Analysis of Pedestrian Head Kinematics During Impact to Car Process Using a Full Deformable Pedestrian Model

Van-Luc Ngo, Ngoc-An Tran, and Van-Hai Nguyen

Abstract Pedestrian head safety test is one of requirements in the safety inspection of new models of car. Therefore, pedestrian head protection is considered for all new model of car in process of research and development. There are two solutions to analyze the protection of car for pedestrian head in collisions that are using full pedestrian model or pedestrian headform impactor. Previous research has analyzed and shown that the two solutions give different evaluation results, but there is no analysis of the cause of the difference or indicating which method is more reliable. Pedestrian head injuries were assessed by the HIC value which is determined through the resultant acceleration of the pedestrian head center of gravity during collisions. Thus, the kinematic characteristics of the pedestrian head will affect the HIC value or the results of assessing the pedestrian safety. This study will analyze the pedestrian head kinematics during impacting process using a full deformable pedestrian model. The obtained results will be compared with the kinematic characteristics of the head impactor to find out the cause of the difference in the evaluation results. This research is very useful to develop the more reliable method of pedestrian head safety tests.

Keywords Full deformable pedestrian model · Pedestrian head kinematics · HIC value · Pedestrian head safety test method

1 Introduction

More and more new models of car appear on the market to meet all the demand of consumers. Pedestrian head safety test is one of the mandatory tests for new model of car to sold in many markets [1]. Therefore, in the process of research and

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development, all new car models are analyzed for pedestrian head safety in collisions. Whether analyzed by simulation or experience, there are two kind of pedestrian models used for impacting tests with cars that are the full pedestrian model and the headform impactor [2, 3]. Figures 1 and 2 show experimental and finite element models using to analyze pedestrian head safety, respectively. Previous research has performed experimental tests to analyzed and shown that the two solutions give different evaluation results [4], but there is no analysis of the cause of the difference or indicating which solution is more reliable.

The level of pedestrian head injury in car to pedestrian impacting tests is calculated base on the HIC (Head Injury Criterion) value, which depend on the variation characteristic of the resultant acceleration of pedestrian head center of gravity (A) in process of collision as following equation [2]:

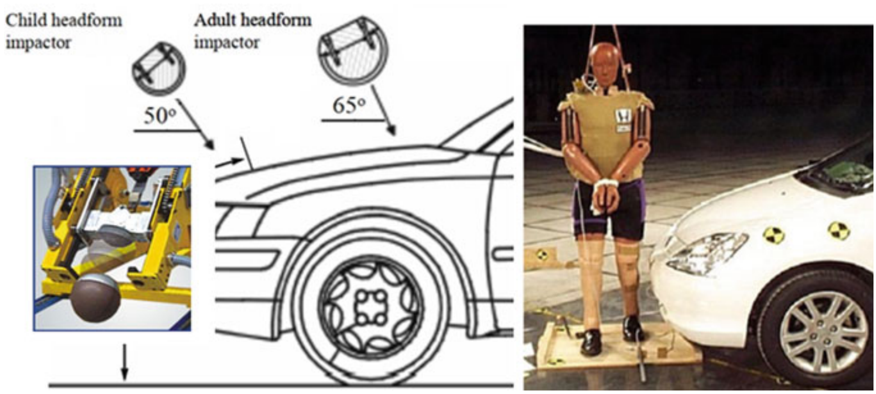

Fig. 1 Pedestrian head models for experimental tests of pedestrian safety [2, 3]

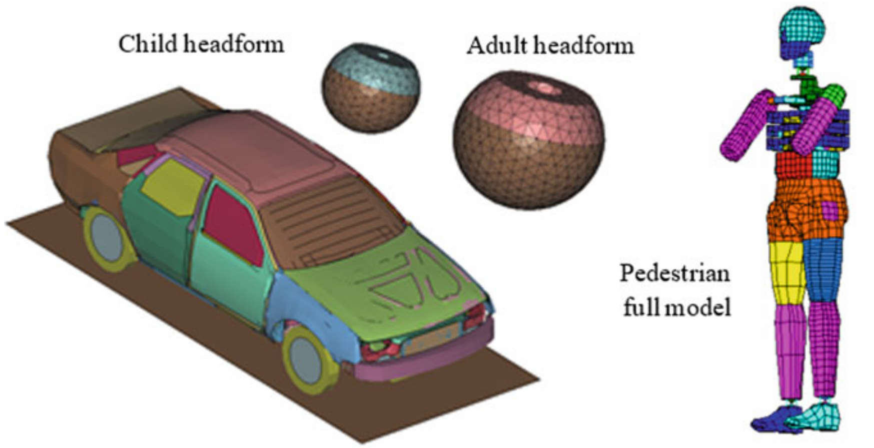

Fig. 2 Finite element models of pedestrian for simulation tests of pedestrian head safety [5, 6]

