Proceedings of the 11th International Forum of Automotive Traffic Safety, 2014, pp 319- 25
No. ATS.2014.313

Simulation Analysis of Impact to Occupant Head Based on Head Impact Regulation FMVSS 201U

Du Tianya[1], Chen Jiqing [2], Huang Wei, Ma Zhengwei
[1] *School of Mechanical and Automotive Engineering, South China University of Technology, Guangzhou, China ,510640,*
[2] *Guangdong Provincial Key Laboratory of Automotive Engineering, South China University of Technology, Guangzhou, China, 510640*
Email: dty_525@163.com

Abstract: The technical requirements and test method of Federal Regulation FMVSS 201U for head impact are introduced in this paper. The head finite element model developed based on 50^{th} percentile Chinese male adult is outlined. The traditional hybrid III free motion head(FMH) finite element model has been substituted by the developed 50^{th} head model, which is applied to the simulation of impact on A pillar according to FMVSS 201U; the dynamics response and injury of head are shed light on based on different impact velocities.
Keywords: FMVSS 201U; Head FEM; Impact; Dynamic response

1 Introduction

On account of great complexity of road construction and car parc increasing in China, road traffic safty need more attention. Over 100000 persons died in traffic accidents every year. The number of injured people even reached 1000000[1]. The head injury always leads to the disability and death, along with tremendous financial loss and psychological trauma in society. In order to improve the vehicle crashworthiness, many European developed countries and America legislated the corresponding rules and brought them into force successively. These regulations promotes the automobile manufacturers for safety effectively. The Federal Motor Vehicle Safety Standard(FMVSS) established and implemented by the National Highway Traffic Safety Administration(NHTSA) is one of the most significant regulations, which is mainly referred to due to the shorter period of studying passive safety in other countries. In 1998, the United States government enforced the FMVSS 201U regulation to decrease injury caused by automobile to occupant head. The free motion headform[2] (FMH) model applied to FMVSS 201U is part of Hybrid III dummy[3] at present. However, the FMH size accorded with American 50^{th} male adult, equivalent to Chinese 95^{th} male adult. It's quite different from Chinese 50^{th} male adult. Hence formulation of the automobile safety regulation based on Chinese human figure demands prompt solution.

The technical requirements and test methods of FMVSS 201U- Occupant Protection in Interior Impact are introduced in the paper, followed by the brief description of Chinese 50^{th} male adult head finite element model developed by South China University of Technology. The model used in simulation is the second script, which has been modified and verified to make sure that it has high biofidelity to be used for simulation analysis of head injury and biomechanical response.

The traditional hybrid III free motion head(FMH) finite element model has been substituted by the modified 50th head model developed by SCUT(South China University of Technology), which is applied to the simulation of different velocities' impact on A pillar according to FMVSS 201U.

2 FMVSS 201U Gordian Technical Requirement Introduction

The vehicle crashworthiness could be classified as primary collision and secondary collision. The security of vehicle external structure is mainly investigated in primary collision while the protection to occupants of restraint system and interior trim parts in secondary collision [4]. The location of impact targets inside vehicle has been defined precisely. The targets distribute in two areas: the upper interior components such as seat belt anchorages, door frame, brace, pillar, sunroof, and the lower interior components. The seat backs, instrument panels, armrests and sun visors are included, as shown in figure 1. The left A-pillar was chosen as impact target part in the simulation.

