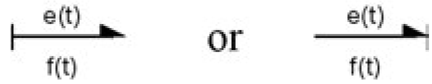


Fig. 5. An edge of a graph with a designation of a causality

The position of a line of a causality gives the information concerning variables, namely, speaks about what from variables is dependent and what independent (fig. 6).

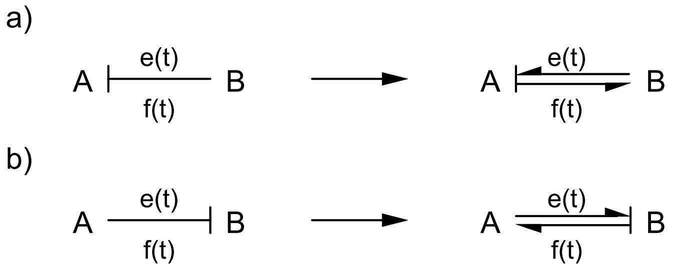


Fig. 6. Possible designations of a causality of the graph of links

On the basis of the analysis causally - consequence links [5] it is possible to draw an output, that the effort variable always should be directed to a causal line, and the flow variable is directed aside opposite to it. Causally - consequence dependences are a formal basis for a writing of ratios between concrete elements and edges of a graph of links. Further the differential equations of considered motion of system were obtained with the purpose of improvement of a technique. In table 1 are reduced different causally - consequence shapes of elements of graphs. This table helps very much at making the equation of motion immediately from the graph of links.

All elements used in a graph method are reduced in table 1. Factors of elements of the graph should not have fixed values necessarily. Very important requirement of a graph method is that only one edge, joint with zero junction, should be marked by a line (see tab. 1). In case of one junction there should be on the contrary, i.e. only one edge, joint with junction may not have a line. On fig. 7 different mechanical elements of kinematics configurations and the edges of graphs appropriate to them are submitted. Graphic conformity for edges of graphs is submitted without a designation causally - consequence links. So we act because at construction of the graph a causality of considered elements is possible to set so that executed there were causal ratios in zero and one junctions of the graph of links.

Elements with one input (fig. 7 a, b, c) are characterized by that there are only one input and an exit through which there is a transmission of energy. The inertial element (fig. 7a) models opportunities of an accumulation of a kinetic energy a mass at translation or rotation. Elements of this type always (in case of mechanical systems) are connected to one junction. Damping elements (fig. 7b) have dissipative properties, i.e. take away mechanical energy at system, not returning it further. Elements of this type in mechanical systems may be connected both with zero, and to one junction. In a case if the mass connected to a support by means of a vertical shock absorber, in the graph of links it is represented by means of connection of damping element to a one junction, in other cases damping elements connect to zero junction.

Tab. 1.

Causally - consequence dependences of elements of the graph of links

Aspect of a causality	Dependences of a causality	Aspect of a causality	Dependences of a causality
Se e1(t)	$e_1(t)$	Sf f1(t)	$f_1(t)$
e1(t) / f1(t) J	$e_1(t)=J\frac{d}{dt}f_1(t)$	e1(t) / f1(t) J	$f_1(t)=\frac{1}{J}\int e_1(t)\cdot dt$
e1(t) / f1(t) C	$f_1(t)=\frac{1}{C}\frac{d}{dt}e_1(t)$	e1(t) / f1(t) C	$e_1(t)=C\cdot\int f_1(t)\cdot dt$
e1(t) / f1(t) R	$e_1(t)=R\cdot f_1(t)$	e1(t) / f1(t) R	$f_1(t)=\frac{1}{R}\cdot e_1(t)$
e1(t) / f1(t) TF m e2(t) / f2(t)	$e_1(t)=m\cdot e_2(t)$ $f_2(t)=m\cdot f_1(t)$	e1(t) / f1(t) TF m e2(t) / f2(t)	$f_1(t)=f_2(t)\cdot m$ $e_2(t)=e_1(t)\cdot m$
e1(t) / f1(t) GY r e2(t) / f2(t)	$e_1(t)=r\cdot f_2(t)$ $e_2(t)=r\cdot f_1(t)$	e1(t) / f1(t) GY r e2(t) / f2(t)	$f_1(t)=\frac{e_2(t)}{r}$ $f_2(t)=\frac{e_1(t)}{r}$
e1(t) / f1(t) 0 e1(t) / f3(t); e1(t) | f2(t)	$e_3(t)=e_2(t)=e_1(t)$ $f_3(t)=f_1(t)+f_2(t)$	e1(t) / f1(t) 1 e3(t) / f1(t); e2(t) | f1(t)	$f_1(t)=f_2(t)=f_3(t)$ $e_3(t)=e_1(t)+e_2(t)$

