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Occupant Injury Analysis in Traffic Accident Based on the Coupling of PC-Crash and MADYMO

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Abstract: The study chose a typical car-to-car accident in CIDAS database and made its reconstruction simulation by using PC-Crash and MADYMO. Firstly, the initial impact velocity, yaw velocity and other information which were defined as initial boundary conditions of MADYMO were obtained by using PC-Crash program. Then the vehicle model, restraints system model (seat belts and airbag) and occupant model were modeled by MADYMO. According to output of physical injury parameters from MADYMO reconstruction, evaluation of driver injury risks was conducted based on human injury tolerances according to Euro-NCAP. The methods advanced provide a way of evaluating and analyzing the protective effect of vehicle to occupants in real accident, simultaneously, occupant injuries in accident can be studied by using the way presented in this thesis.
Keywords: Traffic Accident, Accident Reconstruction, Injury Analysis

1 Introduction

The injury caused by vehicle traffic accidents has been a common challenge globally. The statistics of World Health Organization (WHO) show that nearly 1.2 million people were killed in traffic accidents every year. As the rate of car ownership continues to increase in China and the road traffic and the speed of automobile are gradually improved, the total amount of motor traffic accidents as well as the consequent casualties and property damage have been particularly severe in recent years. The traffic accidents in developing countries like China account for 90% of the total traffic accidents in the world each year[1]. Experts speculate that if no effective measures are taken in time, the total casualties caused by traffic accidents will increase by about 65% worldwide as of 2020.

In terms of accident patterns, the car-to-car accident can be divided into different types including front impact accident, side impact accident and rear-end accident. National Highway Traffic Safety Administration (NHTSA) investigated the car accident types in major developed countries and regions such as United States, European countries and Japan, and the statistics indicated that the car accident pattern that caused the most casualties among the frequent car-to-car accidents was car-to-car front impact accident.

2 Methods and data

2.1 Accident description

The accident case studied in this thesis was selected from CIDAS database.

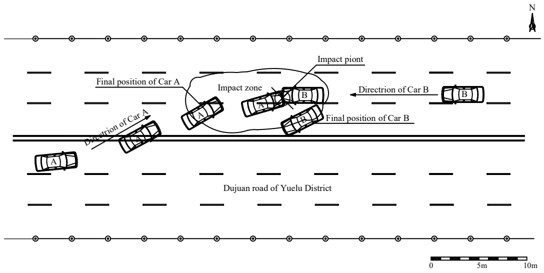

Figure 1 Sketch of car-to car accident

Figure1 shows the sketch of the car-to-car accident. When the accident occurred, Car A was travelling across the double yellow lines against the direction of traffic from west to east, while Car B was running on the right lane in accordance with the traffic rule. Car A had no chance of avoiding Car B, and the two cars smashed straight into the right front of each other. In the accident, the front parts of the two cars were damaged and the head of the driver in Car A was injured.

2.2 Accident reconstruction

The vehicle model database of PC-Crash was used to create the simulation model of car-to-car accident. On this basis, the parameters of the two cars like geometry and quality were set in combination with the practical situation of the accident. Based on the optimized reconstruction simulation, the travel speed of Car A and Car B at the moment when they collided were 46km/h and 67km/h, respectively.

In the accident, the Car A involving occupant injury was selected as the target car model. The translational acceleration in x-axis and y-axis at the center of mass and the time history of the rotation angle around the z-axis (i.e. the yaw θ) were extracted from the PC-Crash results. Since the momentum/impulse method was used in the PC-Crash reconstruction to assume that the exchange of impact occurred within an infinitesimal time step and the impact only acted on the collision center, the impact impulse of the two cars cannot be output directly. Based on the theory of average acceleration proposed by H Steffan et al[2]. and the method "using equivalent acceleration impulse to replace collision impact" proposed by Shen Jie et al[3]. were applied for parameter passing between PC-Crash and MADYMO. Based on the relationship between "impact velocity and impact duration" summarized by Liu Xueshu, et al[6]. appropriate exchange time of impact was selected according to engineering experience as shown in Table 1.

