DEVELOPMENT OF PASSIVE SAFETY DEVICES OF RAIL PASSENGER COACHES

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ABSTRACT

Active safety systems used in rail transport, do not exclude possibility of accidents involving injury and loss of life [1]. In this regard, in design of modern rolling stock there is a need to develop passive safety systems that can reduce the severity of collisions [2,3]. Passenger coaches with devices absorbing kinetic energy of a longitudinal collision, acquire the ability for plastic deformation of the structure and thereby reduce the likelihood of loss at critical loads. The authors propose constructive solutions and calculation of energy consumption of absorbing devices, evaluate their effectiveness on the basis of mathematical modeling results.

Keywords: railway, passenger coach, life-saving device, kinetic energy of collisions, plastic deformation, automatic coupling, shock absorbing device, constructive solutions.

Background. *Existing regulations [4] for design of domestic passenger cars do not contain any guidance on life-saving devices. However, on the initiative of JSC «Russian Railways' a step has been made to change a situation. State standard, regulating the passive safety of passenger rolling stock, – GOST 32410–2013 «Emergency crash systems of railway rolling stock for passenger transportation. Technical requirements and methods of control [5] « was adopted. According to it all passenger coaches should be equipped with energy absorption devices (EAD), which operation is based on neutralization of kinetic energy of the collision through plastic deformation of a car design [6,7].*

Reduction of negative effects of longitudinal collision of cars and provision of effective absorption of kinetic energy are only possible in the implementation of the free movement of bodies toward each other, which is prevented by the construction of automatic coupler devices. Limited progress of absorbing device restricts the approaching of cars. Under the influence of excessive loads coupler head rigidly transmits force to the frame, which prevents from turning on a mechanism for shock energy absorption by a life-saving device.

To eliminate this effect an original structural scheme is developed for installation of automatic coupling equipment, a distinct feature of which is the ability to move the coupler into the car frame that provides the perception of longitudinal forces of collisions by elements of life-saving system, located on the body.

Objective. *The objective of the authors is to investigate possible ways of development of life-saving devices, mounted on passenger cars, to propose constructive solutions and calculation of energy consumption of absorbing devices, to evaluate their effectiveness on the basis of mathematical modeling results.*

Methods. *The authors use mathematical modeling, analysis, evaluation approach, engineering methods.*

Results. *Automatic coupler is performed in a single unit mounted in the car frame. Fixing of front and rear stop shoulders to longitudinal beams of the unit is performed with welding. Automatic coupler unit is fixed to the frame by bolting using fitted bolts. Replacement of the unit of automatic coupling equipment is achieved by cutting of bolting when exposed to loads exceeding standard values.*

The use of such a solution requires changes in the design of the console of the car frame. For smooth movement of the unit inside the frame, center sill in the end portion is broadened in size of striker. Due to weakening of the zone of longitudinal forces transfer end beam of the frame is reinforced.

Preliminary assessment of EAD parameters is conducted in accordance with the scenario of collision characterizing conditions in which the train comes into contact with an obstacle. There are two scenarios: 1) emergency collision at a railway crossing with a car; 2) emergency collision with a freight wagon [5].

The minimum required total power consumption of all EAD placed on the rolling stock is defined by the formula

$$U = \frac{M_1 M_2}{(M_1 + M_2)} \frac{V_1^2}{2}, \qquad (1)$$

where M_1 is a train mass; M_2 is an obstacle mass; V_1 is speed in collision.

A reference train involved in the collision scenarios is a train, consisting of a locomotive and four passenger cars of one design. This refers to the eight-wheel locomotive with an axle load of 19 tonnes, equipped with a rigid body with automatic coupler and draft gear, equipped with EAD in each end portion. Total power consumption of all EAD, mounted on a passenger car (in the sum with an energy consumption of draft gears of two couplings) must not be less than 1/12 of the total energy consumption, calculated by the formula (1). For the design the biggest of obtained values of energy consumption are selected.