The elastic element (fig. 7c) models dependence of elastic force on displacement and accumulates a potential energy of system. The way of connection of the given element in the graph of links is similar to damping element as describe earlier. The mechanical transformer (fig. 7d) will transform variables of the graph of links and is an element with two inputs. It is considered as ideal transmission of mechanical energy. Transmissions of power in such element it is meant with the help half arrows which direction specifies a stream direction of energy.

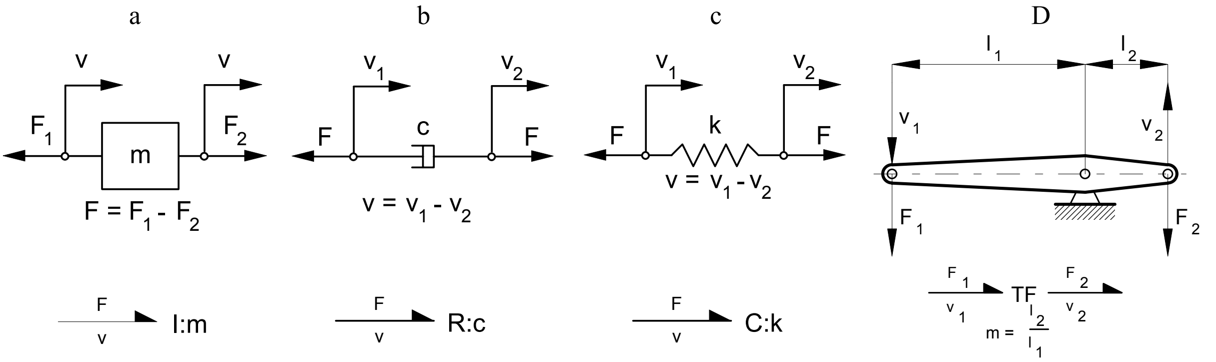


Fig. 7. Conformity of mechanical elements to edges of graphs: a) a inertial element, b) damping element, c) an elastic element, d) an element of type “the mechanical transformer”

In graphs of links mechanical transformers may be joined both to zero, and to one junction. However usually it happens so, that they join with one input a one junction, and another to a zero junction. The big advantage of use of a method of graphs is that fact, that during simulation the careful output of the equations of motion is not required. It implies that the graph itself is representation of structure of the motion equations. Simplification of a stage of a generation of the differential equations of system motion allows to reduce time which is necessary for preparation of realization of numerical experiment.

On the basis of the created phenomenological model of a coach (fig. 3) was created for it the graph of links (fig. 8).