Table 1 Impact velocity and impact duration

Impact velocity (km/h)	60	70	80	120
Consumed time (ms)	80	70	50	40

The moment when the two cars reached the maximum deformation (0.120s) was selected as the moment of impact exchange. The time interval from initial collision to maximum deformation was set at 45ms. Since the PC-Crash collision center (i.e. the midpoint of contact plane when the two cars reached the maximum deformation) was defined as the position where the cars approximately reached the half impact impulse, 0.120s was regarded as the symmetric center of rectangular wave of equivalent acceleration impulse. The time window of the rectangular wave was 90ms (the interval from 0.075s to 0.165s). The time for momentum transfer was used to equalize the impact effect of the two cars.

The time interval of momentum transfer t was set as 90ms according to engineering experience. The components of momentum transfer on the x-axis and y-axis of the inertial coordinate system were calculated. The value of rectangular wave of equivalent impulse was then obtained based on the formula of impulse equation (1).

$$a_x = \frac{I_x}{mt}, \quad a_y = \frac{I_y}{mt} \quad (1)$$

Figure 2 shows the translational acceleration of center of mass of the target car A relative to the inertial coordinate system in the case that the impact effect was considered. In the figure, the value of the curve before 0.075s was the acceleration before collision. After 0.075s, the rectangular wave of impulse was added, and the time window of rectangular wave was 90ms. After 0.165s, the rectangular impact wave ended.

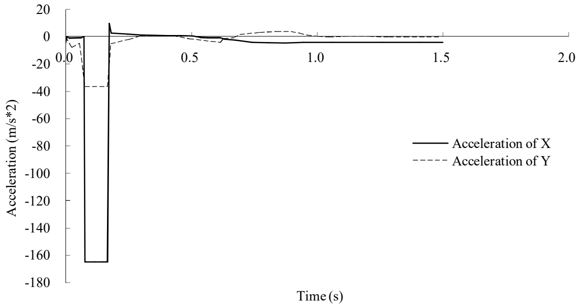

Figure 2 Acceleration curve at the center of mass of Car A

In the multibody dynamics simulation of MADYMO, ball joints are usually used to describe the yawing motion of the research object, and the Euler quaternion including q0, q1, q2 and q3 is used to represent the change of relative angles of ball joints. Based on Euler's laws, an attitude of rigid body can be realized through rotating by a limited angle θ once around a specific axis in the space (unit vector u). The rotation angle around the z-axis was defined as the car's yaw θ. Figure 3 shows the time history curve of the rotation angle of the target car's center of mass around the z-axis.

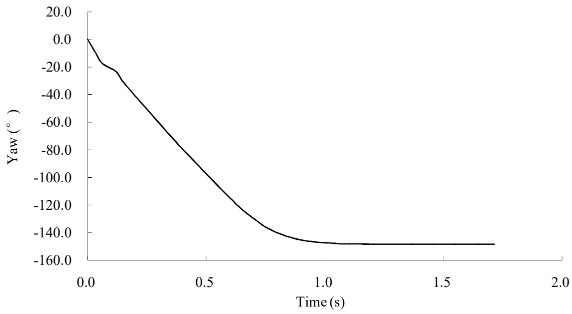

Figure 3 Time history of yaw of Car A's center of mass

Since the yaw's rotation axis of the research object was parallel to the z-axis of the fixed coordinate system in the space, the unit vector u could be represented as $u(0,0,1)$. Figure 4 shows the time history curve of yaw represented by Euler quaternion. Therefore, the initial boundary conditions including the acceleration of the car's center of mass and the time history of yaw which were input in the multibody dynamics simulation of MADYMO were obtained.

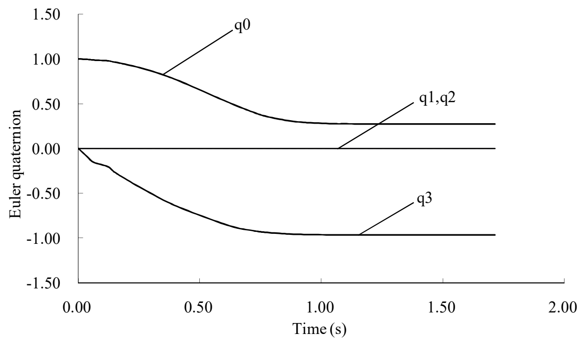

Figure 4 Time history of yaw represented by Euler quaternion

2.3 Modeling of restraint system

The devices that protect occupants in car crash are called occupant restraint system. In this thesis, based on the accident reconstruction in PC-crash, the driver-side MADYMO restraint system was modeled.

