The assessment of pedestrian’s head injury risk at the impact with the vehicle’s windshield

B A Tolea[1], H Beles[1], A I Radu[2], F Scurt[1], G. Dragomir[1]
[1]University of Oradea, Department of Mechanical Engineering and Automotive, Oradea, 1 Universității street, Romania
[2]University Transilvania of Brasov, Department of Automotive and Transportation, Brasov, Eroilor Street, 29, Romania

Email: bogdan.tzolea@gmail.com

Abstract. The goal of this paper, is to establish a pedestrian’s head injury risk, when it impacts a vehicle’s windshield. Hence, three experimental tests were performed, on an experimental test bench. Therefore, we want to determine which area of the windscreen is the most „friendly” in case of car to pedestrian accidents.

1. Introduction

Pedestrians are considered to be the most vulnerable road users, together with cyclists. Therefore, European Experimental Vehicles Committee EEVC, later named European Enhanced Vehicle Safety Committee, established a few experimental tests, in order to enhance the overall traffic safety, respectively to protect the vulnerable road users in case of an accident.

Therefore, the working groups WG 10 and 17, established three tests in order to assess the car „friendliness” in case of an accident.

One of these tests, asses the pedestrian head injury risk in case of an impact with different areas of the car. During the test, pedestrian head is thrown against different vehicle areas, at an impact velocity of 40 km/h [1]. The EEVC avoid doing full scale tests, due to the high cost of the pedestrian dummies, and therefore they use the so called component testing.

Otte has shown in its paper that the most common injured part is the pedestrian’s head [2]. The most common contact between the pedestrian’s head and the windshield occurs in the final phases of the primary impact [3].

The state of the art passive safety devices are the active bonnet and the pedestrian’s head airbag.

Active bonnets get activated before the first contact takes place, in such a way when the pedestrian head hits the base of the windshield, the bonnet will absorb the impact energy.

Later, in 2012 the first pedestrian airbag was introduced by Volvo, composed by the following: control unit of the airbag, the lift cap of the hood, the hatch release mechanism of the hood, the hinges and the sensors [5].

2. Methodology

To determine a pedestrian’s head injury risk, depending on the impact location on the windshield, three experimental tests were conducted on the test bench.

The test bench was designed and developed at University of Oradea, in Mechanical engineering and automotive department. The bench was designed in such a way, that the pedestrian head will have an impact speed of 40 km/h, as in EEVC and Euro NCAP tests.

In the first conducted test, the area of interest was the lower 1/3 of the windshield's lower margin. For the second test, we wanted to determine the injury risk in the windshield upper frame, while for the last test, we wanted to determine the head injury risk when the head impacts the upper 1/3 of the windshield upper frame.
In figure 2 the test bench is presented.

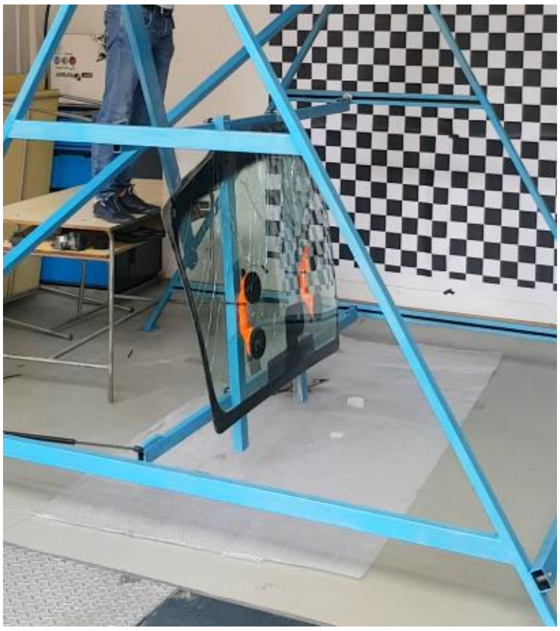

Figure 1. The designed test bench

In all three test, the head velocity at impact with the windshield was nearly 40 km/h, similar with the velocity used during component testing.
In order to extract head kinematic parameters such as acceleration, high speed recording camera were used. We used smartphones able to video record at 480 fps, in full HD. Using Tracker software we were able to determine head acceleration in each test scenario.
The pedestrian's head kinematics after the first test is presented in figure 2.
In the first test, the head impacted the lower 1/3 of the windshield.

