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# EXPERIMENTAL STUDY OF NON-COMPATIBLE COLLISION OF RAIL AND ROAD VEHICLE

***ABSTRACT***

*The paper deals with safety of transport from the point of view of an important social problem, which are accidents at railroad (including tramway) and road level crossings, which means compatibility of rail and road vehicles crash. The scale of such accidents can be very wide. Regarding the statistics and frequency of accidents particularly at railway level crossings and tramway level crossings, a collision simulating the collision of a tram and passenger car was experimentally carried out. The experiment took place at the site of testing laboratory of Rail Vehicles Research Institute in Cerhenice. The experiment was conducted with a passenger car Škoda Superb of the first generation that was exposed to two collisions from both sides. Firstly by the impactor for tram headstock tests and secondly by the tram headstock itself. Both the impactor and the headstock were placed on the experimental vehicle for tests of passive safety of rail vehicles. Various speeds were chosen so that the passenger car could be used for two subsequent experiments without the influence on properties of skeleton´s supporting structure.*

***KEY WORDS***

*tram headstock; headrest; accident; non-compatible crash test; impactor;*

## 1. INTRODUCTION

Accidents of a tram and car are quite a frequent phenomenon in big cities. Their consequences are mostly not fatal but they can cause both minor and serious injuries that could be prevented by changes in design of particular parts of cars and trams. The paper deals with the crash of tram headstock to the lateral structure of personal car. Due to the different design principles of rail and road vehicles, the result can be hardly estimated by the results of standard testing methodologies. The purpose of the experiment is to find out the critical substructures and design measures improving the compatibility of this type of accident.

According to the preliminary statistics in 2012 the Rail Safety Inspection recorded 4,181 accidents on the railroads in the Czech Republic in total. Their number increased by almost 12% compared with 2011. This increase was caused by important growth in the city public transport accidents, i.e. trams and trolleybuses, where the Rail Safety Inspection recorded 17% more accidents than in 2011 [11].

While the number of accidents increased, the statistics of people killed on railroads in 2012 presents the decrease in number of killed people almost by 17% compared to 2011. The statistics of injuries in the last three years shows, however, an increasing trend –

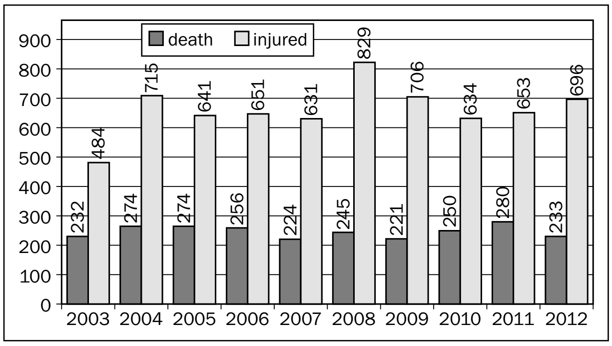


*Figure 1a - Statistics of railroad accidents in the Czech Republic*

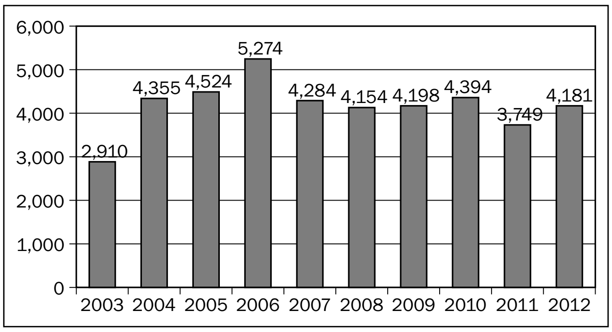


*Figure 1b - Development of the number of accidents*

compared to 2011 the growth is 6% and the number of injuries in 2012 is the fourth highest within the last 10 years [1].

The survey of killed and injured people as a consequence of accidents and the development of the number of railroad accidents are presented in *Figure 1*a and 1b.