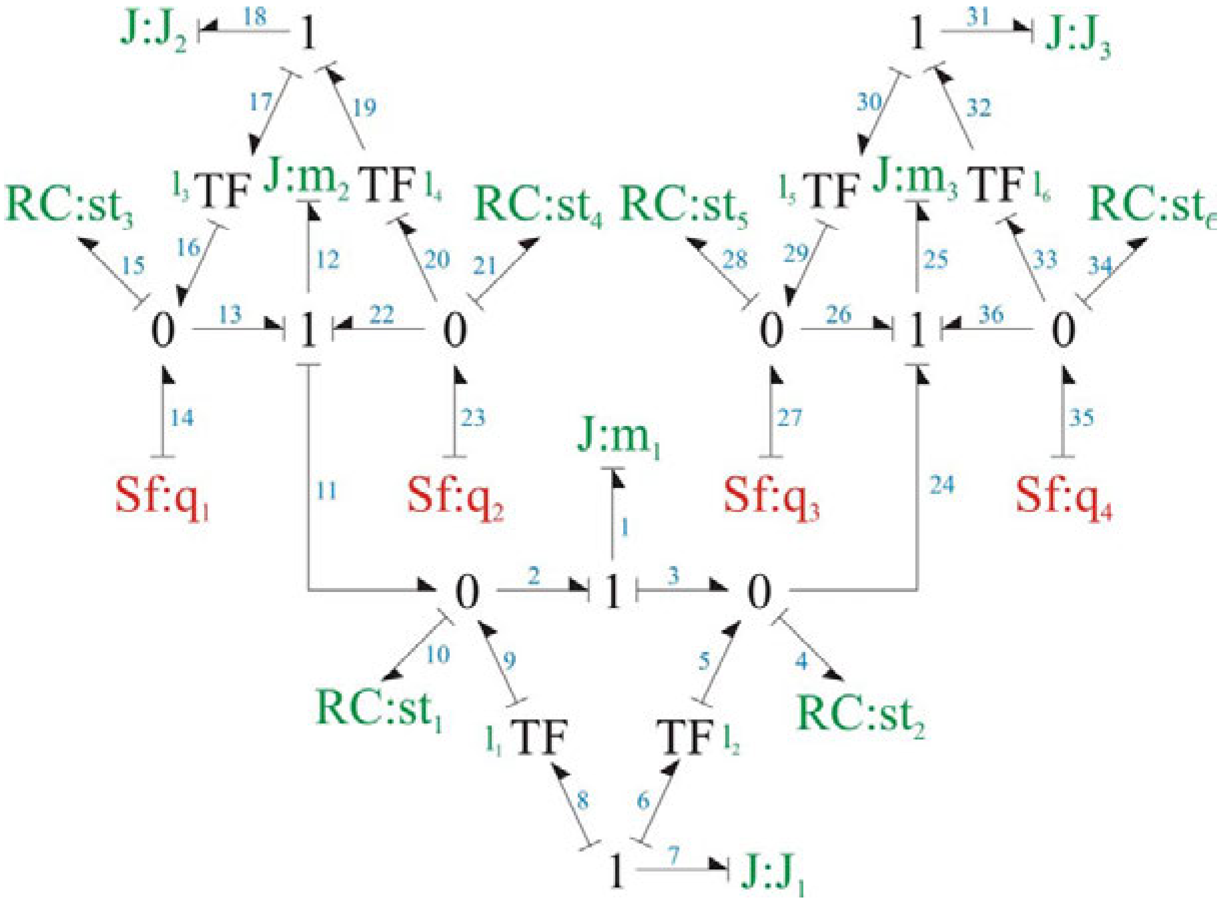


Fig. 8. The graph of links for the carriage 127 Aa

On the presented graph of links (fig. 8) new elements (*RC:st$_i$*) not introduced in table 1 have added. Constructing the graph of links of considered system for its simplification at what the number of edges is diminished. The elements modeling parallel connection of an elastic element (k) and damping element (c) are used.

$$e_i\left(t\right) = c_i f_i\left(t\right) + k_i \int f_i\left(t\right) dt \,. \tag{1}$$

The graph of links prepared thus is a basis for carrying out numerical researches. The equations obtained on its basis are submitted by formulas (2).

