ELECTRIC CAR CRASHENERGY ABSORBING STRUCTURE

Struktura pochłaniająca energię zderzenia dla samochodów elektrycznych

Mirosław CHŁOSTA ORCID: 0000-0002-4921-6908
Andrzej BARSZCZ ORCID: 0000-0002-2979-0734

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Abstract: Most of the current electric cars are derived from recreational vehicles; hence, there is a necessity to develop passive safety systems that meet the current traffic requirements. This paper presents passive safety issues and the results of the real model studies.

Keywords: Electric car, safety zones, protecting structures, passive safety, FEM simulation

Streszczenie: Większość użytkowych samochodów elektrycznych produkowanych obecnie w Polsce wywodzi się z elektrycznych pojazdów rekreacyjnych. Stąd konieczność dostosowania ich konstrukcji nośnych do wymagań bezpieczeństwa stawianych pojazdom drogowym. W artykule przedstawiono wymagania prawne w tym zakresie oraz wyniki badań nad obiektami rzeczywistymi.

Słowa kluczowe: pojazd elektryczny, konstrukcje ochronne, strefy bezpieczeństwa, bezpieczeństwo bierne, obliczenia wytrzymałościowe

Introduction

The car's body structure depends on many factors; it is a truism, but having far-reaching implications for electro-mobility programs in Poland. The question arises whether and in what scale the Polish electric car will be produced. This issue is crucial in a view of the necessity to adopt a proper technology, adequate to the economic aspect of the investment and, at the same time, optimum due to the vehicle manufacturing and maintenance. Protection, and in particular, the degree of passive safety that a modern car must provide should play the key role, irrespectively of the adopted technology. It is the main reason that the authors focused on the passive safety structures' parts of the e-cars.

Active safety is another problem which is solved by mechatronic systems. Advanced Driver Assistance Systems (ADAS) are electronic systems that aid a vehicle driver. Designed with a human-machine interface, they are intended to increase car safety and more generally road safety by avoiding collisions. ADAS relies on inputs from multiple data sources, including automotive imaging, LiDAR, radar, image processing, computer vision, and in-car networking. The additional inputs are possible from other sources separate from the primary vehicle platform, such as other vehicles, referred to as Vehicle-to-vehicle (V2V), or Vehicle-to-Infrastructure (V2X), such as mobile telephony or WiFi data network systems. The advanced driver-assistance systems are one of the fastest-growing segments in automotive electronics with steadily increasing rates of adoption of industry-wide quality standards, in vehicular safety systems, developing technology specific standards, such as IEEE 2020 for Image Sensor quality and communications protocols such as the Vehicle Information API. Next-generation ADAS will increasingly leverage wireless network connectivity to offer improved value by using car-to-car (also known as Vehicle to Vehicle, or V2V) and car-to-infrastructure (also known as Vehicle to Infrastructure, or V2X) data.

State of art in Poland

At the present moment, there is no big native car manufacturer in Poland. With regards to the government promoted projects, it is a big opportunity to initiate the car electric drive and control production. This is a huge challenge for the Polish industry due to its current technologies and funds. For example, it is not possible to start-up the modern car platform manufacturing with the deep stamping technology without the billions € investments. On the other side, there is no opportunity to acquire the main e-cars parts made by worldwide manufacturers, due to share a big development cost.

The usage of the modern modular frames, design for the system platforms, is their alternative. The tailored tubes, with the different material characteristic, are commonly used in the modern frame e-car bodies (Fig. 1).