## 2. HYPOTHESIS

The main idea of the experiment is based on the following presumptions and contentions:

- From the point of view of a side impact the structural properties of cars are tested according to the EHK 95 method where the strength of side structure is verified by the impact of a vehicle (950 kg, velocity 50 km/h) simulating an average passenger car. Further test then lies in the impact onto a stake according to the Euro-NCAP method, which is implemented into approving processes [2].
- Head-on collisions of trams are tested according to approved method. For verification of the properties of a tram headstock a cylinder segment impactor equipped with sensors is used [3].
- The load in both tests is different both in the geometry of impactors and mechanical properties (stiffness).

This means that the principles of both regulations are different and if there is a collision of the above mentioned structures, their mutual behaviour is unpredictable. The chosen experiment method is then based on the goal to verify the compatibility of side structure of a car and front part of a tram.

Parameters of the experiment respect available accidents statistical data and there is an attempt to compare the impact described in ECE 95 regulation with tram impact. The guide can be kinetic energy of the impactor. Kinetic energy is transferred to the deformation work of the car side wall and its lateral movement. The different impact character leads to the different momentum

$$\Delta p = m \cdot \Delta v \quad (1)$$

and different impulse

$$J = F \cdot \Delta t = \Delta p \quad (2)$$

Consequently, the impact dynamics changes for different impactor mass and its velocity. Nevertheless, the kinetic energy of impactor according to ECE 95 (see the test parameters) is:

$$K_{ECE95} = \frac{m \cdot v^2}{2} = \frac{950 \cdot \left(\frac{50}{3.6}\right)^2}{2} = 91.6 \text{ kJ} \quad (3)$$

If the mass of rail testing vehicle is 80 tons (see part 5.1.), the speed of this vehicle is $v$ = 5.4 kmph for identical kinetic energy. The velocity close to this value was the first testing impact parameter. The parameters estimation of the second test (II) respected the statistical data and the experts' opinion; therefore, the test speed was 16 km/h in these experiments. The kinetic energy is quite high in this case ($K_{II}$ = 790 kJ); anyhow, the testing methodology requires safety braking of the test rail vehicle which affects both lateral loading of the structure and especially the car y-axis direction movement.

The effects of forces and strain states of vehicles caused by a collision of two or more vehicles are influenced by many parameters. The parameters for example are:

- Speed of the impacting vehicle at the moment of collision;
- Mass of the impacting vehicle;
- Stiffness of impacting vehicle in longitudinal direction (characteristics of bumpers and stiffness of construction);
- Height of the centre of gravity of the impacting vehicle;
- Stiffness of vertical suspension.

## 3. DESIGN OF EXPERIMENT

The aim of the test was to observe both the deformation of side structure of the car as a consequence of a non-compatible impact and to estimate the possible consequences of such a type of impact for the car crew.

Strain gauges Hottinger 1-LY11-10/350 were installed on chosen places of the car and seven accelerometers inside the car. The accelerometers were placed in the middle of the roof, on the floor tunnel and under the dashboard on the side of a front passenger. The crash test dummies (adapted Manikin) were placed on front seats and three-axis accelerometers were placed in their head and chest as well. The accelerometers were designed and produced in the Laboratory of Special Electronics of the Department of Security Technologies and Engineering at the Faculty of Transportation Sciences, the Czech Technical University in Prague. The allocation of the sensors is displayed in *Figure 2* while the strain gauges placed outside the car body are marked as white stars and the accelerometers inside the car are marked as black stars. The allocation of strain gauges was almost identical in both tests.

