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Principles of building of computer model of passenger cars dynamics for high-speed movement

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Abstract
The structural description of the developed model of dynamics of passenger cars of advanced design for carrying out complex researches by means of computer modeling and basic values are presented in the paper and control of their adequacy is carried out. The constructed model allows us to investigate the dynamic qualities of the car at the specified modes of movement under the conditions, which are close to the present ones. When developing model of dynamics of the high-speed car within the program complex "Universal Mechanism", [9] a multilevel structural method of subsystems is used. Adequacy of the developed model is checked by comparison of the maximum accelerations in the horizontal and vertical directions of body and running gear of the car with bolsterless central suspension, which are determined at current dynamic tests.
Key words: HIGH-SPEED CAR, DYNAMICS, COMPUTER MODEL, METHOD OF SUBSYSTEMS, ADEQUACY OF MODEL, PARAMETRIZATION, IDENTIFIERS

Introduction

Introduction of high-speed passenger traffic, namely train movement with speed of 160 - 200 km/h, belongs to priority problems of development of the railroads of Ukraine. The success of the organization of high-speed transportations significantly depends on technical characteristics of railway vehicles [2-4] that is determined by constructive schemes and parameters of running gears.

To conduct researches of dynamics of the rolling stock without use of imitating modeling of mechanical systems with application of numerical methods of calculations according the selected algorithms becomes almost impossible at the present stage of development of railway branch. Considering the achieved level of theoretical researches of dynamic processes, which accompany the movement of the rail rolling stock, it is expedient to carry out assessment of indicators of dynamics of the high-speed passenger rolling stock and its interaction with a track with application of modern means of computer modeling [1, 3, 4]. In case of such approach, there appears a possibility of increase in efficiency of determination of influence of the current technical condition of running gears and pass at places intended for high-speed movement on dynamic indicators of traffic safety and comfort of transportations of passengers. The possibility of search and selection of optimum parameters of certain mechanical systems according to the chosen schemes of researches for improvement of their dynamic qualities is established.

Numerous researches [3, 4, 10] are devoted to problems of mathematical modeling of dynamics of the high-speed rolling stock. For last decades, rough development of technical solutions on improvement of rail transport has been observed. Thus, so-called bolsterless scheme of a suspension, which were widely adopted subsequently, had begun to be applied by suspension mainly in passenger car building instead of carriages with swing suspension. According to constructional changes, design models of dynamics of the high-speed rolling stock have evolved. Results of the last researches of dynamic indicators of cars on carriages with bolsterless central suspension concerning two-system electric trains by production of “Kryukov Railway Car Building Works” PJSC are provided in the paper [5].

Despite the large volume of the obtained results of researches of dynamic properties of the high-speed rolling stock, its adaptation to operation conditions in the existing railway lines requires further in-depth assessment of matching of wagons of new generation on ensuring the guaranteed traffic safety and smoothness of the course.

Materials and methods

On the basis of the passenger rail of high-speed car of “Ukraina-2” national production in a software package of PC “UM”, the mathematical model of dynamics of the car is developed with the use of method of subsystems. The schematic picture of model of dynamics of the passenger rail car of a series 788 is provided in the Figure 1.