On the basis of technical characteristics of various models of passenger cars produced by JSC «Tver Carriage Works' the required total energy consumption of EAD of life-saving devices are calculated (Table 1). Analysis of the results shows that the minimum total power consumption of all EAD, mounted on a passenger car of a new model series, should be at least 268 kJ.

In accordance with the concept of passive safety of rolling stock the following sequence of EAD response is possible: automatic coupler draft gear; breakable elements of coupling device; energy absorption devices. In modern passenger cars in the construction of the coupler rubber draft gears P-5P are used with stroke of 80 mm and having energy consumption of 40 kJ. Their total energy consumption is at least 188 kJ.

Geometrical dimensions of EAD of life-saving devices of passenger cars are determined based on the possibility of their placement on the bodies in order to ensure trouble-free operation in emergency situations.

Table 1

Calculation of energy consumption of EAD of a passenger car

Car model	Weight of a car M_c, kg	Weight of a train M_1, kg	Scenario 1			Scenario 2		
			Weight of an obstacles M_2, kg	Collision speed V1, m / s	Required energy consumption U, kJ	Weight of an obstacle M_2, kg	Collision speed V_1, m / s	Required power consumption U, kJ
61–4440	62795	327180	10000	20	162	80000	10	268
61–4445	62245	324980			162			268
61–4447	60925	319700			162			267
61–4458	61735	322940			162			268

The most effective dissipation of the kinetic energy of the collision will be observed when EAD are located along the contour of the side wall, due to the design of the car body in a closed supported shell with cutouts for window and door apertures. This design enables to put into operation all its elements in the perception of both operational and emergency longitudinal loads.

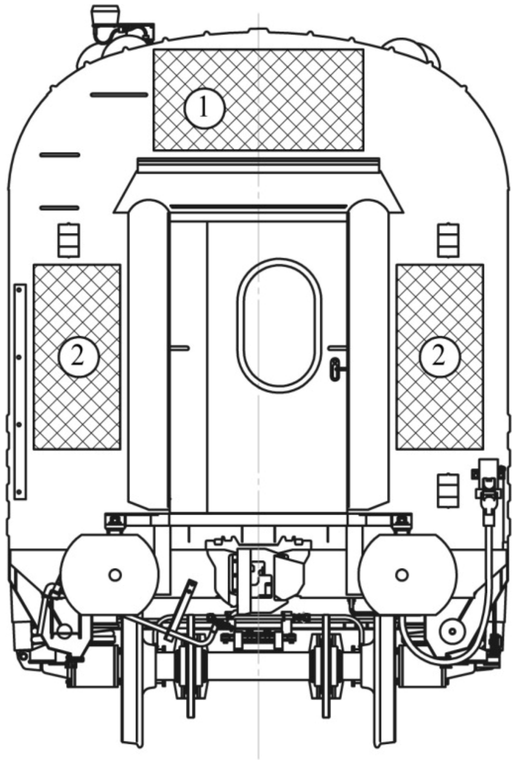
To determine rational geometric dimensions of EAD we will conduct an analysis of cars' approach when there is a collision with an obstacle. At higher speeds there is a complete compression of the absorbing device, which leads to transmission of longitudinal forces on the frame of the car through the coupler head shock in frontal beam of the frame. With further rapprochement frontal beam is destroyed and contact of poppets of buffers and anti-telescoping columns of cars dramatically increases the rigidity of bodies. This means that EAD will the most effectively absorb the kinetic energy of the shock to the moment of contact of buffer devices and anti- telescoping columns. In this case, the stroke of devices mounted on side walls of the car does not exceed 65 mm.

Operating modes of passenger cars suggests movement both in straight sections of the track, and the passage of curves of different radii. On a curved section body rotates about an axis passing through the center of the curve, which reduces the distance between side walls of cars within the curve and its increase outside the curve. In such modes of movement EAD of neighboring cars do not have to touch each other. Technical characteristics set minimum curve radius traveled in the coupling gear of a similar car – 120 m.