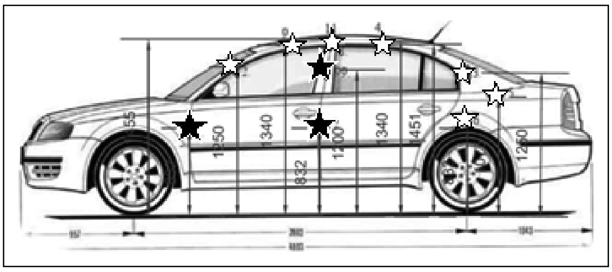

*Figure 2a - Allocation of sensors on the left side of the car (white stars) and in the car (black stars)*

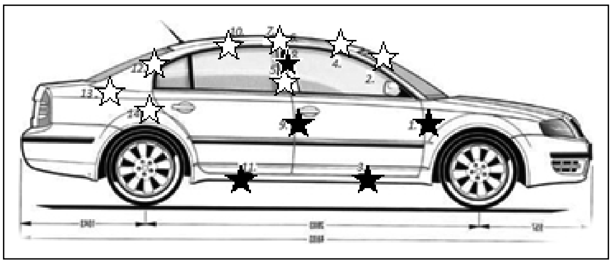

*Figure 2b - Allocation of sensors on the right side of the car (white stars) and in the car (black stars )*

The passenger car was placed on the rails perpendicularly to their axis and was centred (*Figure 3*). Two impacts were gradually led onto the vehicle from both sides. The first impact was made onto the left side of the vehicle by a standardized impactor used in railroad vehicle tests. The other impact was led up onto the right side of the vehicle by a tram headstock that is used when designing contemporary trams. Both the impactor and the headstock were fixed to a testing freight carriage, which was dropped from a hump in the gravity yard and which was immediately after the collision braked with wedges [4].

The course of the collision was recorded not only by sensors (accelerometers and strain gauges) but also by high-speed cameras allocated both outside the vehicles as well as inside. An important act from the standpoint of the environment protection was operation liquids draining before starting the experiment.

The partial goal of the tests was to verify the function of a specially shaped headrest that could reduce the seriousness of head and neck spine injuries in case of side collision. The headrest was produced on the basis of the registered utility model No. 21980 [5]. The headrest was placed on the seat of a fellow passenger instead the standard headrest, which is compulsory equipment of each car.

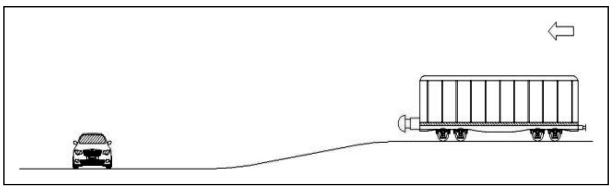

*Figure 3 - The scheme of the experiment*

In order to estimate the seriousness of possible injuries of car occupants the HIC(d) criterion of head injury was used. It was calculated from the measured signals with the help of the DIAdem programme. The HIC(d) is used in a standard way in tests according to EHK and it considers the head rotation.

## 4. DATA RECORDING

The software and hardware produced by the company National Instruments was used to gain and process the data or voltage from strain gauges and accelerometers. The equipment CompactRIO was used as hardware, which is a measuring and control system of small proportions. Its asset is also a real-time and reconfigurable controller (filer). Within graphic software environment LabVIEW (Laboratory Virtual Instruments Engineering Workbench) a programme for collection of data and their subsequent download into CompactRIO was created. CompactRIO was within the course of the collision placed safely in the luggage compartment of the passenger car. As the CompactRIO system is not equipped with environment for data collection, I/O modules are another part of the whole system. Two sorts of modules were installed for the experiment. The first one was NI 9205 that was used for measuring voltage from accelerometers placed in the dummies and the vehicle. It is a 32-channel analogous entry module. The other module was NI 9235, which was used for the strain gauges. In this case it is an 8-channel entry analogous module that simultaneously works as a quarter-bridge strain gauge. Regarding the planned number of strain gauges two modules of this type were needed. The measured data from strain gauges and accelerometers were downloaded into the memory by CompactRIO programme created within graphic software environment LabVIEW [6], [7].

In both collisions 21 outputs from accelerometers were recorded. There were 3 axes of seven accelerometers in total (axes x, y, z). The number of connected strain gauges varied within the course of the entire collision experiment. In the case of the right side impact 15 strain gauges were connected while at the left side impact only 11 of them.