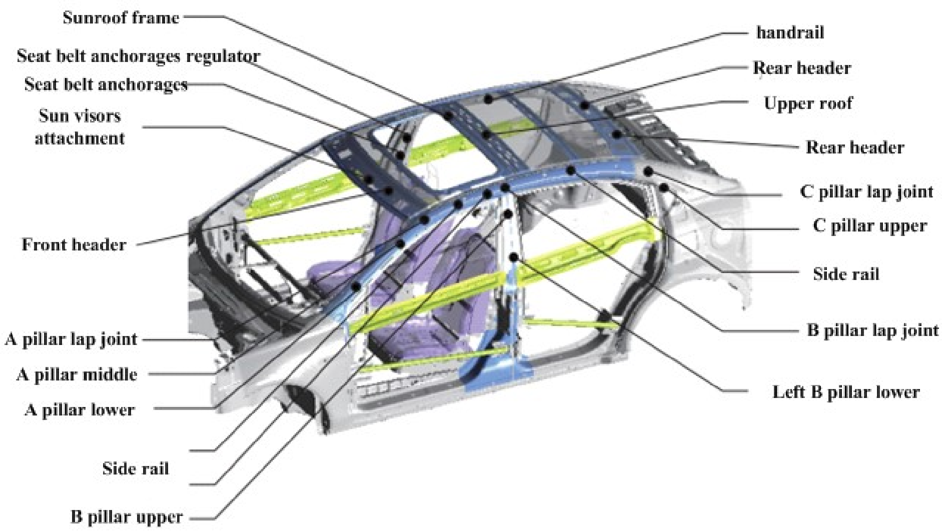


Figure 1. Impact points in vehicle upper part

2.1 AP2 Targets

In accordance with FMVSS 201U, define a vertical transverse plane (Plane 1) at the rearmost point of the windshield trim. The intersection of Plane 1 and the vehicle exterior surface is Line 1. With the vehicle side door open, set a vertical plane tangent to the outboardmost point on Line 1.there is a point (Point 1) on line 1,which is at the location of 125mm inboard of the intersection of Line 1 and the vertical plane. Locate Point 2 along the vehicle exterior surface in a longitudinal vertical plane (Plane2) passing through Point 1, 50mm rearward of Point 1. Locating a line perpendicular to the vehicle exterior surface at Point2. Set the intersection of the line and the interior roof surface as A pillar reference point. Locate the horizontal plane (Plane 3) which intersects point APR. Define the horizontal plane (Plane 4) which is 88 mm below Plane 3. Target AP2 is the point in Plane 4 and on the A-pillar which is closest to CG–F2 for the nearest seating position. CG–F2 is located at the place where the seat is in its rearmost normal design driving or riding position.

As shown in Figure [5] 2.

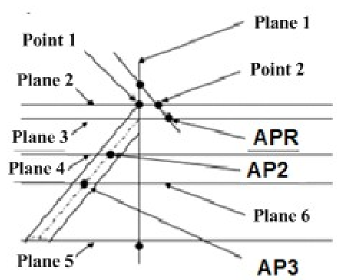


Figure 2. A pillar impact targets

2.2 Configure in Impact Tests

2.2.1 Approach Angle

The FMH attitude is described with approach angle, which is devided into horizontal angle and vertical angle. The horizontal angle of targets is the angle formed by the launched velocity vector of the FMH and the X-axial of vehicle, projecting on the horizontal surface. The vertical angle of target is the angle formed by the launched velocity vector on the midsagittal plane of FMH and horizontal surface.

The headform launching angle is within the range specified in Table 1

Table 1.A pillar approach angle limits

Interior compartment	Horizontal （°）	Vertical （°）
Left A pillar	195~255	-5~50

2.2.2 Impact Velocity

The average velocity of head impact in accidents is 24km/h, therefore NHTSA decided the velocity of head impact test as 19.2km/h or 24km/h, depending on if there is side airbag equipped or not.

When equipped with a dynamically deployed upper interior head protection system, any speed up to and including 19 km/h is required.

Any speed up to and including 24 km/ h is required for vehicles that don't meet the occupant crash protection requirements by means of inflatable restraint systems.

2.2.3 Forehead Impact Zone

The forehead impact zone of the headform is determined according to the procedure. The impacted targets must be in the zone.