Since the equivalent impulse was added between 0.075s and 0.165s and the driver injury mainly occurred during this period, the driver's response during the 120ms time interval from 0.060s to 0.180s was selected for analysis.

The preliminary simulation of dummy positioning and safety belt should be conducted before collision simulation, because there was initial contact force between seat and dummy as well as between safety belt and dummy in the restraint system model. Figure 5 shows the initial positioning state of the driver dummy on seat after the preliminary simulation was completed.

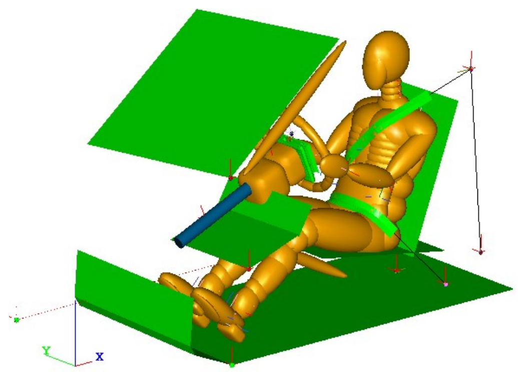

Figure 5 Initial positioning state of driver dummy after the preliminary simulation

The acceleration curve of Car A's center of mass and the yaw velocity response obtained in PC-Crash simulation reconstruction were adopted as the initial boundary conditions for driver injury reconstruction in MADYMO. In addition, a gravity field along the negative direction of the z-axis should be exerted on the restriction system.

3 Results and discussions

3.1 Discussions for risk of injury

The research on risk of injury is to simulate the overall dynamic response of human body during collision and evaluate the calculated physical damage of all parts of human body according to the corresponding injury criteria.

The Euro-NCAP damage indicator and the Abbreviated Injury Scale (AIS) were used to assess the driver's risk of injury. The evaluation criteria for injuries of head, chest, lower limbs and neck are the main evaluation criteria in front impact.

Figure 6 shows the driver's dynamic response during collision. Based on the acceleration of Car A in PC-Crash accident reconstruction, the collision process of the two cars basically ended at 150ms. Therefore, in the reconstruction analysis of the driver's risk of injury, 0~150ms was selected as the time history of the driver's dynamic response in consideration of the car body's acceleration and yaw velocity.

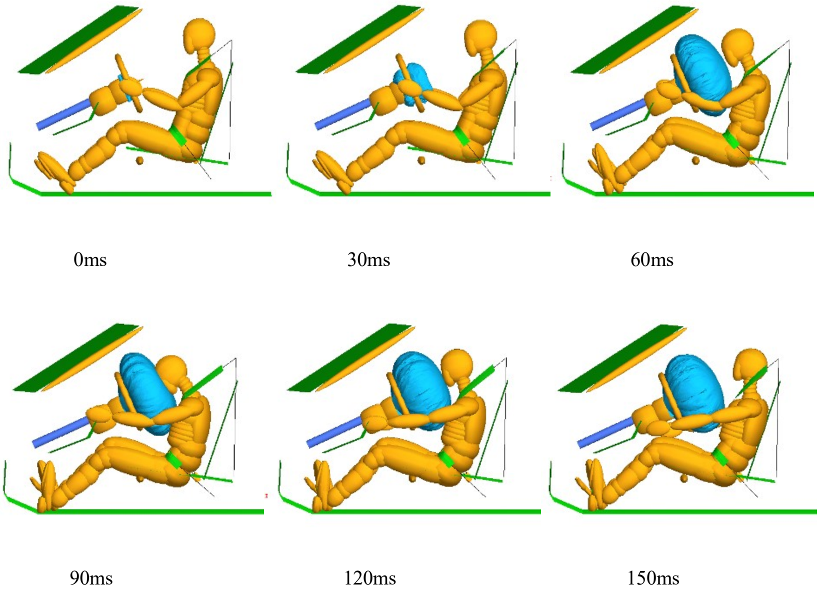

Figure 6 Driver's dynamic response during collision (t=150ms)

Figure 7 shows the time history of resultant acceleration of the driver's head; Figure 8 shows the time history of resultant acceleration of the driver's chest; Figure 9 shows the time history of deformation of the driver's chest. Based on the driver's dynamic response process and the response time history of the driver's head and chest during collision, the driver's risk of injury can be analyzed in three stages:

(1) The first stage (0-60ms). Since 10ms, the forward acceleration acted on the driver's head and chest. Due to the restriction of safety belt on the chest, there was a large difference between the motions of chest and head, and the acceleration of the chest increased more rapidly than the head. At 85ms, the acceleration of the chest reached its peak - 29.70g, and the compression of the chest also reached its peak - 26.6mm.