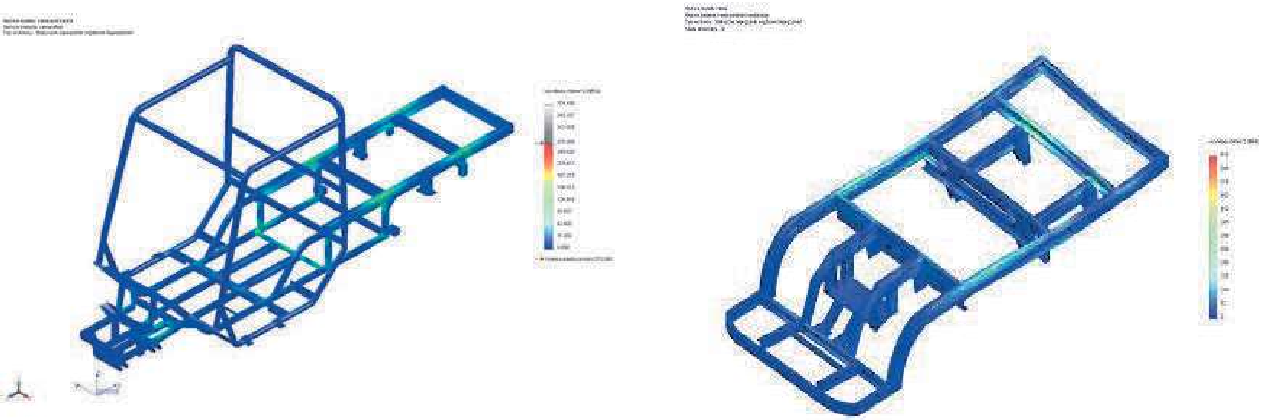

Fig.1. Body structures of the e-car manufactured in Poland

Fig. 2. Modern LEV manufactured in Poland

Fig.3. Crash accident with LEV participation (USA)

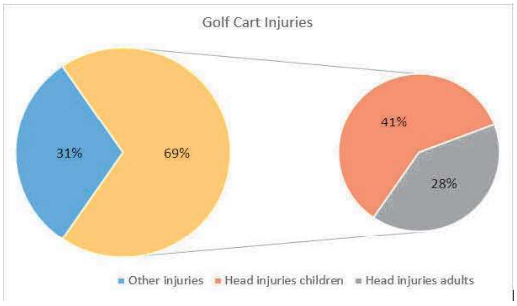

Fig. 4. The main injuries as the effects of accidents with LEV

It should be therefore assumed that it will be a Polish e-car body structure, because the manufacturing technology is well-known in the SMEs.

Nowadays, there are two companies, manufacturing varying-purpose electric vehicles in Poland.

MELEX S.A, with the headquarters situated in Mielec, has the most abundant offer. The industrial electric vehicles for utilization in the industrial areas as well as those ones for typical road traffic are produced. PW BARTESKO Koźmin Wielkopolski focuses mainly on industrial applications but also produces different vehicles intended for urban application (Fig. 2). Although their common usage is relatively rare now, the number of the applications is expected to be increased, especially in relation to the “last mile” delivery vehicles idea spreading out in Europe.

So, the question is: what is the level of passive safety offered by the current constructions and their possible directions of development.

The available information suggests that the introduction the recreational origin vehicles to the road traffic results in a significant increase of the passenger danger in the case of an accident (Fig. 3, 4).

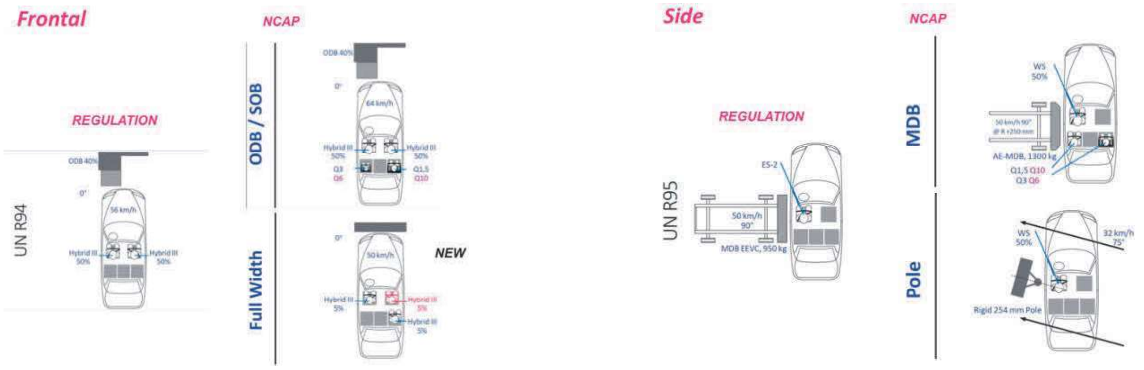

Fig. 5. ECE-R94, 95 and E-NCAP requirements at frontal and side impact of the car

Passive safety requirements

The requirements for passive protection are several dozen – all of them are classified in the relevant approval documents and regulations. These are mainly EURO NCAP requirements and UN/ECE protocol requirements and approval regulations. However, it must be pointed out that these requirements are very limited, in the case of vehicles located in category N1 and lower (Fig. 5).

