

# Use of anthropometric dummies of mathematical models in the safety and comfortableness analysis of a passenger rolling stock

V Kobishchanov<sup>1</sup>, D Antipin<sup>2</sup>, S Shorokhov<sup>3</sup> and A Mitrakov<sup>2</sup>

<sup>1</sup> Bryansk State Technical University, 7, 50 years of October st., Bryansk, 241035, Russia

<sup>2</sup> Candidate, Ural State university of railroads, 66, Kolmogorova st., Ekaterinburg, 620034, Russia

E-mail: adya24@rambler.ru

**Abstract.** Approaches to the safety and comfortableness analysis of a railway passenger rolling stock with anthropometrical dummies of mathematical models usage are offered. There are recommendations about a rolling stock design, based on the analysis of traumatism of passengers and members of train crews, and also based on comfort parameters at various modes of trainmovement.

## 1. Introduction

Safety and comfort of civil passenger traffic is one of the key problems of railway transport functioning. The present stage of Russian railroads development is characterized by modernization of technical means and implementation of a high-speed rolling stock. That is the result of acceptance of railway transport development strategy till 2030 by the Russian Federation government in 2008.

Implementation of the rolling stock of a new generation into operation could be the reason of increased risks of emergency situation, connected with longitudinal train collisions with obstacles. In this regard, development of high-speed railway traffic requires laboration of actions to enhance safety and comfort conditions of civil passenger traffic.

## 2. Results and Discussion

Now there are two main approaches in assessment of the passenger rolling stock safety in emergency situations. They are carrying out natural experiments with the use of physical models of anthropometrical dummies and mathematical modeling of emergency situations scenarios [1]. The implementation of the first approach has not been widely adopted because of the high cost of preparation and carrying out passenger rolling stock tests.

With the development of science and equipment, the possibility of creation of hi-tech physical models of human dummies became possible. These dummies have the same form and mass distribution as an alive human being does. The dummy consists of the separate elements joint with hinges capable of accurate reproducing man's body movements in the collision conditions. Anthropometrical dummies like Dummy Hybrid [2], SID, BioSID [3], BioRID [4] are used for vehicle safety assessment in world practice. They allow estimating the degree of a dynamic impact on passenger sand members of train crews with a high degree of adequacy, both during rolling stock movement and emergency situations.



The assessment of person traumatizing levels is based on the following criteria usage: craniocerebral injury, cervical spine traumatizing, chest and hip traumatizing [2].

A craniocerebral injury criterion is determined in accordance with

$$HIC = (t_2 - t_1) \left( \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a dt \right)^{2.5},$$

where  $t_1, t_2$  – time points, measured in seconds. They define an interval between the initial and the final moments of the head contact with aninjuring object, where a HIC value is maximum;  $a$  – is complex acceleration, evaluated in  $G$ -units.

A cervical spine traumatizing criterion is determined in accordance with

$$N_{ij} = \frac{F}{F_k} + \frac{M}{M_k},$$

where  $F$  – axial compression / stretching force;  $F_k$  – axial force, used for normalization;  $M$  – bending moment;  $M_k$  – bending moment, used for normalization.

A chest traumatizing criterion is determined in accordance with

$$CTI = \frac{A_{\max}}{A_k} + \frac{D_{\max}}{D_k},$$

where  $A_{\max}$  – maximum acceleration;  $A_k$  – acceleration, used for normalization;  $D_{\max}$  – chest pick deformation;  $D_k$  – deformation, used for normalization.

A hip traumatizing criterion is determined in accordance with compression pressure that is imparted axially to each dummies hip.

Physical dummies are also used for the specified assessment of the passenger comfort level in the course of motion, particularly for trains with compulsory inclination of a body in curve tracks.

Within CEN 12299 the average comfort coefficient is applied to definition of passengers comfort on tangent track:

$$N_{MV} = 6 \cdot \sqrt{\left(a_{XP}^{Wd}\right)^2 + \left(a_{YP}^{Wd}\right)^2 + \left(a_{ZP}^{Wd}\right)^2},$$

where  $a_{XP}^{Wd}$  – accelerations, affecting a passenger in the longitudinal direction;  $a_{YP}^{Wd}$  – accelerations, affecting a passenger in the broadside direction;  $a_{ZP}^{Wd}$  – accelerations, influencing a passenger in the vertical direction.