$$\mathrm{HIC} = \mathrm{Max}\left[\frac{1}{T_2 - T_1}\int_{T_1}^{T_2} \mathrm{AdT}\right]^{2.5} (\mathrm{T}_2 - T_1) \quad (1)$$

$$\text{With condition } \Delta T = T_2 - T_1 \leq 15 \text{ ms (mini - second)} \quad (2)$$

The resultant acceleration of pedestrian head center of gravity (A) can be divided into some kinematics components to analyze the variation and the influence of each component on A, including tangential acceleration (At), normal acceleration (An), resultant velocity (V), curvature of pedestrian head model center of gravity trajectory (K).

$$\mathrm{A} = \sqrt{A_t^2 + A_n^2} \text{ with } \mathrm{A_n} = \mathrm{K.V}^2 \quad (3)$$

Above equations show that the HIC value will depend on the variable characteristics of K, V and At. Previous research has analyzed the variation characteristics of pedestrian headform impactor in tests at different locations [7, 8]. That study has shown that testing at different locations the variation characteristics of V and At are not much different, but the variation of K is very complex and has a decisive significance to the A variation characteristic. In this study, the simulation of car impact to the full deformable pedestrian model (Fig. 1) will be performed to analyze the variation characteristic of K. The obtained results will be compared with the result of tests with pedestrian headform impactor to find out the cause of different in results evaluation with two kind of model. The results of this study will be of great significance in the development of an increasingly more accurate test of pedestrian safety.

2 Impacting Simulation to Analyze the Pedestrian Head Kinematics

The full deformable pedestrian model used in this study was developed from the passenger model [6]. This is a finite element model whose deformation is similar to that of real people. This full deformable pedestrian model has been validated to be qualified for use in car-pedestrian collision simulation. The purpose of this study is to analyze the kinematics so the finite model of the car is simplified to reduce the time of simulation. The car model only includes the outside part and assigning a block with a weight equal to the weight of the full car model at the center of gravity of the vehicle. The deformation characteristics of the car shape remain the same as the full car model. The full deformable pedestrian model is setup at rest and the car is impacting at 32 km/h to the leg of pedestrian model at the center of the car bumper. The curvature of pedestrian head center of gravity trajectory (K) is determined by the following formula [9] (Fig. 3):

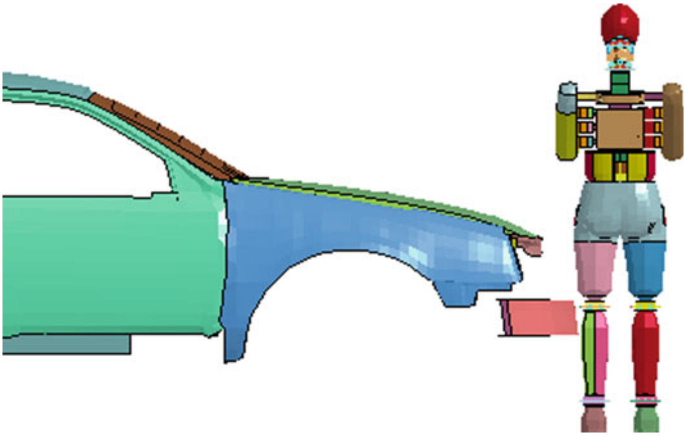

Fig. 3 Setup of car to full deformable pedestrian model impacting simulation

$$K = \frac{\sqrt{(\ddot{z}\dot{y} - \ddot{y}\dot{z})^2 + (\ddot{x}\dot{z} - \ddot{z}\dot{x})^2 + (\ddot{y}\dot{x} - \ddot{x}\dot{y})^2}}{\left(\dot{x}^2 + \dot{y}^2 + \dot{z}^2\right)^{\frac{3}{2}}} \tag{4}$$

where:

$$\dot{x} = V_x; \dot{y} = V_y; \dot{z} = V_z; \ddot{x} = A_x; \ddot{y} = A_y; \ddot{z} = A_z \tag{5}$$

These parameters are determined from the simulation results through the NODE which locates at pedestrian head center of gravity.