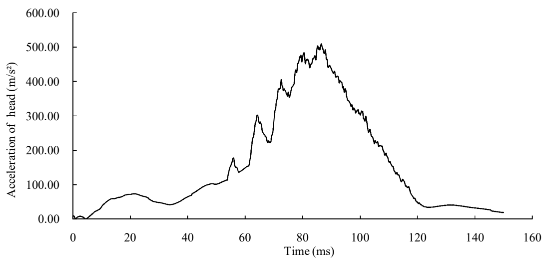

Figure 7 Time history of resultant acceleration of the driver's head

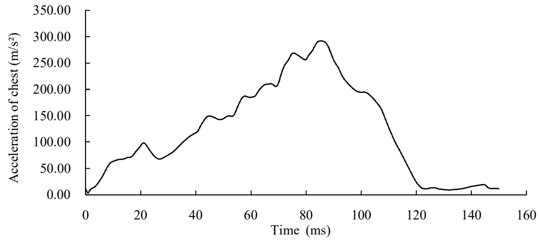

Figure 8 Time history of resultant acceleration of the driver's chest

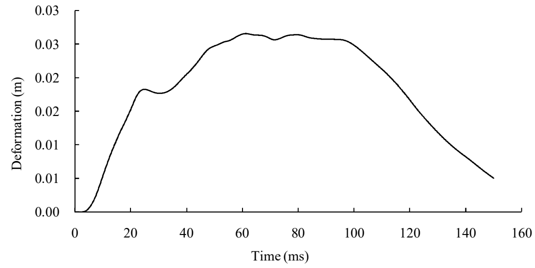

Figure 9 Time history of deformation of the driver's chest

(2) The second stage (60-120ms), in which the airbag contacted with the driver's head. At 60ms, the airbag was completely expanded. Based on the dynamic response process, the driver's head did not collide with the steering wheel due to the protection of the airbag. At 90ms around, the driver moved forward to the farthest position in the front, the peak of the head's acceleration was about 52g, and the head's HIC36 value was 351.33.

(3) The third stage (120-150ms), in which the driver was in the state of spring-back. At 150ms around, the protection from airbag and safety belt tended to be over.

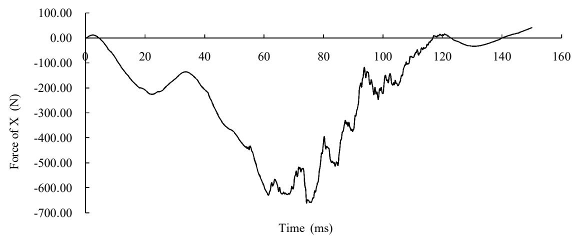

Figure 10 Time history of load on the driver's neck in the x-axis

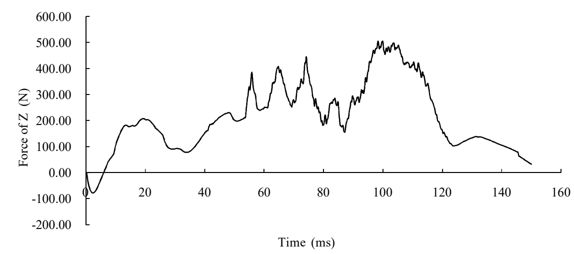

Figure 11 Time history of bending moment on the driver's neck around the y-axis

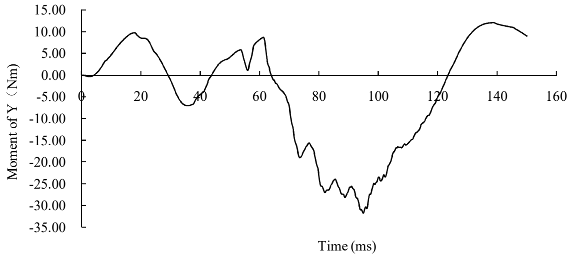

Figure 12 Time history of load on the driver's neck in the z-axis

During collision, the load and bending moment on the driver's neck are shown in Figure 10-12. Figure 10 shows the time history of load on the driver's neck in the x-axis; Figure 11 shows the time history of bending moment on the driver's neck around the y-axis; Figure 12 shows the time history of load on the driver's neck in the z-axis. Due to the restriction from airbag, the bending moment formed by the inertia of head and neck was restricted. Therefore, the time when the neck's stretch bending moment reached its peak was close to the head's acceleration phase. At 95ms around, the neck's bending moment reached its peak - 31.74Nm.