## 5. RESULTS

### 5.1. Impactor test

The first impact test was carried out by a standardized impactor that is according to standards used in railroad vehicle tests. The impactor is made of a cylinder segment with an outer diameter of 250 mm fixed to a testing freight carriage of 80 tons weight. The impact speed was 4 kmph. The moment of impact is recorded in *Figure 4*.

Figure 4 - Impact of a standardized impactor

Within the course of the collision only relatively small deformations of side structure of the vehicle appeared. The right side of the car was pressed towards the ground and the right front tyre was partly removed.

Figures 5 and 6 show the courses of acceleration measured by the accelerometers placed in the heads of the dummies and the courses of deformation of the car´s structure calculated from the strain gauges data. As mentioned above the accelerometers recorded signal in three axes. The final course of acceleration, which was put together from particular components according to the formula is displayed in *Figure 5*:

$$a = \sqrt{a_x^2 + a_y^2 + a_z^2} \quad (4)$$

From the measured signals it is obvious that the maximum acceleration in the head of the driver dum-

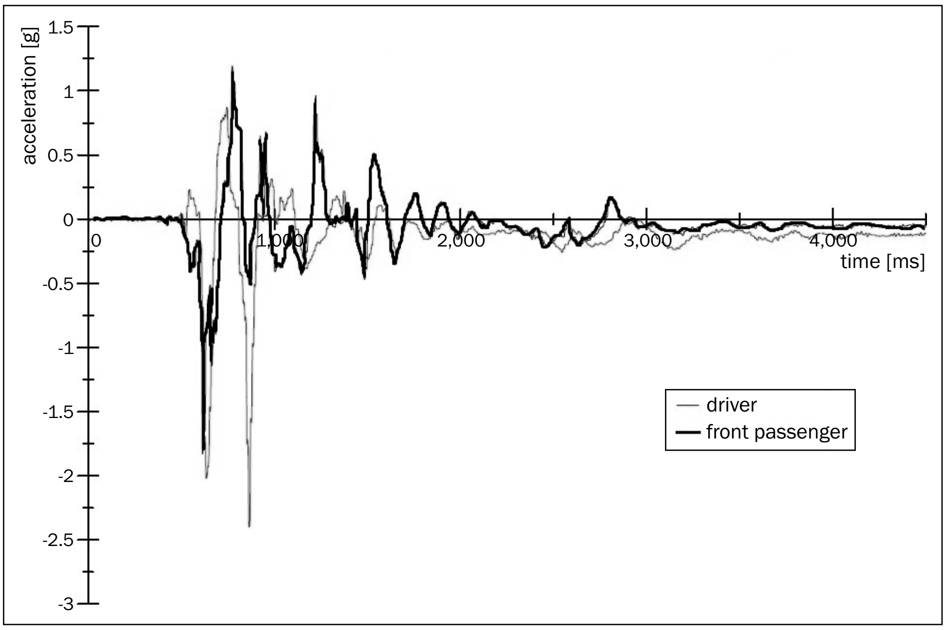


Figure 5 - The course of final acceleration in the heads of dummies during the impact