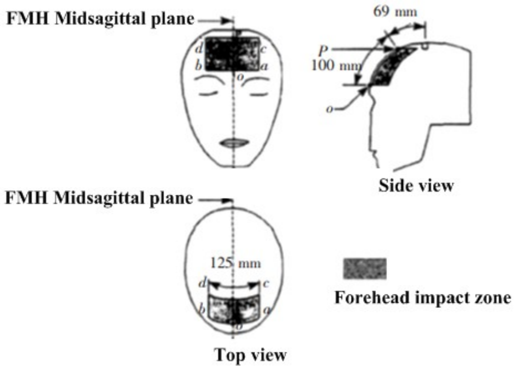


Figure 3. Forehead impact zone

2.3 Performance Criterion

The HIC(d) shall not exceed 1000 when calculated in accordance with the following formula:

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

Where the term a is the resultant head acceleration expressed as a multiple of g (the acceleration of gravity), and t_1 and t_2 are any two points in time during the impact which are separated by not more than a 36 millisecond time interval.

For the free motion headform:

$$HIC(\mathrm{d}) = 0.75446 * HIC + 166.4$$

3 Chinese 50th Male Adult Head Finite Element Model

The Chinese 50th male adult head finite element model has been modified based on the old script developed by Cai Zhihua[6,7] from South China University of Technology. The altered parts include brain tissue, skull, skin, etc. The material characteristics of model have also been revised. Moreover, for the sake of improving the computational accuracy, the mesh quality was enhanced in later modification. The modified model is shown in figure 4. The model mass is 4.52kg, measuring up the regulation.

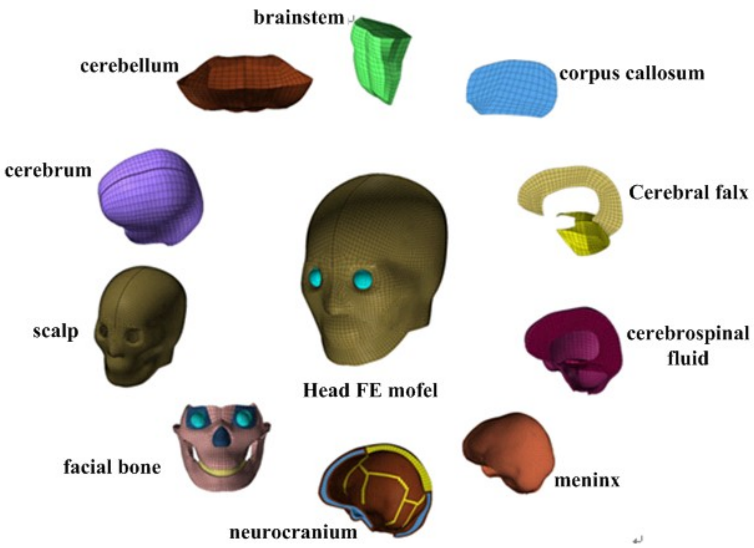


Figure 4. Modified head finite element model

The modified head model has been verified by an experiment executed by Nahum[8] for closed head impact injury, revealed that it has high biofidelity to be used for simulation analysis of head injury and biomechanical response.

Table 2.Model parameters

Part	Material type	density（g/cm[3]）	elasticity modulus (Mpa)	Poisson's ratio	G_0（Kpa）	G_∞（Kpa）	β（s-[1]）
Scalp	elasticity	1.20	16.7	0.42			
cerebral dura mater	elasticity	1.14	31.5	0.45			
pia mater	elasticity	1.14	11.5	0.45			
cerebrospinal fluid	viscoelasticity	1.04	2 190		1	0.9	80
cerebrum	viscoelasticity	1.14	2 190		10	2	80
cerebellum	viscoelasticity	1.14	2 190		12.5	2.5	80
brainstem	viscoelasticity	1.14	2 190		22.5	4.5	80
cerebral falx	elasticity	1.14	31.5	0.45			
tentorium	elasticity	1.14	31.5	0.45			
tissue	Material type	density（g/cm[3]）	elasticity modulus (Mpa)	Poisson's ratio	yield stress(Mpa)	failure strain	
Cortical bone	elastic-plastic	2	15000	0.25	32	1.5%	
cancellous bone	elastic-plastic	1.3	4600	0.3	28	1%	