To determine rational installation locations of EAD on side walls the motion of a coupling gear of two similar cars on the minimum allowable curve was considered. In this embodiment two location options of EAD were assessed: in zone 1 and in zone 2 (Pic. 1).

Analysis of calculation results of cars passing a curve showed that when EAD is located in the zone 2 maximum stroke of elements to contact with anti-telescoping columns does not exceed 40 mm, which is explained by the need to maximize the area of contact between EAD and neighboring cars. Such a stroke will not ensure efficient operation of elements that gives grounds to conclude that their stay in such areas is inappropriate. Moreover, service conditions for transitional areas and control of abutment density of picking up of adjacent cars to each other complicate.

Location of EAD in the zone 1 allows obtaining the elements' stroke of more than 200 mm and providing absorption of shock kinetic energy of more than 1 MJ. However, the use of energy-absorbing elements on side walls of cars requires strengthening of their support structure to achieve the expected level of rigidity of a base. In this regard, for energy absorption of the shock it is offered to incorporate EAD in the car frame structure and to place it over the unit of the automatic coupler. Calculations showed that after the full compression of the absorbing device and start of the automatic coupler unit displacement prior to selection of gaps in buffers there is an ability to provide stroke of EAD of 65 mm. This means that in the design of energy absorbing element energy consumption of at least 94 kJ should be assumed.

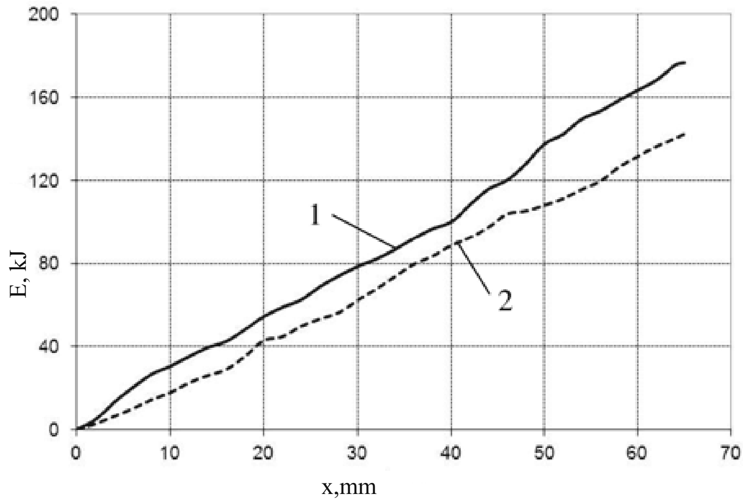


Pic. 1. Considered areas of EAD location.

Design of EAD structure and the choice of rational parameters take into account restrictions on dimensions and weight of elements, manufacturability and cost of manufacture. There are two variants of EAD embodiment:

– 1st option – a tubular structure consisting of a package of thin-walled tubes, placed in a closed box;

–2nd option 2 –honeycomb structure composed of rectangular cells formed from thin-walled sheets installed crosswise; cells are placed in a closed box.



Pic. 2. Dependency graph of energy consumption of elements from their deformations: 1 – tubular structure; 2 – honeycomb structure.

The effectiveness of energy absorption of offered options is evaluated by means of mathematical modeling based on formed laminose finite element models. Simulation of EAD deformation as a result of applied shock was carried out taking into account geometrical and physical nonlinearity of device materials. Through simulation graphs of dependence of EAD energy consumption from their deformations were obtained (Pic. 2).

Conclusions. *Analysis of the data led to following conclusions:*

– Tubular structure of EAD is the most efficient;

– During plastic deformation of the tubular EAD kinetic energy of about 175 kJ in the deformation of element 65 mm can be absorbed, which corresponds to the requirements for life-saving devices of modern passenger cars.

Thus, by equipping passenger cars with offered EAD total energy consumption of life-saving system will be 430 kJ, which exceeds required value by 60%.

Stated constructive solutions to improve passive safety of domestic passenger cars in emergency situations can help to reduce the risk of injury to passengers and train crew, as well as to reduce damage to rolling stock in collisions.

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