$$\begin{cases} 0 = m_1 \dfrac{d\dot{y}_1}{dt} + c_2\left(\dot{y}_1 + l_2\dot{\varphi}_1 - \dot{y}_3\right) + k_2\int\left(\dot{y}_1 + l_2\dot{\varphi}_1 - \dot{y}_3\right)dt - c_1\left(l_1\dot{\varphi}_1 + \dot{y}_2 - \dot{y}_1\right) + \\ -k_1\int\left(l_1\dot{\varphi}_1 + \dot{y}_2 - \dot{y}_1\right)dt \\ c_3q_1 + c_4q_2 + k_3\int q_1dt + k_4\int q_2dt = m_2\dfrac{d\dot{y}_2}{dt} + c_1\left(l_1\dot{\varphi}_1 + \dot{y}_2 - \dot{y}_1\right) + k_1\int\left(l_1\dot{\varphi}_1 + \dot{y}_2 - \dot{y}_1\right)dt + \\ -c_3\left(l_3\dot{\varphi}_2 - \dot{y}_2\right) - k_3\int\left(l_3\dot{\varphi}_2 - \dot{y}_2\right)dt - c_4\left(-l_4\dot{\varphi}_2 - \dot{y}_2\right) - k_4\int\left(-l_4\dot{\varphi}_2 - \dot{y}_2\right)dt \\ c_5q_3 + c_6q_4 + k_5\int q_3dt + k_6\int q_4dt = m_3\dfrac{d\dot{y}_3}{dt} - c_2\left(\dot{y}_1 + l_2\dot{\varphi}_1 - \dot{y}_3\right) - k_2\int\left(\dot{y}_1 + l_2\dot{\varphi}_1 - \dot{y}_3\right)dt + \\ -c_5\left(l_5\dot{\varphi}_3 - \dot{y}_3\right) - k_5\int\left(l_5\dot{\varphi}_3 - \dot{y}_3\right)dt - c_6\left(-l_6\dot{\varphi}_3 - \dot{y}_3\right) - k_6\int\left(-l_6\dot{\varphi}_3 - \dot{y}_3\right)dt \\ 0 = J_1\dfrac{d\dot{\varphi}_1}{dt} + l_2\left[c_2\left(\dot{y}_1 + l_2\dot{\varphi}_1 - \dot{y}_3\right) + k_2\int\left(\dot{y}_1 + l_2\dot{\varphi}_1 - \dot{y}_3\right)dt\right] + \\ +l_1\left[c_1\left(l_1\dot{\varphi}_1 + \dot{y}_2 - \dot{y}_1\right) + k_1\int\left(l_1\dot{\varphi}_1 + \dot{y}_2 - \dot{y}_1\right)dt\right] \\ -l_3c_3q_1 + l_4c_4q_2 - l_3k_3\int q_1dt + l_4k_4\int q_2dt = J_2\dfrac{d\dot{\varphi}_2}{dt} + l_3\left[c_3\left(l_3\dot{\varphi}_2 - \dot{y}_2\right) + k_3\int\left(l_3\dot{\varphi}_2 - \dot{y}_2\right)dt\right] + \\ -l_4\left[c_4\left(-l_4\dot{\varphi}_2 - \dot{y}_2\right) + k_4\int\left(-l_4\dot{\varphi}_2 - \dot{y}_2\right)dt\right] \\ -l_5c_5q_3 + l_6c_6q_4 - l_5k_5\int q_3dt + l_6k_6\int q_4dt = J_3\dfrac{d\dot{\varphi}_3}{dt} + l_5\left[c_5\left(l_5\dot{\varphi}_3 - \dot{y}_3\right) + k_5\int\left(l_5\dot{\varphi}_3 - \dot{y}_3\right)dt\right] + \\ -l_6\left[c_6\left(-l_6\dot{\varphi}_3 - \dot{y}_3\right) + k_6\int\left(-l_6\dot{\varphi}_3 - \dot{y}_3\right)dt\right] \end{cases} \tag{2}$$

4. THE ANALYSIS OF MOTION OF THE COACH ON THE RUGGED TRACK

Motion model of a coach on a rugged track was analyzed. For the definition of characteristics of an irregularity of a track real profile records of a track on piece of line Katowice - Sosnowiec with a direction Częstochowa were used. As a result of statistical treatment experimental data the average characteristics are obtained by means of which it was possible to set a characteristic irregularity of harmonic type. It is supposed, that originally the coach goes with speed *v* on ideally track, and then to an instant t=0 its first wheel pair starts motion on a track which vertical coordinate is described by function

$$y(t) = \frac{a}{2}\cdot\left(\cos\left(p\cdot t\right) - 1\right), \tag{3}$$

where $p = \dfrac{2\cdot\pi\cdot v}{\lambda}$ - frequency of an irregularity of a track. Amplitude of an irregularity is $a = 0{,}02$ m, its length - $\lambda = 10{,}0$ m. Other wheel pairs start motion on a rugged track with a time delay, which depends on speed of carriage and geometry of a coach.

On fig. 9 the model of a considered coach created by means of application package ADAMS 11.0 is shown. As are considered only oscillations in a longitudinal plane of symmetry and the created model is two-dimensional, having 6 degree of freedoms.

