Research of the head equivalent velocity in the simulation of human-vehicle collision accident

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Abstract. In this paper, the equivalent velocity of head model based on HIC value is studied. Firstly, based on the existing pedestrian model, a large number of experimental simulation and statistical analysis have been completed after modification, and the functional relationship between HIC value and vehicle pedestrian contact speed has been obtained. Then, a separate head model is established according to the contact characteristics of the original dummy model, and the functional relationship between the HIC value and the collision speed when the head hits the windscreen is obtained by simulation, and the equivalent velocity relationship between the collision speed of the head model and the human-vehicle contact speed is deduced. Finally, according to the existing finite element head model and the coupling calculation method, the simulation results under the coupling calculation condition are explored. The equivalent velocity relation proposed in this paper has guiding significance to the value of collision velocity in the head collision model and also promotes the development of research on human-vehicle collision accidents.

1. Introduction

Road traffic accidents have caused great economic losses and casualties. Car-pedestrian collision is the main form of road traffic accidents. Therefore, human-vehicle collision has become a common concern of researchers all over the world [1-2]. As an important tool of accident identification, the reappearance of human and vehicle collision accidents has attracted more and more attention in the field of automobile safety. Many scholars at home and abroad use MADYMO software to simulate and reproduce human-car collision accidents by establishing automobile models and pedestrian models [3-4]. In 1999, Happee and Wismans et al. developed a commercial version of multi-rigid-body biomechanics pedestrian dummies based on MADYMO [5]. Research institutions including Tsinghua University [6], Jilin University [7] and Hunan University [8] conducted relevant studies on improvement and application of pedestrian subsystem models.
In order to simplify the human-vehicle collision model, a separate head and windscreen collision model is used to replace the entire complex human-vehicle collision model, so the relationship between the head collision speed and the human-vehicle contact speed is required to be known. MADYMO software is applied to separately establish the head-windshield collision model, aiming at exploring the relationship between the human-vehicle contact speed of the human-vehicle collision model and the equivalent speed of the head model by means of software simulation.

2. Method

Computer simulation software MADYMO is used to set up a computer simulation system model of pedestrian collision, and the relationship between human body collision motion state and vehicle type and speed is studied by using the collision model. Two different types of vehicles (mini and sedan) are selected for model establishment and analysis.

2.1 The car model

Shanghai Volkswagen 2014 POLO is selected as the mini car model, and PASSAT 2014 1.4t manual honorable edition is selected as the sedan car model. According to the vehicle data, the model is established as shown in figure 1-2.

2.2 Rigid body head model

The rigid head model is established by referring to the characteristics of pedestrian model head, as shown in table 1 and figure 3.

|          | Mass (kg) | Radius (mm) | Hysteresis model | Sluggish rate | Damping coefficient | The moment of inertia |
|----------|-----------|--------------|------------------|---------------|---------------------|----------------------|
|          | 15        | 165          | 1                | 1.8E+7        | 4000                | 2E-2,2.22E-2,1.45E-2,0,0,0 |

With the help of PASSAT vehicle model and rigid-body head model, a collision model between the head and the windshield glass perpendicular to the windshield glass is established, as shown in figure 4.
2.3 Finite element head model

The head model in this paper is modified from the finite element adult head impact model of MADYMO. The parameters are shown below, Mass: 4.5kg; Radius: 169mm; Moment of inertia 0.010 0.0108 0.0108 0.000 0.000 0.000; the materials and properties of each component of finite element are shown in table 2.

| Part                  | Material     | Attribute                        |
|-----------------------|--------------|----------------------------------|
| Head cap, head sphere | aluminium    | Quadrilateral shell(thickness: 0.001mm) |
| Scalp                 | PVC          | Eight-node solid element         |
| Inside, outside skin  | PVC/NULL    | Quadrilateral shell(thickness: 0.001mm) |
| Acceleration sensor   | aluminium    | Quadrilateral shell(thickness: 0.001mm) |

PASSAT is selected for the car model to establish the finite element coupling model, as shown in figure 6.