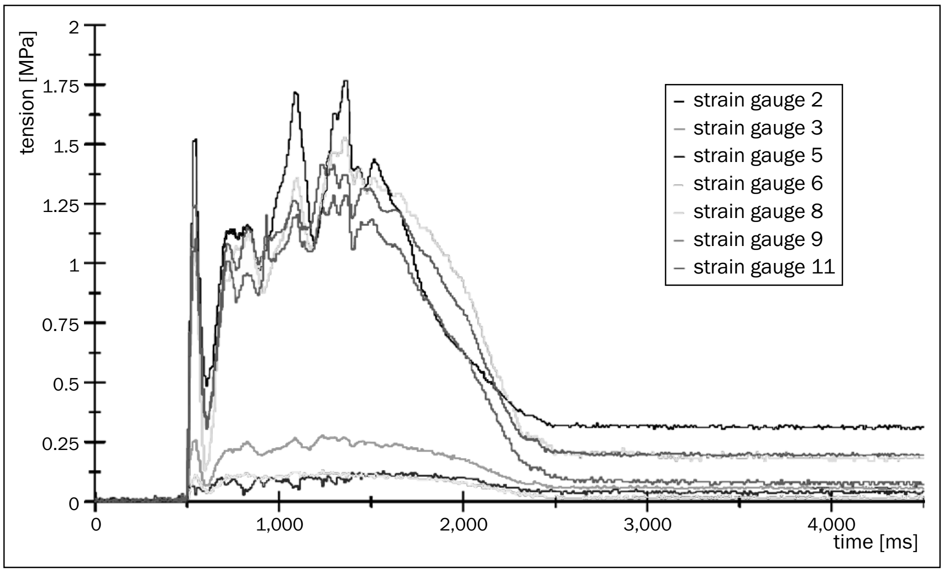


Figure 6 - The course of deformation of the selected parts of the vehicle

my reached the value of about 2.5 g, in the case of the front passenger it was about 1.75 g. The value of HIC(d) criterion was in both cases comparable and it was calculated from the interval of 36 ms as 166, which is far below the limit of 1,000 [8].

*Figure 6* displays the course of deformation of the selected parts of the car body where the strain gauges were fixed. From the graph it is obvious that we can mostly observe elastic deformation of the side structure.

## 5.2. The tram headstock test

In the second test the same car, which was not damaged by the first test and its vital structures remained unharmed, was used. The collision was carried out by a tram headstock at a speed of 16 kmph (*Figure 7*).

The moment of the impact is recorded in *Figure 8*.


*Figure 7 - Tram headstock*

*Figure 8 - The impact by a tram headstock*


*Figure 9 - The situation after the test*

The higher speed compared to the first test also meant much higher kinetic energy of the freight carriage and bigger deformations of the side structure of the car body. The car was pushed before the carriage

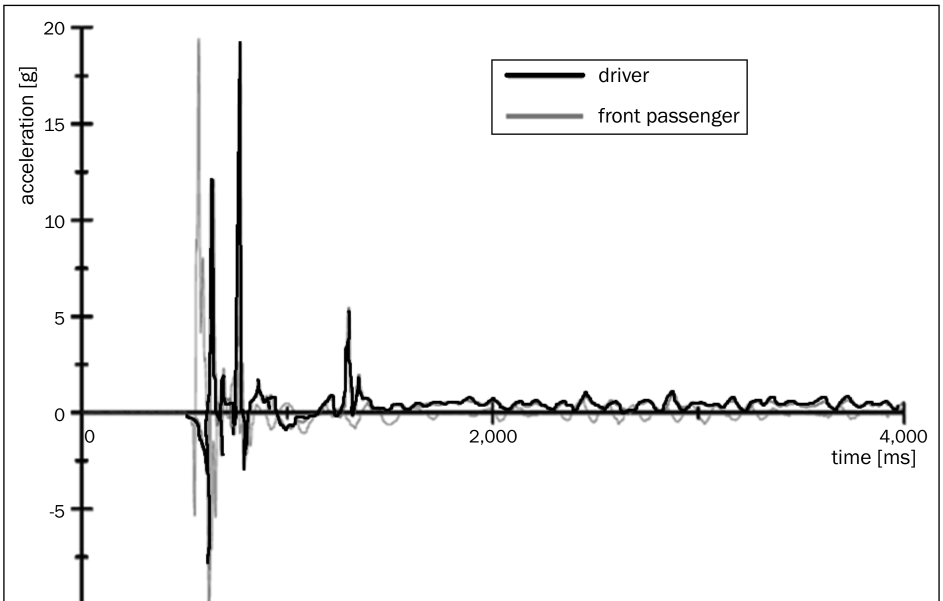


*Figure 10 - The course of the resulting acceleration in the heads of dummies in the collision with headstock*