4 Head Impact Simulation Based on FMVSS 201U

4.1 Procedure conditions

According to FMVSS 201U regulation, the simulation analysis of A pillar-head impact was simulated with three different velocities (18km/h, 24km/h, 30km/h), keeping the approach angle constant, to analyze the effect of impact velocity on head injury and dynamic response. The model was set as free boundary condition because of the short computation time. AP2 was chosen as impact target. The simulation period was 15 seconds.

Table 3. simulation parameters

target	impact velocity	horizontal	vertical
AP2	18km/h	20°	230°
AP2	24km/h	20°	230°
AP2	30km/h	20°	230°

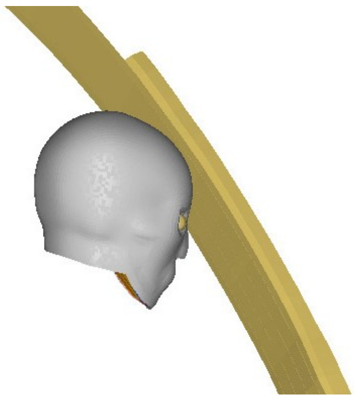


Figure 5. A-piilar impact simulation

4.2 Result Analysis

The simulation was processed in LS-DYNA, obtaining the impact force-time curve, the acceleration-time curve and the stress contour.

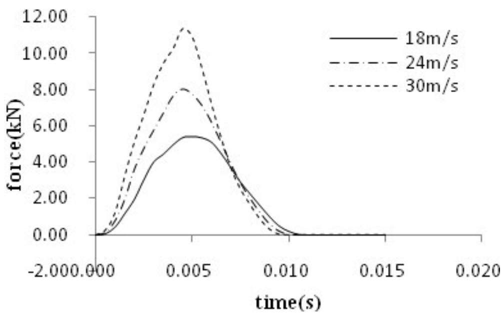


Figure 6. Force-time curve

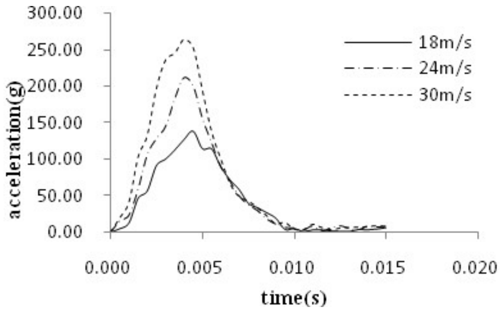
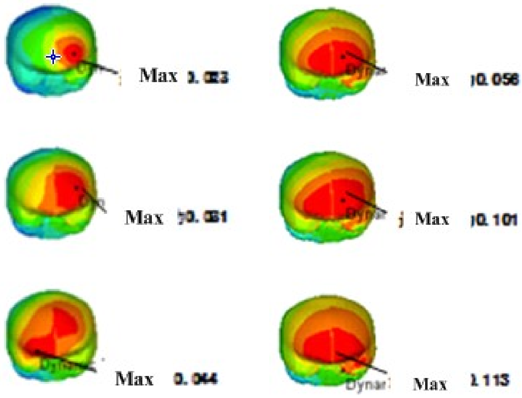
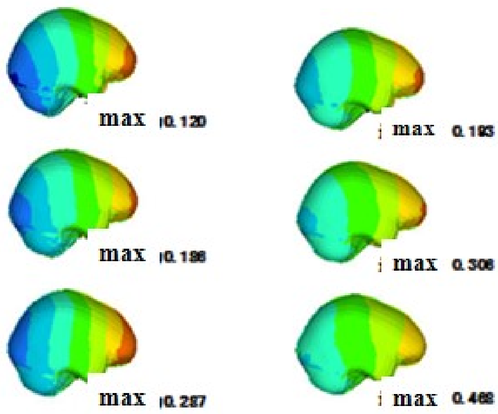


