Development and Verification of the Child Headform Numerical Impactor

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Abstract: Mechanics is a science that studies motion and is therefore a fundamental building stone for many other scientific disciplines. These other disciplines include human biomechanics and therefore the response of the human body to some mechanical stress. This article is devoted to the creation and verification of the child headform impactor, which is used in the automotive industry in the development of new vehicles. The child headform impactor is a test object representing a child's head and is used to verify the safety of a vehicle in the event of a collision with a child. The so-called Head Injury Criterion (HIC) is evaluated on the impactor and the deformation zones on the bonnet of the vehicle are then modified according to this criterion in order to avoid serious or critical head injuries. The development and verification of the numerical model of the child headform impactor was based on experimental measurements. Physical impact tests were performed with the headform impactor fired at a bent steel plate, evaluating and comparing the HIC with the results from the simulations. The certification of the impactor was based on the rules of the certification test, i.e. free fall of the impactor on a rigid steel plate and the acceleration of the impactor was measured.

Keywords: Impact test; Child headform impactor; FEM; Pedestrian protection

1 Introduction

The aim of car manufacturers is to minimise the number of traffic accidents by using active and passive safety systems. Active safety systems try to prevent crisis situations and avoid accidents. These systems include e.g. ABS (Anti-lock Braking System), ESP (Electronic Stability Programme) and many others. Despite the sophistication of active safety systems, traffic accidents cannot be completely prevented. In cases where collisions cannot be prevented, passive safety systems come into action. The aim of these systems is to minimize the risk of serious injury to a person health. In a collision with a pedestrian, the pedestrian's head hits the bonnet or windshield of the car. The head impact is the most critical in terms of pedestrian safety and it is simulated with headform impactor. The acceleration time history curve of the headform impactor after contact with the bonnet is evaluated and the HIC (Head Injury Criterion) is then calculated from this curve. The aim of this work is to develop and verify a numerical model of the child headform impactor that would match as closely as possible the results obtained from experimental tests [1,2].

2 Experimental and numerical investigation

There are studies that deal with a similar problem of creating and validating a numerical impactor of a child or adult head. Researchers are also focusing on the material properties of rubber and many other areas related to the pedestrian protection [3-5]. A headform impactor (see Fig. 1) is an assembly of multiple components designed to meet given biomechanical properties similar to those of the human head. It consists of an aluminium hemisphere and a

synthetic cover. Its outer diameter shall be 165 mm ±1 mm and its weight shall be 3.5 kg ± 0.07 kg. The cut-out in the hemisphere shall contain one tri-axial accelerometer or three uniaxial accelerometers. Their first natural frequency shall be greater than 5000 Hz. The position of the accelerometers from the centre of the hemisphere shall be defined for a direction perpendicular to the direction of measurement ±1 mm and in the direction of measurement ±10 mm. The Channel Frequency Class (CFC) response value shall be 1000 Hz and the Channel Amplitude Class (CAC) response value shall be 500 g for acceleration [6].

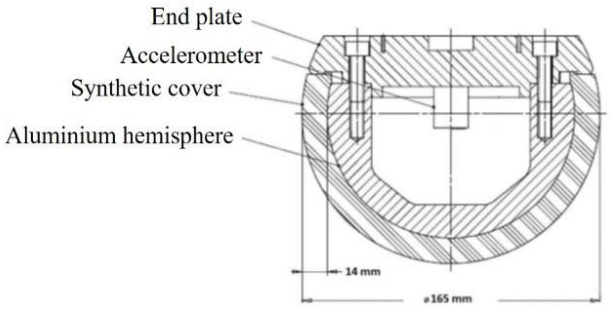

Fig. 1 Main parts of the child's headform impactor [6].

The aluminium hemisphere and the end plate were meshed with bigger quad elements. The synthetic cover was meshed with the smaller quad elements as the synthetic cover is in direct contact with the sheet metal. The new numerical model of child headform impactor is shown in Fig. 2 and the cut through the impactor where the sensors are placed can be seen in Fig. 3. Viscoelastic Ogden Rubber for Solid Elements (Ogden-Based Viscous Response) was chosen as material model for the synthetic cover.

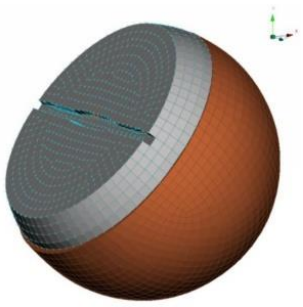

Fig. 2 Numerical model of the child headform impactor.