Figure 2 Pedestrian's head kinematics in the first test
In the second test, the head impacted the upper windshield frame, and its kinematics is presented in figure 3.

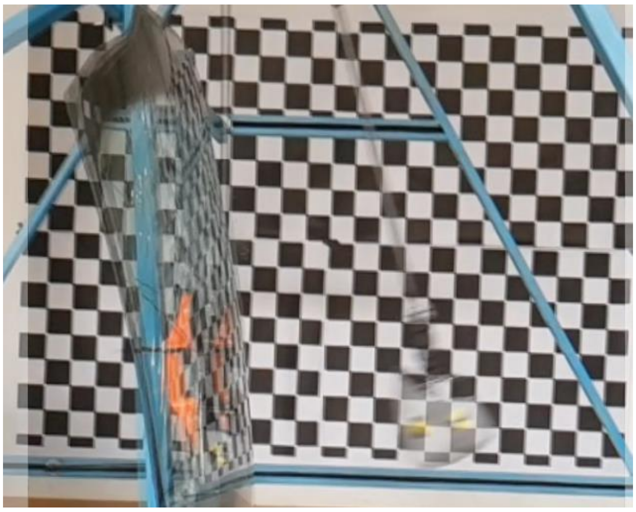

Figure 3. Pedestrian’s head kinematics in the second test

In the third test conducted, the head impacted upper 1/3 of the windshield, and its kinematics is presented in figure 4.

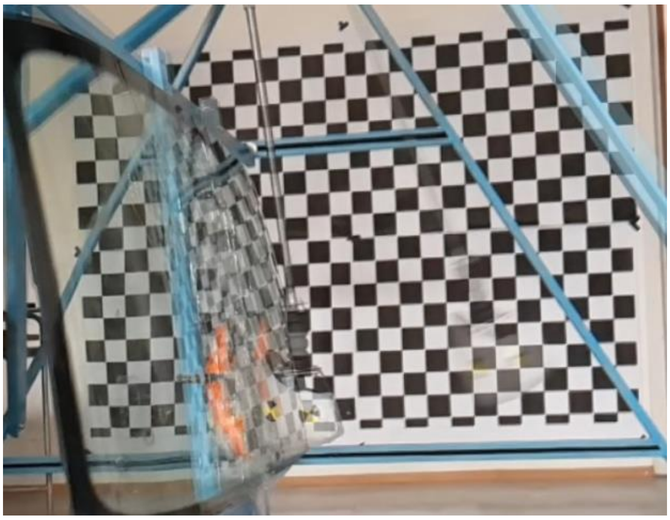

Figure 4. Pedestrian’s head kinematics in the third test

3. Results

The resultant head acceleration diagrams determined with the data extracted from the tests carried, figures below (figure 5).

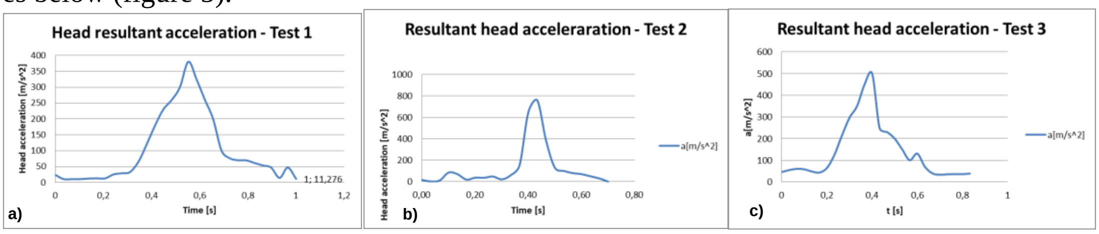

Figure 5. Resultant head acceleration for tests performed: a) the first test; b) second test; c) third test

In order to determine the potential lesions that brain may suffer, many methods were proposed to quantify both dynamic and kinematics parameters. The most common method that quantifies the head tolerance is HIC (Head Injury Criteria). This value is the integration of the resultant acceleration, on different time intervals. In case of the pedestrian accidents, HIC value on a 15 ms interval is used.