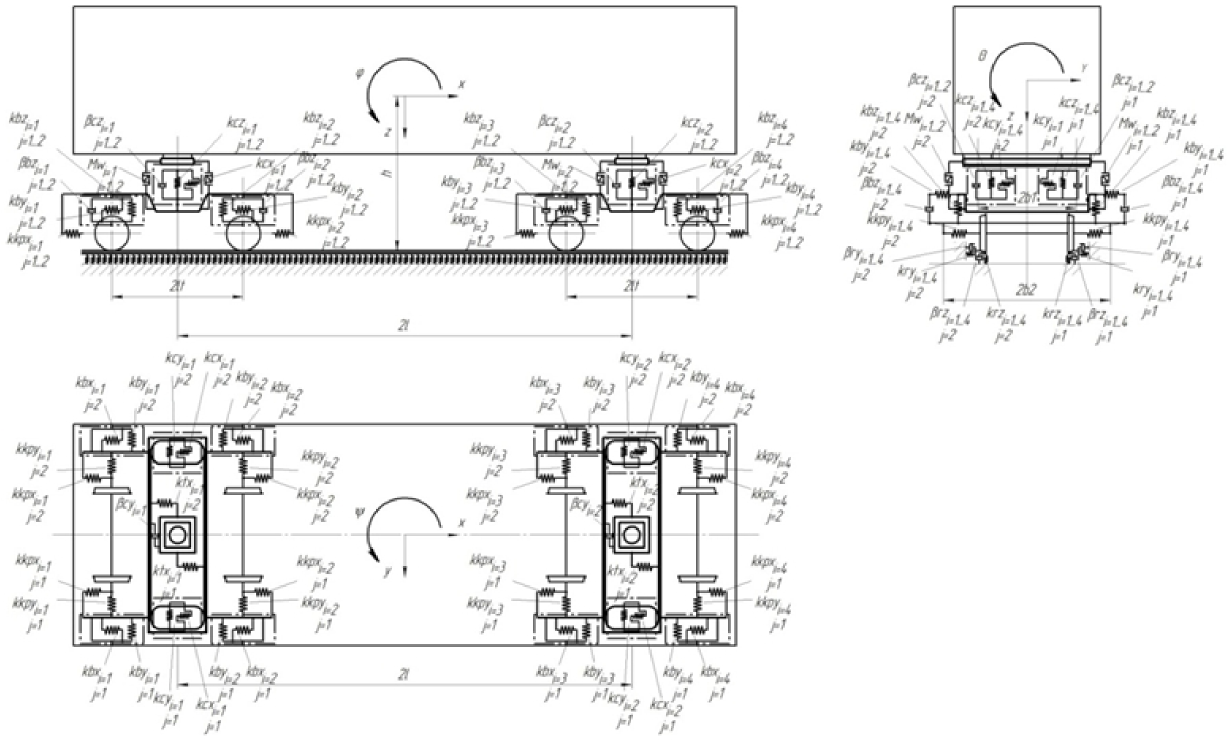
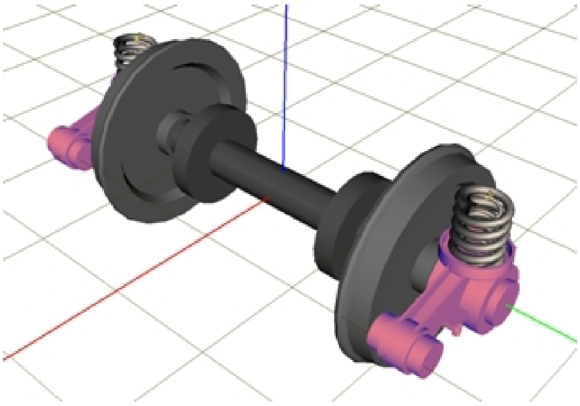


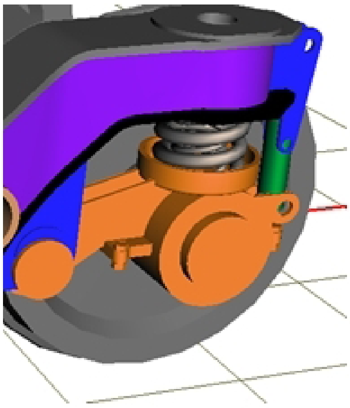
Figure 1. Settlement scheme of the passenger car

An object “Passenger car” is structurally complete system, which consists of separate subsystems of the solid bodies interconnected by joints and power elements. The model of system has three levels: 1 - “Wheel couples with axle equipment”; 2 - “Carriage”; 3 - “Passenger car”. The general model contains identical subsystems with equivalent identifiers of mass and inertial characteristics of bodies, elastic and dissipative properties, power links.

The subsystem “Wheel couple with axle equipment” is formed from two solid bodies - axle boxes, which are connected by means of rotators to wheel couple with six levels of freeness. A general view of a subsystem is shown in Figure 2 a.



a)



b)

Figure 2. The subsystem “Wheel couple with axle equipment”

Axle-box suspension with the lever of suspension rod, which limits horizontal and angular movements of wheel couples concerning a carriage frame (Fig. 2), is presented in the model by linear power elements of elastic and viscous type reflecting the cylindrical springs, and bipolar elements reflecting hydraulic vibration absorber. They are reflected by linear power elements of elastic and viscous type with the set rigidity parameters specified by means of identifiers.