3 Results and Discussion

Figure 4 describes the variation of V and K in the simulation of collision between a car and full deformable pedestrian model. The process of collision between car and full deformable pedestrian model can be divided into two stages. The first stage from the moment the leg of full deformable pedestrian model touches the bumper of car until the shoulder of full deformable pedestrian model touches the bonnet surface. The second stage follows the first stage to the end of the pedestrian head to bonnet surface collision.

The results show that V increases slightly in the first stage. The V accelerate slowly in the initial time due to inertia of head part and this part can rotates flexibly relative to the body part. Meanwhile, K increases sharply at the moment of the leg touch the bumper, and then decreases rapidly to the stable value until the head touches the bonnet surface. The sharp increase of K in the initial moment is due to the head jerking and the trajectory of head center of gravity changed direction suddenly, then

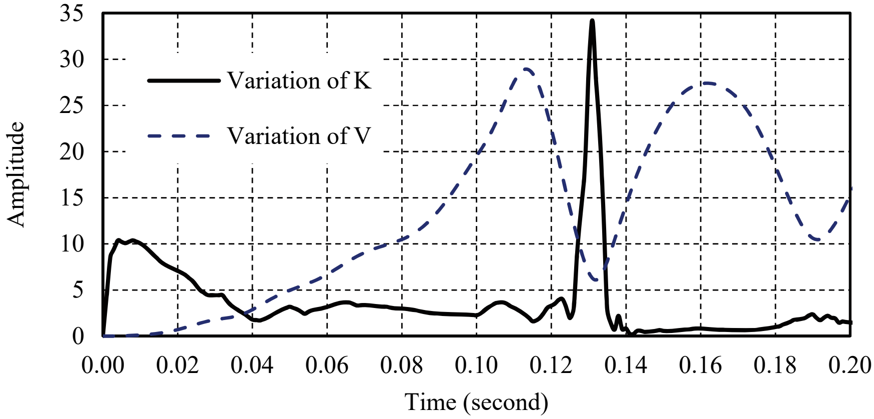

Fig. 4 The variation of K and V when test with the full deformable pedestrian model

the head model center of gravity is almost moving in a circular curve, so K keeps stable. The center of circular curve is the contact point between the leg, hip, shoulder and the car, respectively.

In the second stage, V increases very rapidly at the initial moment because of the collision between the pedestrian shoulder and bonnet surface until the pedestrian head part touches the bonnet surface. From the time of the head part of full deformable pedestrian model touches bonnet surface to the time bonnet surface reaches maximum deflection V decrease suddenly due to the resistance of the bonnet surface. Then the bonnet surface tends to be elastic and V increases significantly due to receiving part of the elastic energy. At this moment, pedestrian head bounces back cause K increases suddenly to a very large value. After that, the trajectory of pedestrian head part has little change in the direction of motion because of moving with the body thrown out, so K decreases sharply to a low stable value. Figure 5 shows more closely about the variation of K corresponding to duration of the head part of full deformable pedestrian model impact to the bonnet surface to compare with the variation of K in pedestrian head safety test using headform impactor.

Figure 5 shows the variation of K in simulation of pedestrian head safety tests with adult headform impactor [8]. The full deformable pedestrian model is an adult human model and the position of impact with the bonnet also corresponds to the impacting test area with the adult headform impactor. The K of full deformable pedestrian model forms a very clear and symmetrical peak. Meanwhile, the K of adult headform impactor forms an asymmetrical peak, after time of headform impact to bonnet surface, K remains quite large value. At many positions, K forms a very skewed peak, at the end of the collision K decreases a little and then continues to increase to a larger value. The variable characteristics of K show that the trajectory of head center of gravity direction only drastic changes at the moment of bonnet reaches maximum deflection in tests with the full deformable pedestrian model. In contrast, in tests using headform impactor, the direction of head center of gravity

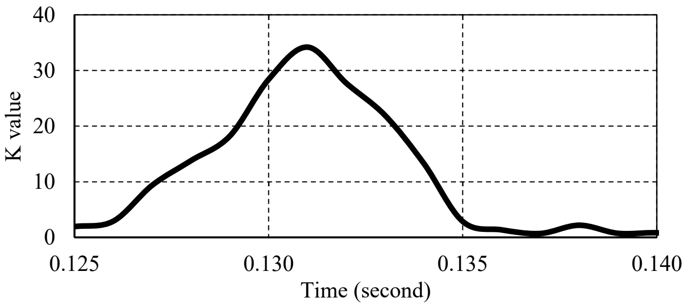

Fig. 5 The variation of K of full deformable pedestrian model in the moment of impact

trajectory change continuously from time of bonnet reaches maximum deflection to the end of impact process.