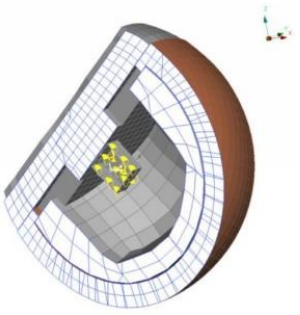

Fig. 3 A cut through the impactor model.

Table 1 and Table 2 show the values of the masses, the coordinates of the centre of gravity (CG) as well as the moments of inertia around the individual axes of the current and new computational model.

Table 1. Comparison of the masses and coordinates of the center of gravity of the current and new impactor.

	Mass [kg]	**CGx [mm]**	**CGy [mm]**	**CGz [mm]**
Current impactor	3.452	-25.299	0.00017	97.486
New impactor	3.504	-26.473	-0.41295	98.429

Table 2. Comparison of the moments of inertia of the current and new impactor.

	I_{xx} [kg.mm^2]	**I_{yy} [kg.mm^2]**	**I_{zz} [kg.mm^2]**	**I_{xy} [kg.mm^2]**	**I_{yz} [kg.mm^2]**	**I_{xz} [kg.mm^2]**
Current impactor	9360.63	8688.04	9664.03	0.00597	-0.20834	784.90
New impactor	9585.57	8869.70	9859.68	-0.01155	-3.76055	777.89

The certification test shall be carried out by free fall of the impactor (see Fig. 4). The impactor shall be allowed to fall freely from a height of 376 mm ±1 mm at an angle of 50° ±2° onto a rigid steel plate at least 50 mm thick and 300 mm x 300 mm in dimensions. This test shall be carried out three times for the impactor, each time rotating the impactor 120° about the axis of symmetry. The test shall be carried out at a temperature of 20 °C ± 2 °C, the temperature deviation being valid for a relative humidity of 40 % ± 30 %. The resulting measured values from the certification test shall be in the range 245 ÷ 300 g, which, when converted, gives acceleration values in the range 2 403 ÷ 2 943 m/s^2 [6].

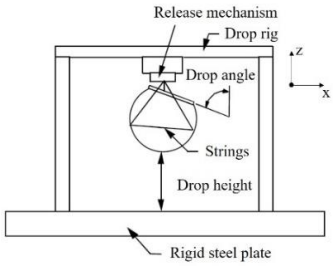

Fig. 4 Child headform impactor certification test set-up [6].

The free sheet impact test (see Fig. 5) is carried out by throwing the impactor into a sheet of 1120 x 1120 mm. The plate is 0.7 mm thick and has a free area of 1000 x 1000 mm. The sheet metal is folded by 20 mm over the free width of 1000 mm and its angle to the horizontal support is 15°, which is intended to approximately simulate the shape and position of the bonnet of a car. The sheet is loosely clamped on a rigid frame with rounded edges. The sheet is initially flat, but when mounted on the rigid frame, it is clamped under the rails on the right and left edges, which creates an elastic deformation of the sheet and achieves the desired 20 mm bending shape. The sheet metal clearance under the rails is 0.3 mm. Its position in the longitudinal direction is secured by pins. The impactor is thrown against the plate at an angle of 50° at a speed of 11.3 m/s, which represents a speed of 40.68 km/h. The contact point of the impactor with the sheet metal is in the centre of the sheet metal. During the test, the time history of the accelerations is recorded and the HIC_{15} (Head Injury Criterion) value is calculated, which indicates the severity of the head injury at impact [6].

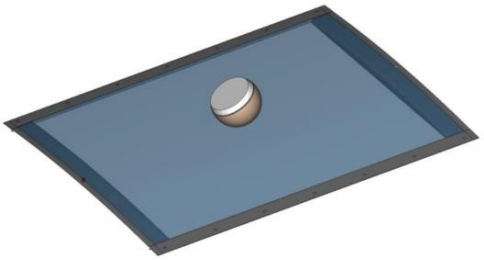

Fig. 5 Simulation of head impact test.