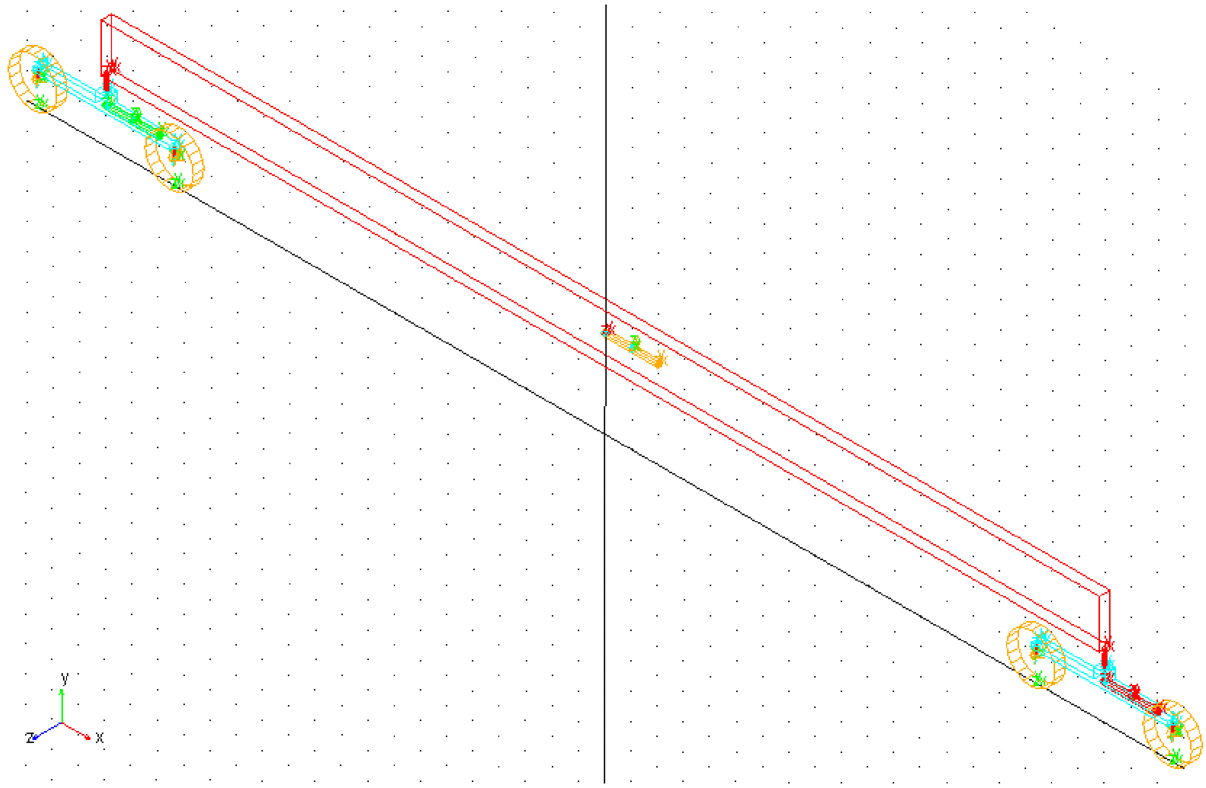
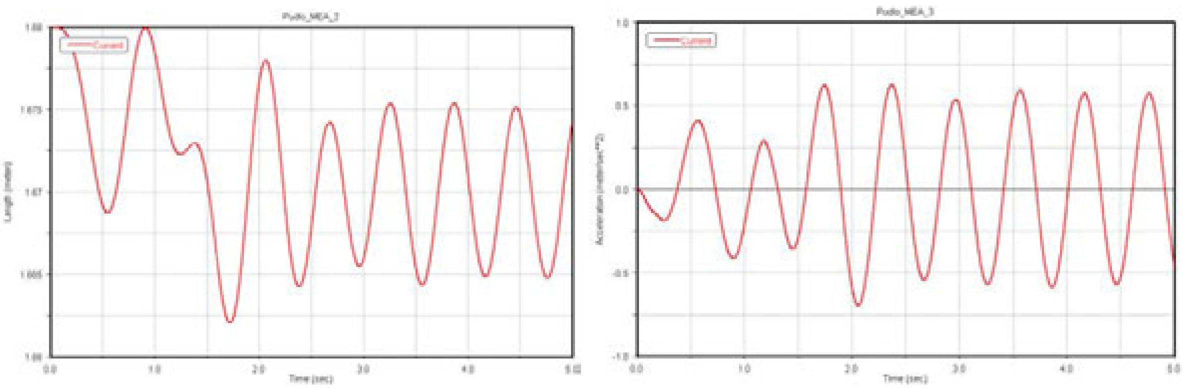