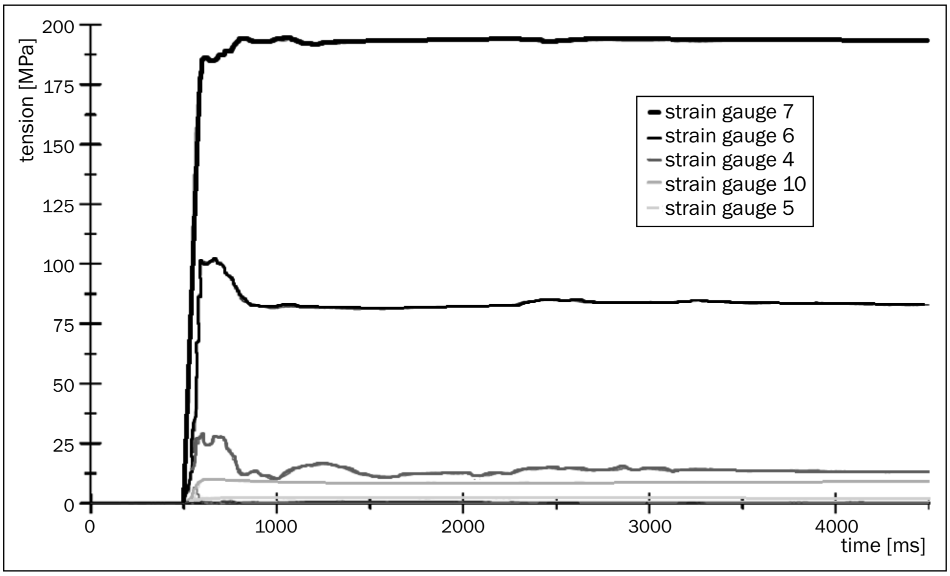


*Figure 11 - The course of the strain in the car body in case of impact by a headstock*

for about 10 metres, there was deformation of the right doors (front and back) and breaking of window panes on the right side. After visual inspection we could say that both the headstock and the car preserved their structure and mechanical features. The situation after the crash test is recorded in *Figure 9*.

The measured acceleration on dummies reached a comparable maximum value of almost 20 g. The course of acceleration in the head of the driver and the front passenger is displayed in *Figure 10*.

From *Figure 11*, which displays the courses of strain of selected car body parts, we can conclude that plastic deformation of the vehicle side structures and roof (strain gauge 4) prevails.

### 5.3. Function of a special headrest

In the case of the dummy on the passenger seat additional safety equipment was used. It was a headrest shaped in a special way that could increase the protection of head and neck spine of a passenger in case of a side collision. This headrest is particularly used for transportation of children in the age of 10 – 12 years whose weight is over 30 kg and height of about 150 cm. Though such a child can be still often transported in a child restraint system it cannot provide the baby with sufficient protection in case of a possible accident. Usually a childof the height of about 150 cm cannot fit in a child restraint system with an integral headrest, since the system is not comfortable for a child due to its dimensions. These children mostly use then only a booster combined with conventional safety belts. In a side collision the head and neck spine of a child passenger is not protected at all. From the point of view of statistics of traffic accidents the rate of side collisions to front collisions is roughly 1:2. According to the EU statistics traffic accidents are the second most frequent cause of death of children 10 – 14 years of age. The percentage of children whose physical parameters do not fit the categories recommended by the child restraint systems producers is estimated at 5 – 10%.

A common headrest cannot prevent the head of a passenger from moving in case of side collision and there is a threat of serious injury of head and neck spine due to direct contact with solid parts of the car interior, for example, side door.

Cars are still very often not equipped with side airbags and so in case of traffic accident child passengers on these seats are exposed to high risk of a serious injury of head and neck compared to a child who can be still transported in a child restraint system with integral headrest.