Due to the continuous development of manufacturing processes, as well as changes in the technical consciousness of the recipients, the mentioned requirements are undergoing modifications. A new directive that imposes the commercial vehicles and trucks manufacturers the necessity of a new type of the energy-absorbing crumple zones that increase drivers' safety during the crash accident.

In the modern solutions, a big attention is also paid to the protection of the pedestrian as a frequent participant of the accidents.

Research work undertaken

Passenger cars passive safety has been one of the main goals for automotive corporations – with protective structures currently being mainly under the requirements of the European and US testing rules for the passenger cars. In this area, each of the automotive corporations has conducted many studies, but they relate to the modern superstructures based on the modern modular floorboards and self-supporting structures. However, there is no information available on the scope of activities relating to LEV with frame structures.

The studies of protection systems mainly in the field of military vehicles, due to meet the different, non-civilian, requirements, were carried out in Poland. The vast majority of self-supporting bodyshell structures are therefore considered and the results of the frame support structures relate to a very narrow group of military cars and elite sports cars.

IMBiGS Protective structure for the frame structure car

During the years 2013 – 2016, Institute of Mechanization of Construction and Rock Mining (IMBiGS) participated in the PLUS-MOBY international project on the development of electric car. The challenge has been undertaken to ensure the proper passive protection for the driver and passengers. As a result of the research work, a framework structure has been developed, which incorporates solutions to meet the current requirements (Fig. 6).

In the successive years, IMBiGS has undertaken its own work on the development of a protective structure for commercial electric vehicles with a GVWR of up to 3.5 tones. Protective structure computer models, including a bumper and shock absorbent assemblies, have been

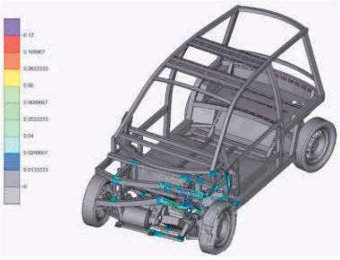

Fig. 6. Results of the PLUS-MOBY car safety zones simulations (courtesy of consortium)

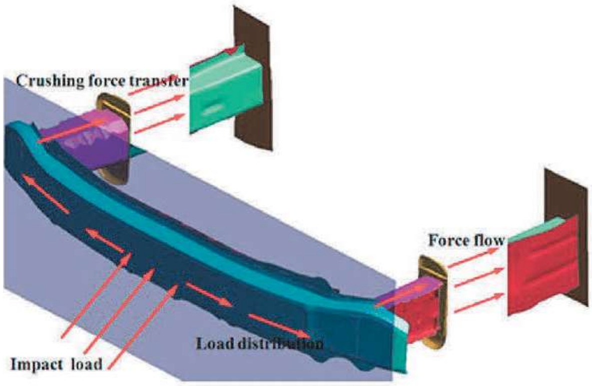

Fig. 7. Force distribution in the passive safety car's part

developed as the results of this work. It was based on the US pick-up cars, which are largely built on frame chassis and partly modeled on the solutions used in the rail industry (Fig. 7, 8).

The main project assumption was to provide multiple actions in low loads conditions following relatively long periods of time, contrary to the protective parts used in the automotive industry. This was achieved by applying of the appropriately shaped rod movable relative to the external element running with the elastomer plies.

Protective structure testing in IMBiGS

The developed bumper design with shock absorbent units was subjected to impact resistance test with defined energy value (Fig. 9). The applied test was the same test object used in the FOPS (Falling Object Protective Structure) test procedure (Fig. 10). Three main test cycles were carried out: the central point impact and side, near the absorbing energy unit, impact (Fig. 11, 12).

The conclusions of the test results show that the designed protective unit behaves as expected. The inner element moves in and the elastomers were compressed at the first phase of impact. In the second phase, the main parts work and the destruction of metal structures began. Values of the real and FEM calculated deformation are very similar (Fig. 13).

The deformation concerned both the internal and the external element of the "crashbox" (Fig. 14).