Figure 7. Acceleration-time curve

It reveals that different velocities don't affect the impact duration, maintaining 10 ms. The peak value of impact force is reached at 5ms while acceleration peak value reached earlier. However, both the curves run the same trend. Value increased as time passed, decreasing after reaching the peak. With the impact velocity raising, the force and acceleration increases faster and the peak values get greater.



(a) 1ms **(b) 2ms**



(c) 3ms **(d) 4ms**

Figure 8. Brain tissue stress contour

The brain tissue stress contours at 1ms, 2ms, 3ms, and 4ms are shown in figure above. The stress distribution pattern at different moment is in accordance. Stress concentrated in impact area at beginning. The stress contour shed light on typical impact/contrecoup distribution pattern. In fore impact zone, stress produced by compression is positive. In contralateral occipital bone zone, stress produced by tension is negative. Brain tissue suffered higher stress in the wake of higher impact velocities, following the increasing peak stress in impact zone as well as the contralateral zone.

Table 4. Brain tissue impact results

Velocity(km/h)	HIC	HIC_d	Forehead peak stress （MPa）	Back nest peak stress （MPa）
18	518.628	557.684	0.193	-0.110
24	1212.99	1081.55	0.306	-0.158
30	2451.52	2015.97	0.468	-0.211

The result of head-Apillar impact simulation reveals that HIDd value was becoming greater while impact velocity rose. The HIDd was 518.628 at velocity of 18km/h, which indicated the head injury was slight and in the reasonable range. When velocity was set as 24km/h, HIDd climbed over 1000, even reaching 2015.97 when 30km/h. it signified the brain tissue would get seriously injured and the probability of getting AIS3+ damage will greatly increase.

5 Conclusions

Under the frame work of FMVSS 201U regulation, the simulation analysis of A pillar-head impact was studied with different velocities, the traditional FMH model substituted by modified 50th Chinese male adult head finite element model. AP2 was chosen as impact point. The result indicates that the head injury risk becomes higher as impact velocities increasing, which can be basis data of automobile safety regulation formulation.

References

[1] Carsten O and Day J. Injury priority analysis task a.USA: Department of Transportation National Highway Traffic Safety Administration (NHTSA) 1988 2-30.

[2] Finite Element Model of FMH[G]. First Technology Safety Systems (FTSS), 1998.

[3] National Highway Traffic Safety Administration,Dept. of Transportation Standard No.201: Occupant Protection in Interior Impact, 49 CFR, Ch. V, Parts 571. 201[s]. Federal Motor Vehicle Safety Standards, October 1998.

[4] Wang Yajun, Chen Chaozhuo, Wu Shenrong. Application of FMVSS201 in vehicle collision interior impact to occupant head Injury [J].J Automotive Safety and Energy, 2010, 1(2):127-131.

[5] Xu Baining, Yao Chunge. Simulation on Head Impact of Interior Trim Based on Generator[J].Auto Engineer, 2013(9):30-32.

[6] Cai Zhihua, Lan Fengchong, Chen Jiqing, Shi Lei. Construction and Validation of the Assessment Model for Human Head Injury in Vehicle Traffic Accident[J].Automotive Engineering, 2012, 34(9):782-786.

[7] Shi Lei. Study on Human Head Biomechanical Response and Simulation in Vehicle Collisions[D]. Guangzhou: South China University of Technology, 2011.

[8] Nahum A,Simth M D.An experimental model for closed head impact injury. In:Proc of 20th Stapp Car Crash Conference. Dearborn: Society of Automotive Engineers,1976,785-814