The subsystem “Carriage” consists of two subsystems of wheel couples with axle equipment and carriages frames, and also elastic elements of the central suspension and power elements - vibration absorbers, levers of axle-box suspension, torsion device (Figure 3).

The system “Passenger car”, which graphic picture is shown in Figure 4, is formed from 19 solid bodies, 18 linear ones and 22 bipolar power elements.

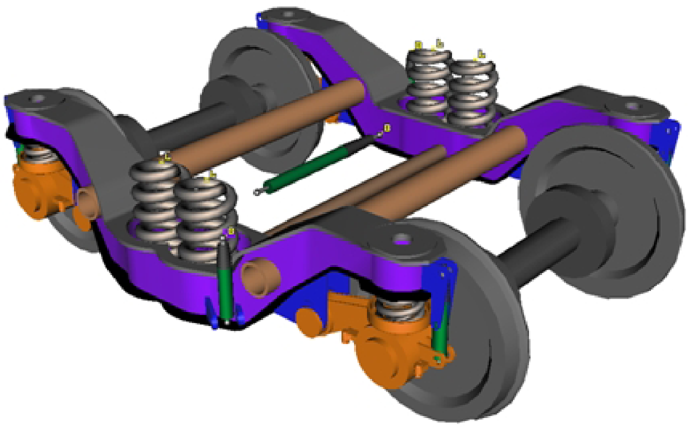


Figure 3. The subsystem “Carriage”

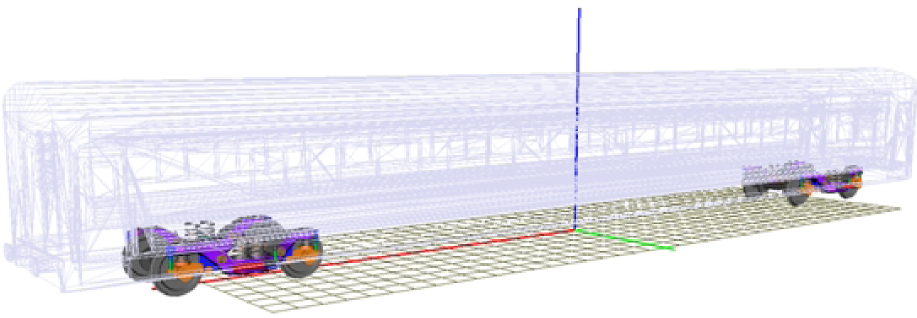


Figure 4. The system “Passenger car”

Movement safety conditions, road performance and influence on pass of railway vehicles of the railroads are estimated by dynamic indicators. Conditions of regulations [7, 9] are the basis for requirements to dynamic characteristics of cars of a track of 1520 mm. This document, in particular, determines standard requirements, according to which new passenger rail cars as well as those, which are modernized, with constructional speeds up to 160 km/h should be calculated and designed. Today in Ukraine, there are no regulating documents, which establish requirements for high-speed railway vehicles, in particular, requirements to rather dynamic indicators at speeds higher than 160 km/h.

According to these Regulations, dynamic qualities of cars of a track of 1520 mm are estimated by dynamics coefficients, horizontal cross forces affecting the wheel couples from frames of carriages, and vertical and horizontal cross accelerations of bodies, frames of carriages and axle equipment. Safety conditions of movement are determined by stability coefficients in case of wheel couples running off the rails and coefficients of the car cross stability in case of its turnover under the influence of side forces when moving in a curve.

According to European regulating documents, the requirements, which are established concerning dynamic indicators of railway vehicles for a broad range of speeds, are determined. For assessment of dynamic characteristics of wagons, the following indicators are used: forces between a wheel and rail - the side directing force of Y and force of Q affecting a wheel in the vertical direction; forces affecting the carriage - the amount of side axel forces of H; acceleration of frames of carriages $\ddot{y}^{+}$ measured in the cross direction; accelerations of a body $\ddot{y}*$ and $\ddot{z}*$ measured in the cross horizontal and vertical directions. Stability of wheel couples in rail track is estimated by ratio of the directing force to vertical Y/Q.