The simulation shows that in process of testing, the full deformable pedestrian model the head is connected to the body so the head bounces back and squeezes close to the body and moves together. In contrast, the headform impactor is a separate part with a spherical structure that moves freely in impact process. In tests using headform impactor, because of the friction force between the head and the bonnet surface, the headform impactor rotates hard, this rotation continues after the end of the collision, so direction of head center of gravity trajectory change continuously or K keep the high value. Moreover, at some positions due to the great resistance, the headform impactor rotates very strongly, causing the direction of head center of gravity trajectory change to be very large. Equation (3) shows the dependence of An on K and V. After the collision, although V decreases but K increases and keep in very high value, it will make An still large. Therefore, A is still large and will affect to the HIC value. This result shows that there is a difference in the variability characteristics of K, this cause the difference in the variability characteristics of A as well as HIC value or testing results (Fig. 6).

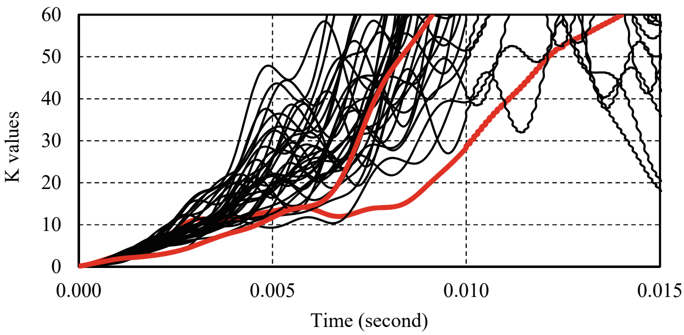

Fig. 6 The variation of K of headform impactor in the moment of impact [8]

4 Conclusions and Recommendations

This study has simulated the collision between car and a full deformable pedestrian model to analyze the variation of head kinematics as well as K which is curvature of pedestrian head model center of gravity trajectory. The results show that in the duration of collision between the head and the bonnet surface K forms a very symmetrical peak in variation diagram. This result is different from the variable characteristics of K when tested with the headform impactor. Thus, it can be seen that the results of pedestrian head safety tests with full deformable pedestrian model and headform impactor models will have different results due to the different variation characteristic of K. Further research should analysis more detailed to answer the question which model gives more accurate results in pedestrian head safety testing and solutions for improving the tests.

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References

1. Directive 2003/102/EC of the European Parliament and of the Council of 17 November 2003
2. EEVC/WG 17 Report, *Improved Test Methods to Evaluate Pedestrian Protection Afforded by Passenger Cars*, European Enhanced Vehicle-safety Committee (1998, updated 2002).
3. C. Masson, T. Serre, *Pedestrian-Vehicle accident-Analysis of 4 Full Scale Tests with PMHS* (Project French National Institute for Transport and Safety Research, 2007)
4. Y. Matsui, A. Wittek, A. Konosu, *Comparison of Pedestrian Subsystem Safety Tests Using Impactors and Full-Scale Dummy Tests*. SAE Technical Paper Series (2015)
5. T.-L. Teng, T.-H. Nguyen, Development and validation of FE models of impactor for pedestrian testing. J. Mech. Sci. Technol. **22**(9), 1660–1667 (2008)
6. T.-L. Teng, T.-K. Le, Development and validation of a pedestrian deformable finite element model. J. Mech. Sci. Technol. **23**, 2268–2276 (2009)
7. T.-L. Teng, V.-L. Ngo, Analyzing pedestrian head injury to design pedestrian-friendly hoods. Int. J. Autom. Technol. **12**(2), 213–224 (2011)
8. V.-L. Ngo, Analysis of headform impactor kinematics during the collision process, in *International Conference on Advanced Mechanical Engineering, Automation and Sustainable Development* (2021), pp. 389–395
9. Information on https://en.wikipedia.org/wiki/Curvature