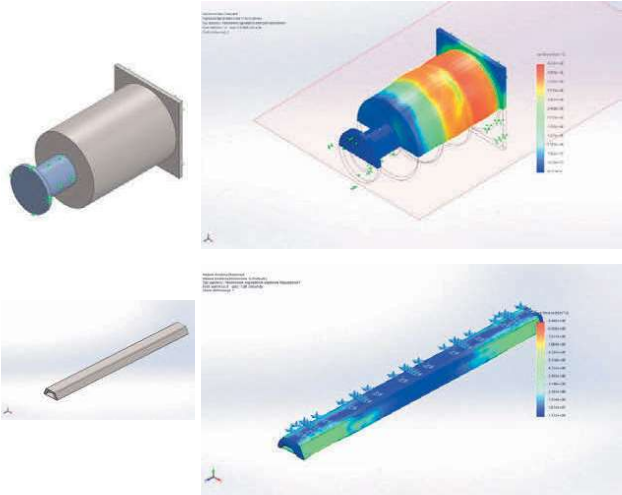

Fig. 8. Crash-box elements design in IMBiGS

Fig. 9. IMBiGS bumper with crash-box for LEV

Fig. 10. Bumper test preparation on the test bed

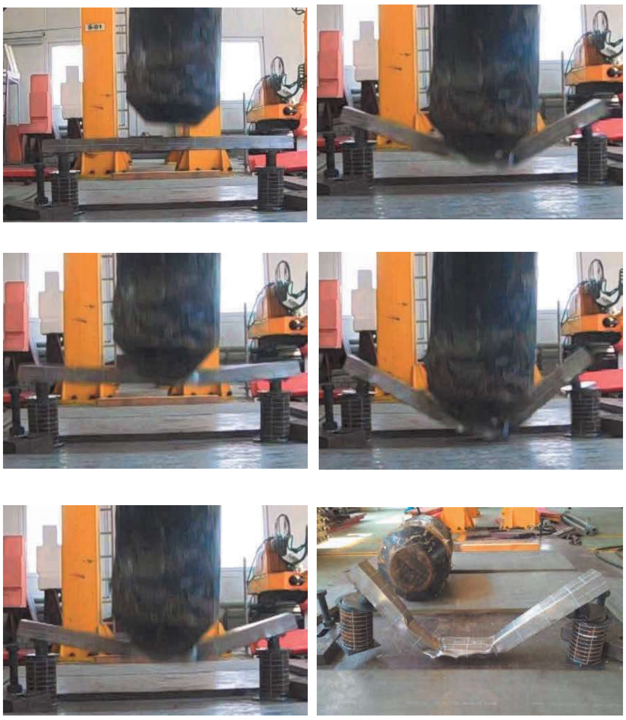

Fig. 11. Bumper with crash-boxes frame-by-frame shots – center point test.

Fig. 12. Bumper with crash-boxes frame-by-frame shots – 25% side movement test.

Fig. 13. Passive safety assembly with crash box–FEM simulation and site test results comparison

Fig. 14. Car beam with crashboxes – automotive manufacturing example

Fig. 15. Crash box elements – before and after the impact test. Modification #1

Fig. 16. Crash box elements – modification #2

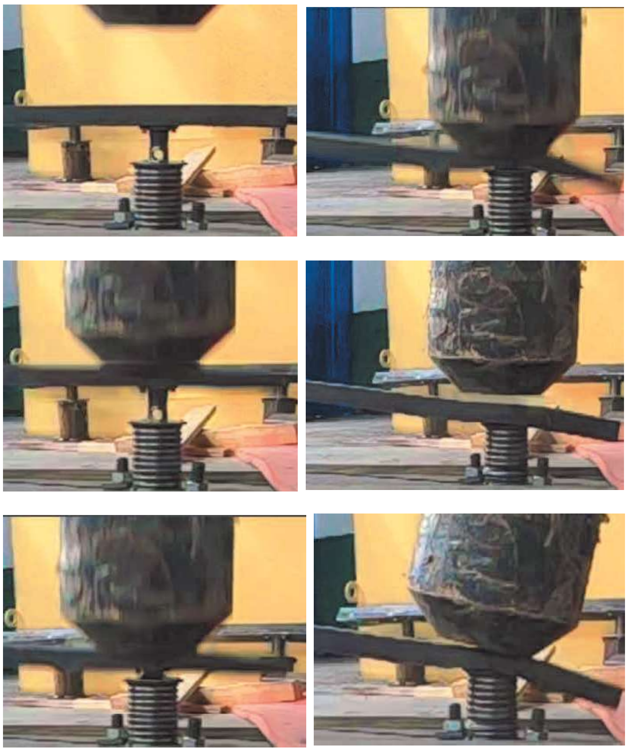

Fig. 17. Bumper with modified crash boxes – frame-by-frame impact test shots.