The HIC_{15} allows the severity of head injuries in a crash to be quantified. The relationship for calculating the HIC_{15} value, as well as the limit values, are based on experimentally obtained data

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

where

$$a = \sqrt{a_x^2 + a_y^2 + a_z^2}, \tag{2}$$

where a_x^2, a_y^2, a_z^2 represent the accelerations in each axis and a is the resulting acceleration in multiples of g (1 g = 9.81 m/s^2). The values t_1 and t_2 are the two time instants during the impact that determine the start and end interval of the recording, which is a maximum of 15 ms.

After creating a computational model of the new impactor and after defining all boundary conditions and creating a simulation, the next step was to compare the results from the simulation with the results from the real tests. Acceleration curve and HIC_{15} values from tests and simulations of the current and new impactors are shown in Fig. 6.

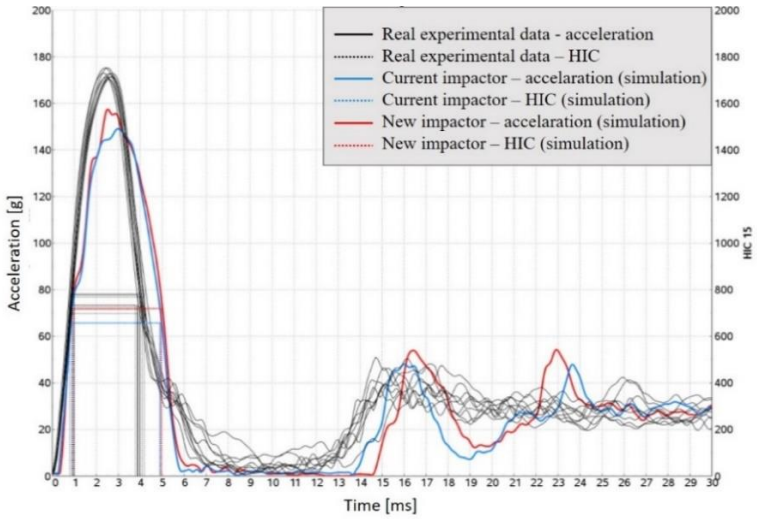

Fig. 6 Comparison of time histories from tests and simulations of the current and new model of the impactor.

3 Adjusting a new model based on test results

In the basic setup, the free sheet had a thickness of 0.7 mm, a density of 7850 kg/m^3, the clearance under the rail was 0.3 mm, the coefficient of shear friction between the steel parts was 0.1 and between the sheet and the impactor was 0.65. To adjust the new numerical model of the impactor to the results of the experimental tests, several variants were created, where different test parameters were changed such as the coefficient of friction between the steel parts (from 0.1 to 0.3), the mesh on the contact surfaces was refined, and the material models of the individual parts of the impactor were changed. The effect of each change was monitored and evaluated by simulating the impact of the impactor on the sheet metal and also compared with the experimental results. Several such resulting curves from the simulations can be seen in Fig. 7.

During the impactor adjustment process, two paths were created for subsequent impactor adjustment. In the simulations, it was shown that there is sliding of the synthetic cover between the cover and the aluminium hemisphere of the impactor as well as between the synthetic cover and the sheet metal. As a result of eliminating this error, a pre-tension between the cover and the aluminium hemisphere was defined to simulate the stretching of the cover on the hemisphere. Thus, the impactor labelled IMP_01 was an impactor without pre-tension and IMP_02 was an impactor with pre-tension.