Considering such situation of problem of assessment of level of comfort and traffic safety in case of development of computer model of the high-speed passenger rail car, the initial values satisfying both Regulations requirements and the European regulating documents are created.

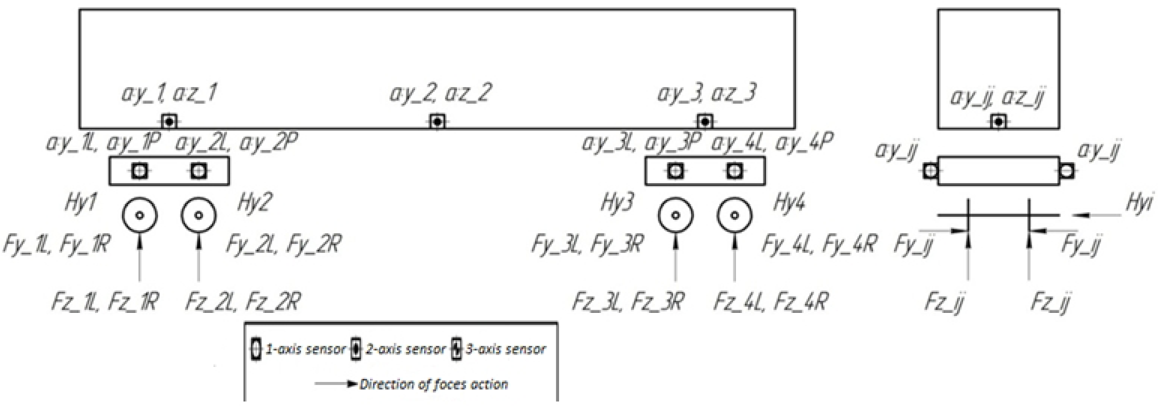


Figure 5. The scheme of placement of sensors for determination of initial values

The computer model of dynamics of the high-speed car contains 14 groups of initial values which include:

- side forces Y acting from wheels on a railway line (the designation is "Fy_ij", where i - number of wheel couple, i = 1…4, j – left or right wheel of wheel couple, j = l, r);

- vertical forces Q acting from wheels on a railway line (the designation is "Fz_ij", where i - number of wheel couple, i = 1…4, j – left or right wheel of wheel couple, j = l, r);

- frame forces H acting from wheels on a railway line (the designation is "Hyi", where i - number of wheel couple, i = 1…4);

- horizontal cross accelerations of a body of the car taking into account installation places of sensors (designation "ay") according to the scheme (see Fig. 5);

- vertical cross accelerations of a body of the car taking into account installation places of sensors (designation "az") according to the scheme (see Fig. 5);

- horizontal cross accelerations of frame of the carriage taking into account installation places of sensors (designation "ay") according to the scheme of sensors placement (see Fig. 5);

- vertical accelerations of frame of the carriage taking into account installation places of sensors (designation "az") according to the scheme of sensors placement (see Fig. 5);

- coefficients of vertical dynamics of axle-box suspension;

- coefficients of horizontal dynamics of axle-box suspension;
- stability coefficients in case of running off the rails;
- stability coefficients in case of running off the rails (Nadal criterion);
- cross movements of wheel couples of car;
- horizontal and vertical roughnesses of a railway line.

Results

The procedure of simulation of dynamics of the high-speed rolling stock with use of specialized comprehensive computer programs of calculation of mechanical systems, detail reproduction of a structure of car, its technical condition, accounting of the valid rails structure, the modes of movement of rail wagons, etc. are necessary conditions of reliability of computer model. The proof of adequacy to the constructed model will be correspondence of results of calculations to experimental data and the established standard requirements of assessment of dynamics indicators. As values for comparisons, it is reasonable to use acceleration as the most informative of dynamic indicators of rail wagons.

Confirmation of model adequacy is performed by comparison of modeling results with standard sizes of the maximum values of vertical and horizontal accelerations of model of a car body over a carriage frame at the place of location car center plate and in the middle part of body obtained in case of a model experiment (testing of model). Calculations are executed in case of the fixed value of movement speed V = 160 km/h.

Results of test calculation are presented in Figure 6. In this animation window, changes in time are reflected. In particular, pictures of power loading of wheels by contact forces (top left) and oscillograms of accelerations of frame of the carriages (lower left) and bodies are given (top right).