Therefore, the HIC formula is [8][9][10][11][12][13]:

$$HIC = \left\{ \left[\frac{1}{t_2 - t_1} \int_{t1}^{t2} a \cdot dt \right]^{2.5} \cdot (t_2 - t_1) \right\}_{MAX} \quad (1)$$

Where ‘a’ is the head resultant acceleration, measured in m/s2, while the t1 and t2, represent the time interval on which the HIC value is being calculated. In most cases, the area of interest where the calculation is made for HIC value, is where the peak resultant accelerations are.
By, using Mathcad software, and inputting the HIC formula together with the data obtained, we were able to determine HIC values for all three tests performed:

$$HIC_{test1} = \left\{ \left[\frac{1}{t_2 - t_1} \int_{t1}^{t2} a \cdot dt \right]^{2.5} \cdot (t_2 - t_1) \right\}_{MAX} = 200 \quad (2)$$

$$HIC_{test2} = \left\{ \left[\frac{1}{t_2 - t_1} \int_{t1}^{t2} a \cdot dt \right]^{2.5} \cdot (t_2 - t_1) \right\}_{MAX} = 620 \quad (3)$$

$$HIC_{test3} = \left\{ \left[\frac{1}{t_2 - t_1} \int_{t1}^{t2} a \cdot dt \right]^{2.5} \cdot (t_2 - t_1) \right\}_{MAX} = 480 \quad (4)$$

To summarize the obtained values, a diagram, together with the head impact locations was created, and is presented in figure 6.

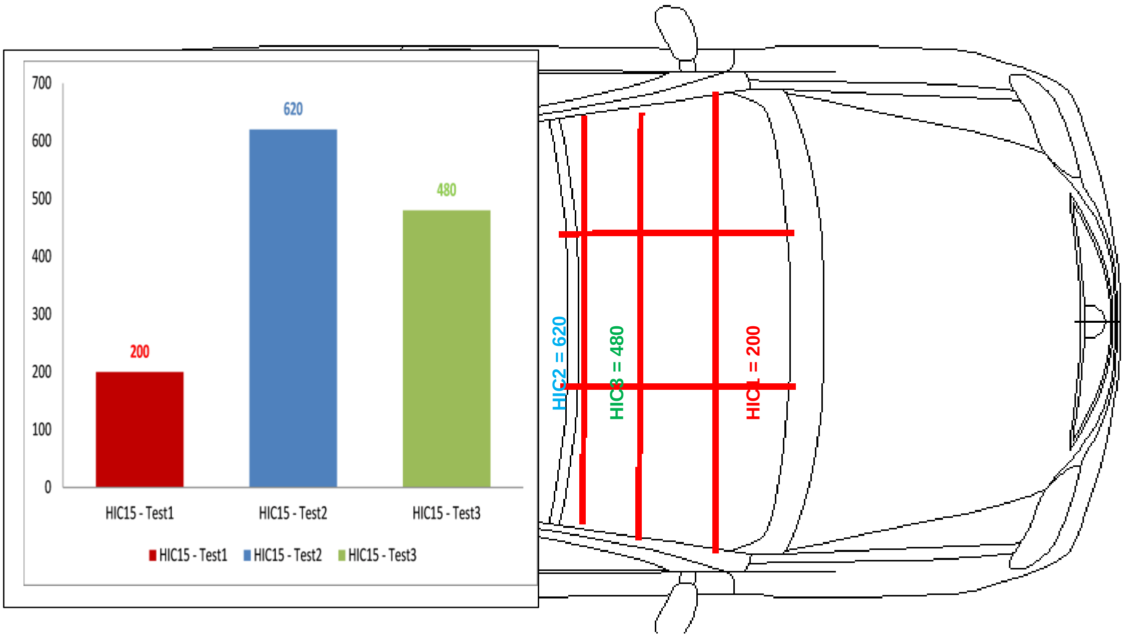

Figure 6. The calculated HIC values depending of head impact location

4. Conclusions

From the obtained values, we can conclude that the highest chance for a pedestrian to be serious injured after an impact is in case of an impact with the windshield frame (upper area), while the lowest chance is in the centre lower part of the windshield. The highest HIC value calculated was 620 for the second test scenario, while the lowest HIC value was obtained in the first test. The HIC value for the first test was 68,8% lower than in the case of the second scenario, while for the third test, was 23,4% lower than the second test.