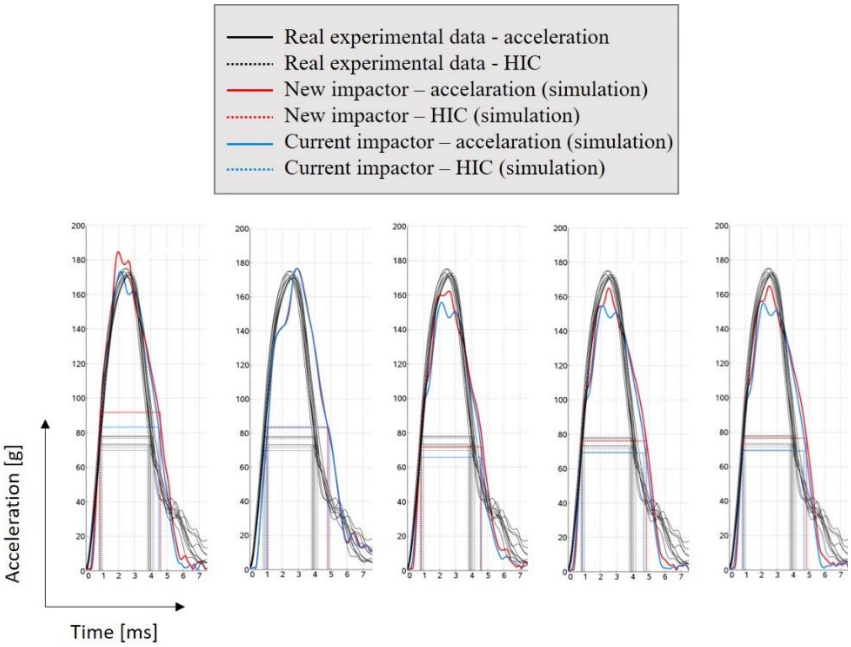

Fig. 7 Results from simulations with several changes in boundary conditions.

Conclusion

Two numerical models of the child headform impactor were created and simulations of the impact tests were performed on a slightly bent sheet plate to simulate the bonnet of a car. The results of the numerical analysis were compared with the results from experimental measurements. Fig. 8 shows the agreement in the obtained results and therefore it is possible to conclude that both impactors are describing the behaviour of the real impactor in experimental tests with high accuracy.

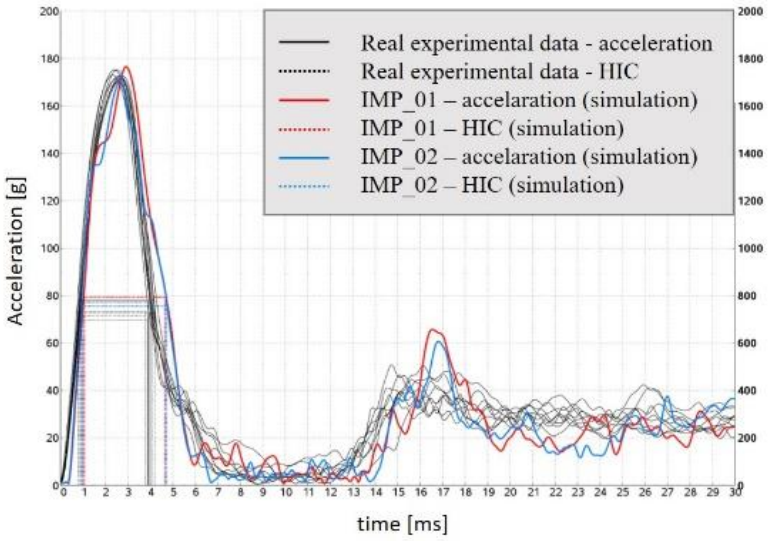

Fig. 8 Comparison of experimental and numerical results.

Fig. 9 shows the results of the acceleration of the impactors from the certification test. The impactor IMP_02 has exceeded the upper allowed acceleration limit and therefore failed the certification test. IMP_01 has passed the certification test and can be used in pedestrian protection simulations.

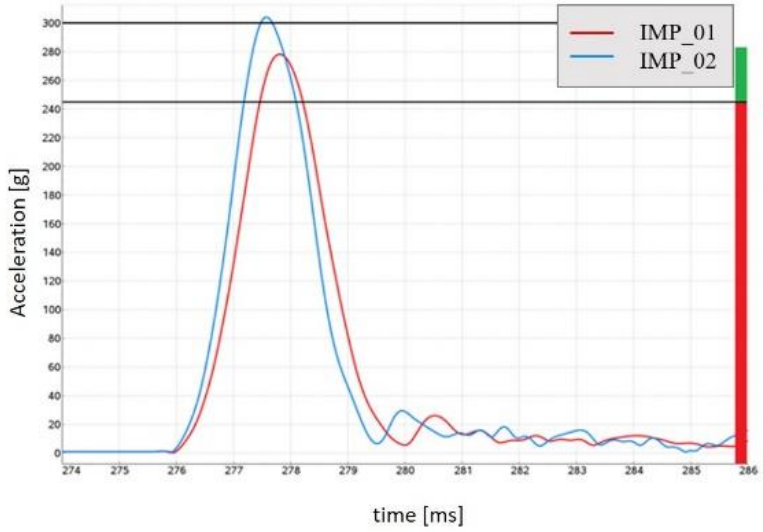

Fig. 1 Results from numerical simulation of certification test of child headform impactor.

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