Fig. 9. The model of a coach created with help software ADAMS 11.0

On fig. 10 vertical displacements of a gravity center of a body of the coach calculated with help ADAMS (fig. 10a) and the appropriate accelerations (fig. 10b) are shown. The amplitude of displacements does not exceed 0,02 m. Accelerations after transiting an initial track section (transition) acquire the almost periodic character appropriate to forcing irregularity of a track. Their magnitudes on exceeds 0,7 m/s^2.

For comparison on fig. 11 similar displacements of a body of the coach, graph theories calculated on the basis of application, and a set of equations (2) are shown was solved by means software MATLAB. Comparison of magnitude of displacements displays good conformity of the carried out calculations, so also initial mathematical models.

Similar graphs of displacements for the first (fig. 12) and second (fig. 13) bogies are reduced in figures two by two. Thus the first graphs are the calculations executed with help ADAMS, and the second - by means of graph theory. As we see, different initial approaches lead to similar results.



a b

Fig. 10. Displacements and accelerations of a gravity center of a body of the coach at the initial stage of motion on the rugged track, defined with help ADAMS

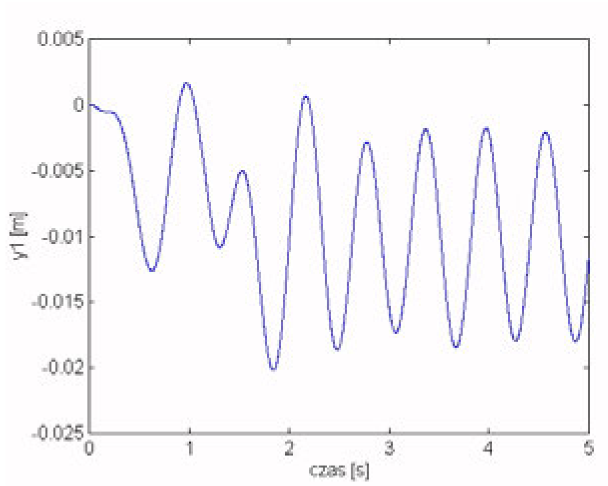
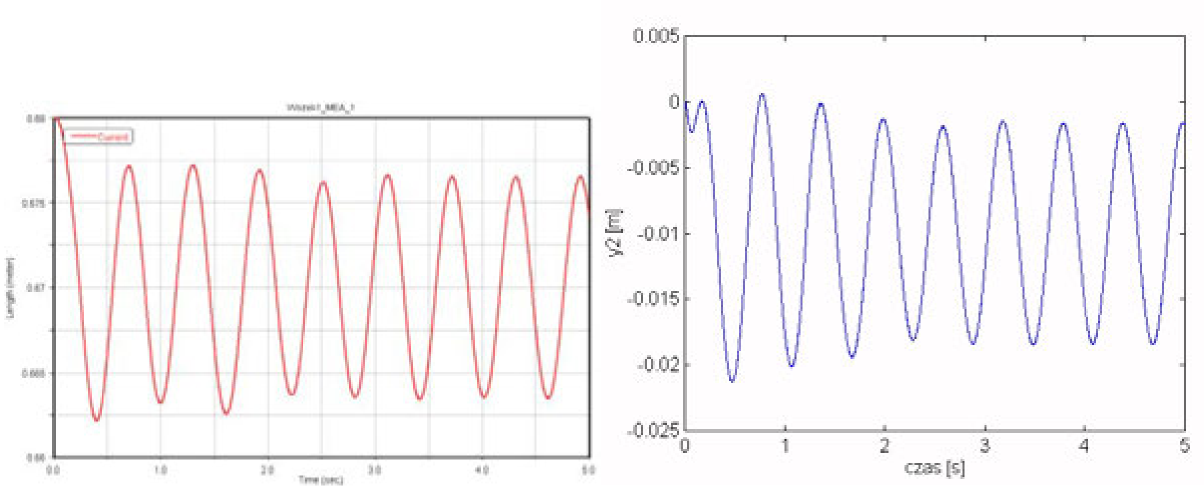
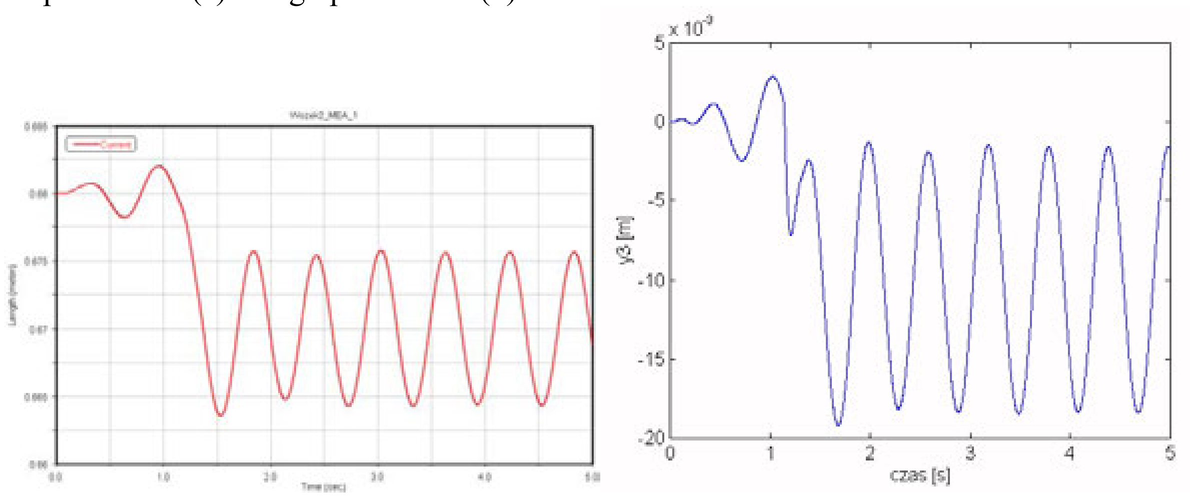


Fig. 11. Displacements of a gravity center of a body of the coach at the initial stage of motion on the rugged track, defined by means of graph theory and package MATLAB



a b

Fig. 12. Comparison of displacements of a gravity center of the first bogie, defined with help ADAMS (a) and graph theories (b)