The design bumper bar was deformed as modeled the deflections, and the entire structure was finally behaved in a similar way of the protective structures used in the automotive industry. The analysis found, however, that the strength of the structure was too high, and the visual inspection and deformation measurements allowed determining the potential section weakening zones. The changes were already introduced at the third stage of the research model.

The modifications included the weakening of the external body's strength by milling grooves with a depth of 1.5 mm and a width of 6 mm at distances of 11 mm from each other, with the unchanged interior elements (for one component - marked "I M") and the addition with the holes in the internal element (for the second component, the marked "M II"). The real object tests have been performed after the modifications (Fig. 15, 16, 17).

Designed in IMBiGS the modification in the form of alternately arranged holes made the near axial element's deformation. The total length of the element after impact was 58 mm to the bottom surface of the backing plate, versus 126 mm before the impact (Fig. 17 – 20)).

The test carried out allowed setting up the following hypothesis concerning the mechanism of destruction:

Fig. 18. Modified crash box elements deformation after the impact test

Fig. 19. Modified crash box elements deformation after the impact test (next)

Fig. 20. Comparison of the modified crash box elements before and after the impact test

1. In the first phase of the impact, the inner element is pushed into the outer body of the crashbox components, while the elastomer shock absorbers of section I and section II are crushed. The internal subassemblies clearances are erased at the same time.
2. When the resistance of the spacers is reached, the deflection of the bumper beam begins. It leads to the inner element and guide sleeve deformation and next to the crashbox body component deformation.
3. Deformation of the inner element is significant and mainly concentrated in the upper part, adjacent to the bumper beam. The outer diameter of the piston tube increase with an initial value of ϕ = 44 mm to the end value ϕ = 46 mm on the entire length and ϕ = 60 mm at the shortening the length of the active part by 48 mm – the initial value h_1 = 115 mm to h_2 = 67 mm.
4. At the same time there was a deformation of the inner sleeve in the upper part, integrated with the damping piston. These strains are symmetrical and gradual changing on the sleeve tube diameter and its shortening. Longitudinal deformation amounted to 2 mm and a diameter change of 5 mm – from the initial ϕ = 44 mm to the end value ϕ = 49 mm.
5. In this case, the deformation of the body is irregular and includes a breakdown in its upper part, leading to a shortening of the active height from h_1 = 149 mm to h_2 = 138 mm, the change by 11 mm.

Conclusions

1. The results obtained through impact tests of the real protective structure showed a significant compliance with the expectations for correlation with the computational method (FEM). The deformation of the external and the internal components are in match with the initial assumptions adopted at the preliminary stage. It should be noted that there is a satisfactory accuracy of the location of the largest deformation locations. Studies have shown that

it is possible to obtain a controlled deformation of crashbox assemblies by using commercially available materials.

2. Functional optimization of the developed components is possible through the CAD models calculation, allowing the most favorable mechanism of destruction of the structure. The real models that optimize the construction of the crashbox components have shown that by their proper shaping, they can lead to a controlled and repetitive deformation of the components.
3. The characteristics of the deformation elements can be developed by appropriately shaping the sections of the metal elements and the selection of a structure dedicated to the total weight of the vehicle in the range to GVWR (max) of 3.5 tones.

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Mgr inż. Andrzej Barszcz
Sieć Badawcza Łukasiewicz – Instytut Mechanizacji Budownictwa i Górnictwa Skalnego; Racjonalizacji 6/8, 02-673 Warszawa, e-mail: a.barszcz@imbigs.pl

Dr inż. Mirosław Chłosta
Sieć Badawcza Łukasiewicz - Instytut Mechanizacji Budownictwa i Górnictwa Skalnego;
e-mail: m.chlosta@imbigs.pl