Therefore, we can conclude that the frame of the vehicle windshield is more critical in case of an impact with the pedestrian head, while the centre of the windshield is a `friendly` area. We can also say that, the manufacturers reduced the head injury risk in the lower area of the windshield, respectively on A pillars, with the pedestrian airbag, but the head injury risk is still high on the upper area of the windshield's frame.

5. References

[1] Kuehn, Matthias, Robert Froeming, and Volker Schindler. 2005. Assessment of vehicle related pedestrian safety. In In Experimental Safety Vehicles Conference, pp. 05-0044. 2005.

[2] Otte D. Verletzungsmechanik des Kopfanpralls von Fußgängern bei Windschutzscheibenkontakt an PKW. Verkehrsunfall und Fahrzeugtechnik. 1998; 36 (11).

[3] Burg H, Moser A, editors. Handbook of Accident Reconstruction: Accident Investigation-Vehicle Dynamics-Simulation. Basics. CreateSpace Independent Publishing Platform; 2013.

[4] Xu D, Zhu X, Miao Q, Ma Z, Wu B. The research of reversible pop-up Hood for pedestrian protection. InProceedings of 2010 IEEE International Conference on Vehicular Electronics and Safety 2010 Jul 15 (pp. 42-47). IEEE.

[5] Jakobsson L, Broberg T, Karlsson H, Fredriksson A, Gråberg N, Gullander C, Lindman M. Pedestrian airbag technology–a production system. In23rd International Technical Conference on the Enhanced Safety of Vehicles (ESV) National Highway Traffic Safety Administration 2013 (No. 13-0447).

[6] European Enhanced Vehicle-safety Committee. EEVC Working Group 17 Report—Improved Test Methods to Evaluate Pedestrian Protection Afforded by Passenger Cars. TN0 Crash-Safety Research Centre: Delft, The Netherlands. 1998 Dec:6-8.

[7] Kalliske I, Friesen F. Improvements to pedestrian protection as exemplified on a standard-sized car. SAE Technical Paper; 2001 Jun 4.

[8] Radu, A.I., Trusca, D. and Toganel, G., 2018, November. Influence of tire pressure on the braking distance when driving on snow and asphalt. In IOP Conference Series: Materials Science and Engineering (Vol. 444, No. 7, p. 072013). IOP Publishing.

[9] Radu AI, Cofaru C. Study of current state of crash testing. Bulletin of the Transilvania University of Brasov. Engineering Sciences. Series I. 2015 Jul 1;8(2):31.

[10] Radu A.I., Trusca D, Toganel G. , 2018, Comparison of Passenger Vehicle Braking Distance When Traveling On Snow and Asphalt at Different Velocities, AMMA - The International Congress of Automotive and Transport Engineering, AMMA 2018

[11] Oţăt O.V., Dumitru N, Oţăt V, Dumitru I. Determination of Kinematic and Dynamic Behavior in the Driver's Skull upon the Impact with the Steering Wheel. In International Congress of Automotive and Transport Engineering 2016 Oct 26 (pp. 812-819). Springer, Cham.

[12] Oţăt O.V., Marinescu G, Oţăt V. Analyses and statistics on the frequency and the incidence of traffic accidents within Dolj County. The 11th edition of The International Congress of Automotive and Road Transport Engineering, University of Pitesti, Faculty of Mechanics and Technology, Scientific Bulletin Automotive series, year XXIV, no.28, CAR 2017

[13] Oţăt O, Nicolae D, Ilie D. Dynamic models to analyse the influence of the seat belt in a frontal collision. InIOP Conference Series: Materials Science and Engineering 2017 Oct (Vol. 252, No. 1, p. 012017). IOP Publishing.