This dependence is used for specification of the percent of passengers experiencing discomfort:

$$P_{CT} = 100 \left\{ \max \left[ A \cdot |\ddot{y}_{ls}|_{\max} + B |\dot{y}_{ls}|_{\max} \cdot C; 0 \right] + \left( D \cdot |\dot{\phi}_{ls}|_{\max} \right)^E \right\},$$

where  $\ddot{y}_{ls}$  – broadside acceleration of the car body,  $m/s^2$ ;  $\dot{y}_{ls}$  – changes of broadside acceleration of the car body per 1 sec,  $m/s^3$ ;  $\dot{\phi}_{ls}$  – angular speed, rad/sec;  $A, B, C, D, E$  – constant, accepted in accordance with CEN.

It's important to consider the influence of motion sickness estimated by a motion sickness dose for a rolling stock, equipped with a system of car body constrained inclination

$$MSDV_z(t) = k_{MSDV} \sqrt{\int_0^t a_{wf}^2(t) \cdot dt},$$

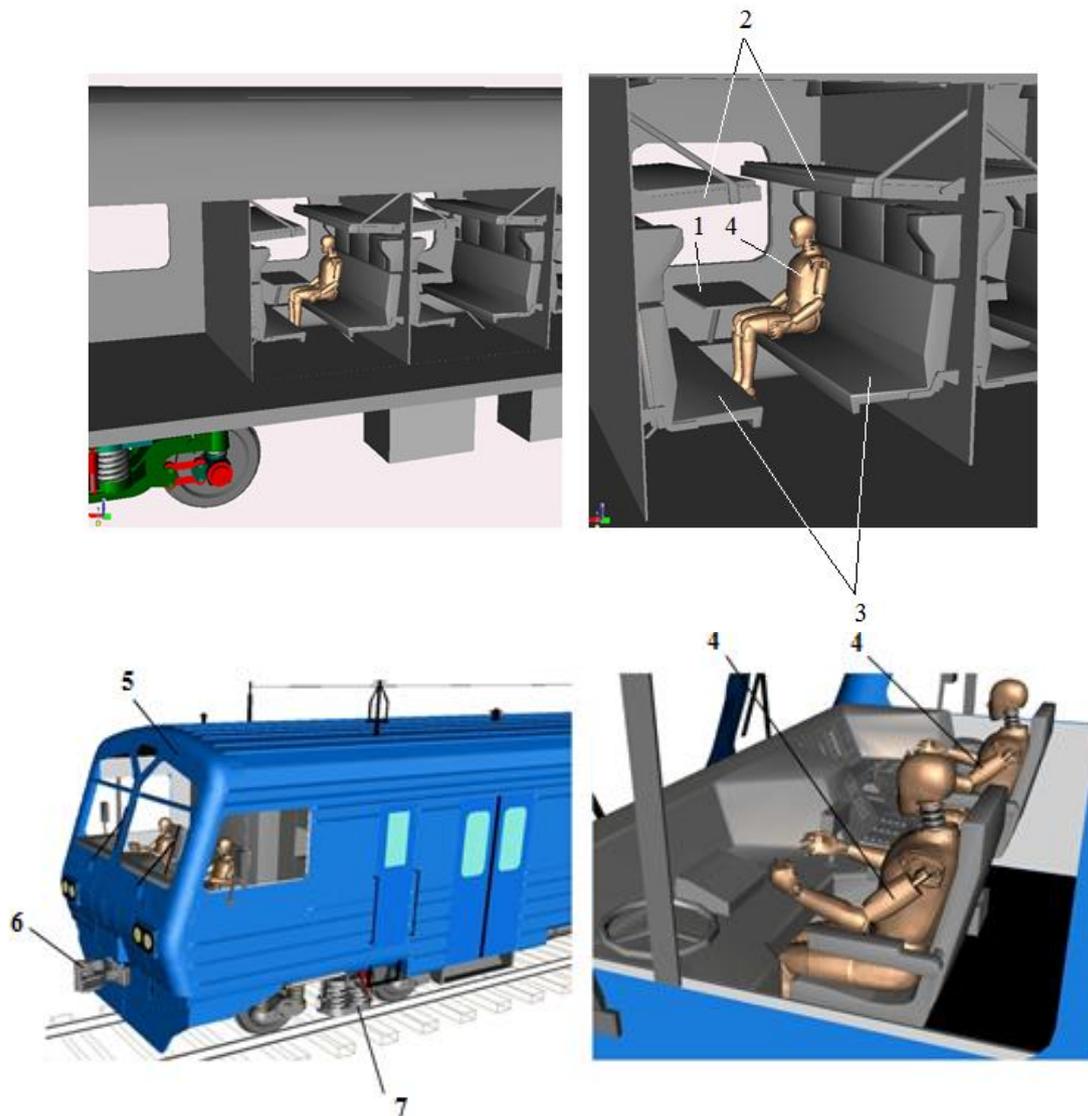
where  $a_{wf}$  – frequency-weighted vertical acceleration,  $m/s^2$ ;  $k_{MSDV} = 1/3$  – coefficient for the mixed non-adaptable public of the adult women and men, they most probably will be influenced by the motion sickness effect.