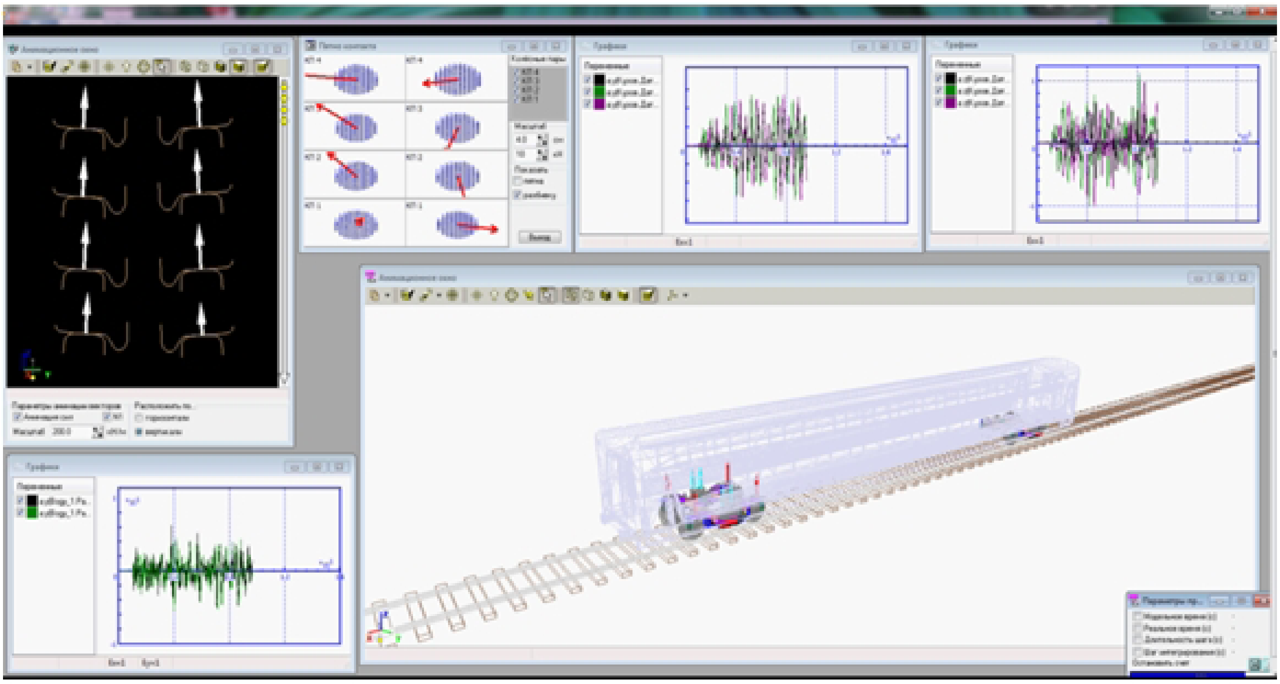
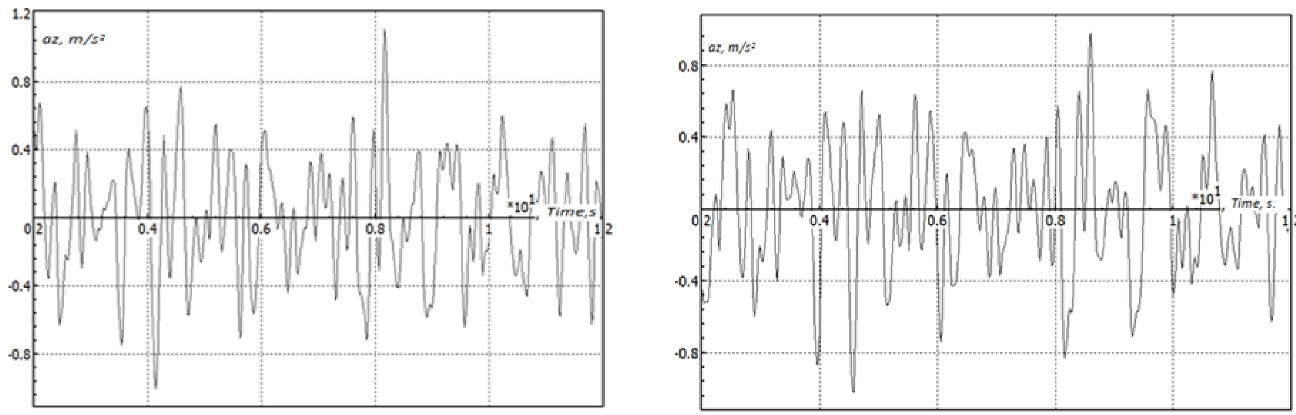