3. Result and discussion

3.1 Dummy HIC value analysis

This paper firstly selects the POLO vehicle model and the modified TNO Hy2bridIII dummy model (the 50-percentile male dummy) to complete the simulation, as shown in figure 7. A total of 25 sets of simulation experiments with a speed of 6 to 30 m/s are completed, and the data obtained are shown in figure 8. The function of HIC value and contact speed is obtained by fitting with the five-spline interpolation, as shown in equation 1.
3.2 Head collision HIC analysis

The model shown in figure 4 is used for simulation. A total of 26 experiments ranging from 5 m/s to 25 m/s are completed at an interval of 1 m/s, and quadratic spline interpolation is performed. The obtained data are shown in figure 9, and the fitting function of HIC value and head collision speed for PASSAT model is obtained, as shown in equation 3.

\[ y = 107.34x^2 - 1657.1x + 6990.1 \]  
\[ R^2 = 0.9992 \]  

The model in figure 4 is changed from PASSAT to POLO, and a vertical collision model of POLO windshield glass and rigid body head is established. The simulation also completes a total of 26 experiments ranging from 5 m/s to 25 m/s at an interval of 1 m/s, and carries out two spline interpolation fitting. The obtained data are shown in figure 10, and the fitting function of the HIC value and the head collision speed when the model is POLO is obtained, as shown in equation 4.

\[ y = 112.24x^2 - 1770.2x + 7589.3 \]  
\[ R^2 = 0.9997 \]
It can be seen from the two experimental data that there is a good quadratic fitting relationship between HIC value and collision velocity.

Based on the above equations, the relationship between the collision speed of pedestrian head and windshield glass and the contact speed of human and vehicle collision can be deduced. For example, when POLO collision speed is 10m/s, equation (4) shows that HIC value is 1111.3. According to equation (1), the contact velocity is 8.96m/s.

3.3 Coupling simulation of head finite element model

A total of 10 groups of simulations from 5m/s to 14m/s are conducted using the model shown in figure 6. The simulation results are shown in table 3.

| Collision speed (m/s) | HIC value | Peak acceleration (m/s²) |
|-----------------------|-----------|--------------------------|
| 5                     | 490.658   | 996                      |
| 6                     | 630.72    | 1029                     |
| 7                     | 761.71    | 1074                     |
| 8                     | 993.44    | 1424                     |
| 9                     | 3471.8    | 4000                     |
| 10                    | 5803.32   | 6154                     |
| 11                    | 6361.7    | 7001                     |
| 12                    | 6824.08   | 6811                     |
| 13                    | 7652.69   | 6617                     |
| 14                    | 8823.2    | 7488                     |

Generally speaking, the peak acceleration and HIC values of the finite element head model are larger than those of the multi-rigid body model at the same collision velocity. When the collision speed is less than 9 m/s, the acceleration curve presents an elevation peak with no obvious peak value (less than 1500 m/s²) as shown in figure 11. When the collision speed is more than 9m/s, the acceleration curve changes significantly and an obvious peak phenomenon occurs (more than 6000 m/s²) as shown in figure 12. And then the acceleration and the HIC values increase dramatically.

![Figure 11. Head acceleration at 7 m/s](image1)

![Figure 12. Head acceleration at 11 m/s](image2)

However, when the speed is more than 14 m/s, the head will be penetrated. Therefore, it is impossible to continue the simulation. Moreover, when the speed is 10 m/s, the acceleration curve of the head is obviously different, and the peak acceleration has an obvious growth trend.

4. Conclusion

According to the collision results between the head model and the windscreen, there is an obvious quadratic relationship between the HIC value and the collision speed of the head model. And the HIC
value also has a definite functional relation with the contact speed of human and vehicle. Through the formula derived in this paper, the relationship between the collision velocity of pedestrian head and windshield and the contact velocity of human and vehicle collision can be obtained, which provides a basis for the use of simple head-windscreen collision model to replace the complex human-vehicle collision model for the analysis of human and vehicle accidents.

The penetration of the coupled model shows the shortcomings of the multi-rigid-body model. The multi-rigid-body model does not consider the damage limit of the model. According to the actual situation, when the collision speed reaches a certain threshold, the windshield glass will be damaged, resulting in a huge change in its mechanical properties. Therefore, the multi-rigid-body model is only a mechanical model under ideal conditions and is not fully usable. Therefore, the model needs to be further improved to adapt to the corresponding actual situation and use conditions.

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