a b

Fig. 13. Comparison of displacements of a gravity center of the second bogie, defined with help ADAMS (a) and graph theories (b)

As we see from comparison of presented graphs, small differences take place only in an initial stage of motion, do not bring the essential contribution and may be explained by computational errors.

В результате расчетов были определены 6 собственных частот колебаний и соответствующие им собственные формы. Их сравнение двумя методами показало хорошее соответствие описанных выше методов расчетов. Такой подход позволяет в дальнейшем для более сложных феноменологических моделей проводить сравнение результатов и определять возможные ошибки в построении моделей.

As a result of calculations 6 fundamental frequencies of oscillations and the own shapes appropriate to them were defined. Their comparison by two methods has shown good conformity of methods of calculations described above. Such approach allows further for more complex phenomenological models to carry out comparison of results and to define probable errors in construction of models.

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Abstract

В работе проведен анализ вертикальных колебаний пассажирского вагона, движущегося по неровному пути. Рассмотрены вертикальные перемещения, ускорения отдельных элементов модели вагона, определены собственные частоты и собственные формы колебаний. Определены динамические силы, действующие на колесные пары. Проведено сравнение двух методов расчетов, общепринятого, основанного на создании математической модели вагона и его анализа при помощи ППП ADAMS, а также теории графов. Показано хорошее соответствие рассмотренных методов.