Figure 6. Calculation dynamics of the movement of the high-speed car

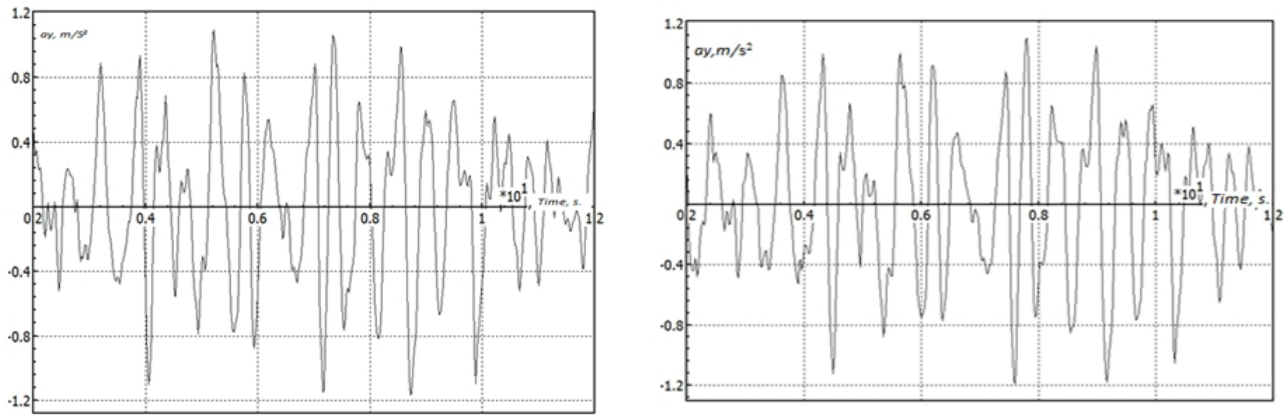
Calculation implementation of accelerations of a car body is separately presented in Figures 7 and 8. Validation of the developed car computer model is carried out by the comparison of results of modeling and current dynamic tests of a prototype model of car of type “Meta”, which were carried out by Dnipropetrovsk National University of Railway Transport [8]. The maximum values of accelerations of a body obtained by calculations and experimentally at a speed of movement of 160 km/h are presented in Table 1.

Table data testify about satisfactory correspondence of results of calculations and experiment. However, distinctions of the compared values according to horizontal accelerations are 0.9%, and according to vertical ones - 12%. Thus, the conducted testing confirms adequacy to the developed computer model.



a) b)

Figure 7. The oscillogram of vertical accelerations of a car body in the place of location of car center plate 1 (a) and car center plate 2 (b)



a) b)

Figure 8. The oscillogram of horizontal accelerations of a car body in the place of location of car center plate 1 (a) and car center plate 2 (b)

Table 1

The way of results obtaining	Horizontal accelerations of a body, m/s^2	Vertical accelerations of a body, m/s^2
Computer modeling method	1.18	1.10
By results of current dynamic tests	1.17	1.25

Conclusions

1. The developed basic computer model of dynamics of high-speed car allows us to carry out adaptation of model to the modified number of cars. Parameterization of the developed computer model with use of symbolical designations of identifiers of system allows us to change necessary parameter without interference into the program module of the description.

2. The dynamic indicators generated as basic data of analytical model corresponding to standard values that are used for assessment of ride performance of cars of track of 1520 mm satisfy the list of indicators, which are applied in case of admission to continuous operation of railway vehicles of the railroads on a track of 1435 mm.

3. The created computer model for in-depth parametrical studies of dynamics of passenger railway vehicles will allow one to reduce considerably dura-

tion and costs in case of development and putting into operation of high-speed cars of advanced design.

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