The special headrest is made of an energy absorbing material and is fixed up with side guards for the head. The headrest is equipped with braces (a common design of conventional headrests) that can be placed into the existing holes of the headrests on the back seats of a vehicle.

For maximum efficiency the equipment has to be completed with the use of conventional safety belts [9].

For pilot verification of the function of the designed headrest the impact tests onto the side of a passenger car with impactor and tram headstock were used. For more detailed judging of the efficiency of this equipment it is desirable to create a mathematical model and to compare the criteria of head and neck spine injuries at various collision speeds. Also, a validation test in laboratory conditions is necessary.

The view into the passenger car interior is presented in *Figure 12*.


*Figure 12 - View into the passenger car interior*

## 6. DISCUSSION

The experiment that was carried out focused on two areas:

- vehicle-human interaction from the point of view of passenger safety;
- verification of the compatibility of the testing methods within the area of road and rail vehicles.

The vehicle-human interaction in the case of the collision with rail vehicle (tram) was verified with the carried out test. The space for crew survival remained in both cases and the modified headrest, which was installed, would with a high rate of probability contribute to the reduction of the load on the head and neck spine of the front passenger, particularly at lower collision speed. From the result data it is obvious that both collision objects were deformed uniformly and that compatibility remained preserved quite well at the certain impact speed. The passengers would not probably sustain such injuries that would immediately threaten their lives. The experiment gave good image on force conditions within tram-passenger car collision which according to statistics is one of the most common accidents of rail vehicles [10].

The evaluation of result deformations of a vehicle shows good compatibility of both structures. However, this result is based on construction parameters, which are not legislatively linked. The proposal that follows from the test result is to create common methods of testing the side structures of cars and front parts of a tram. These methods could be broadened onto voluntary test with a side impact of the same impactor. The condition of a consensus is maintenance of force courses in a defined corridor.

## 7. CONCLUSION

The article describes the lateral crash of personal car with tram front part. The aim of the test was the evaluation of deformation compatibility of vehicle side wall and tram front part, compared with ECE 95 methodology and utilizing testing methodology of rail vehicles legislation for road vehicles testing and design. Last but not least, the special passive safety element for lateral impacts – the adapted headrest was tested. The results prove the stiffness and deformation compatibility in the tested products; anyhow, the expansion of the lateral test to the specific impact geometry and loading conditions is useful from the passive safety point of view. The special headrest proved the necessity to improve the safety of occupants in case of lateral impact. The biomechanical response of head during test was well limited by the headrest design.

The harmonisation of passive safety regulation of road and rail vehicles brings profit in passive safety level in case of mutual impact of vehicles, which meet frequently in the real everyday traffic.

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### *ABSTRAKT*

*Příspěvek řeší problematiku bezpečnosti dopravy z hlediska závažného společenského problému, a to nehod na křížení železniční cesty a silnice (včetně tramvají), tedy kompatibility nárazu železničního a silničního vozidla. Spektrum takových nehod může být velmi široké. Vzhledem k statistikám a četnosti nehod, zejména na železničních přejezdech a kříženích tramvajových tratí, byl experimentálně řešen kolizní děj, simulující náraz tramvaje a osobního automobilu. Vlastní experiment proběhl v areálu zkušebny VÚKV a.s. v Cerhenicích.*

*Vlastní pokus proběhl s osobním automobilem Škoda Superb první generace, který byl vystaven dvěma kolizím ze dvou stran. Jednak impaktorem pro zkoušky čelníků tramvají a jednak vlastním čelníkem tramvaje. Jak impaktor, tak i čelník byly umístěny na zkušebním vozidle VÚKV a.s. pro zkoušky pasivní bezpečnosti kolejových vozidel. Byly zvoleny různé rychlosti tak, aby bylo možné osobní automobil využít pro dva po sobě následující testy bez ovlivnění vlastností nosné struktury skeletu.*

*KLÍČOVÁ SLOVA*

*tramvajový čelník; opěrka hlavy; dopravní nehoda; nekompatibilní náraz; impaktor;*

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