A discomfort level can be also predicted in accordance with the dose of motion sickness. The value of the ‘discomfort level’ is graduated on a scale from 0 (‘I feel well’) to 3 (‘I feel absolutely awful’) and is determined by the following dependence:

$$IR(t) = \frac{MSDV_z(t)}{50}$$

Specialists of the ‘Railway rolling stock’ chair of Bryansk state technical university have developed a solid-state computer model of an anthropometrical dummy of Hybrid III 50<sup>th</sup> Percentile Male [5] in the area of the program complex of kinematics and dynamics modeling of bodies systems of ‘Universal mechanism’. During modeling the dummy was divided into the following elements: a head, a neck, a top part of a trunk, a shoulder, a hip, etc., joint by means of hinges in one model. All elements of the dummy were simulated from rigid bodies with the real weight and geometrical characteristics corresponding to anthropometrical characteristics of the ‘average’ adult man.

The safety assessment of home car model 61-4440 and electric train ED4M (Figure 1) was carried out using the developed computer model of the anthropometrical dummy.



**Figure 1.** Fragments of computer models of a passenger car and electric train ED4M:  
 1 – table; 2 – sleeping berth; 3 – sofas; 4 – anthropometrical dummy; 5 – rigid car body model;  
 6 – subsystem ‘automatic coupling’; 7 – subsystem ‘bogies’.

For this purpose the computer models of train impacts with the corresponding obstacles [6] were carried out in the area of the program complex 'Universal Mechanism'. Characteristics of impact models corresponded to standard documentation of design of rolling stock mechanical safety systems for civil passenger traffic and were used as test scenarios for its safety assessment.

The comfortableness assessment of a home electric train with systems of car body constrained inclination in curve tracks was also carried out (Figure 2).



**Figure 2.** A solid-state computer model of an electric train:

- 1 – subsystem 'head car'; 2 – subsystem 'trailing car';  
3 – subsystem 'railmotorcar'; 4 – solid-state anthropometrical dummy

### 3. Conclusion

The oscillograms of parameters of dynamic interaction of dummies with interior elements of the car and a control cabinet of an electric train were received as a result of train emergency impact modeling with obstacles. There is traumatizing criteria calculation in accordance with obtained values of dynamic efforts. These values are compared with rated ones, expressing the allowed levels of man traumatizing in emergency situation. The analysis of these results has allowed revealing the most injury-causing elements of rolling stock interior considered units and make the conclusion about their safety.

The parameters of rolling stock comfortableness have been determined in accordance with the given dependences during modeling of electric train movement along various railway tracks. The obtained results have been compared with the rated values defining comfortable conditions of passenger travel of various age categories. The results obtained from the safety and comfortableness analysis of the passenger rolling stock can be used in developing technical solutions of trains, locomotives. These researches are vital for the enhancement of electric trains mechanical safety in case of emergency impacts with obstacles, as well as for the improvement of transportation comfort with regard to a possible train speed increase.

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