3.2 Analysis results of risk of injury

Based on the tolerance limits to injuries of all parts of human body in Euro-NCAP test requirements, the reconstruction results of injury of risk were assessed. In this case, the driver's HIC value was 351.33, lower than the value in regulations (1000), indicating the probability that the head may have the risk of injury at AIS3 or above was lower than 5%. The results suggested the risk that the head was injured in the accident was very low, which was consistent with the information in the driver's medical record and the head's injury level (AIS1) collected in the hospital where the driver was treated.

Table 2 Output of dummy's injury parameters

Injured part	Injury parameters	Injury value (peak)	Standard value in Euro-NCAP
Head	HIC36	351.33	1000
Neck	Positive shearing force on neck Fx (kN)	0.14	3.1
	Negative shearing force on neck Fx (kN)	0.93	3.1
	Tension of neck Fz (kN)	0.51	3.3
	Stretch bending moment of neck My (Nm)	31.74	57
Chest	Resultant acceleration (g) of chest at 3ms	29.4	38
	Amount of compression of chest RDC (mm)	26.6	50
	Viscosity index VC (m/s)	0.092	1.0
Lower limbs	Compressive force of thigh (kN)	1.13	3.8
	Tibia index (TI)	0.6	1.3
	Compressive force of shank (kN)	0.51	8.0

The VC value of the chest's maximum deformation was 26.6mm, lower than the specified 50mm in regulations; the chest's viscosity index was 0.092m/s, lower than the specified 1.0m/s in regulations. In addition, the injuries on the neck, thigh and shank were all lower than the corresponding injury index in regulations, indicating the risk of injury on these parts was relatively low. In motor traffic accidents, the risk of the occupant's injury was greatly affected by the intrusion of the car body's deformation [9]. In the research, the cab was not deformed largely, so the space for the driver's survival was guaranteed. Based on the above analysis, the driver's injury in the accident was classified as mild injury (AIS1). The research results were consistent with relevant medical reports.

Table 2 lists the main injury values of all parts of the driver dummy and the standard values in Euro-NCAP.

4 Conclusions

(1) The dynamic parameters before, during and after the two cars collided were output through the accident reconstruction in PC-Crash. The reliability was verified based on the final parking positions and motion trails of the two cars.

(2) The equivalent impact impulse was adopted to obtain the impact impulse and yawing motion parameter of the car body, which were regarded as the initial input boundary conditions for reconstructing the risk of injury in MADYMO.

(3) The reconstruction model of the driver's risk of injury was set up in MADYMO. On this basis, biomechanics-related parameters of the driver's injury were calculated and the risk of injury was analyzed. The result analysis indicates that the coupled simulation and reconstruction method based on PC-Crash and MADYMO can better reproduce the driver's dynamic response process during collision. Meanwhile, it is able to provide an accurate prediction for the injured parts of driver in traffic accidents.

References

[1] PEDEN M, et al. Word Report on Road Traffic Injury Prevention. Geneva,Word Health Organization, 2004: 1-5.

[2] H. Steffan and B. C. Geigl. A New Approach to Occupant Simulation Through the Coupling of PC-Crash and MADYMO. SAE Paper, No. 1999-01-0444

[3] H. Steffan, A. Moser and B. C. Geigl. Validation of the Coupled PC–CRASH -MADYMO Occupant Simulation Model. SAE Paper, No. 2000-01-0471

[4] SHEN Jie,JIN Xian-long, Guo Lei, ZHANG Xiao-yun.The Accident Reconstruction based on Occupant Kinematics. Journal of Shanghai Jiaotong University,2006.40(6):p.963-967

[5] YangX ingmei, Yang Jikuang, LiHongjian, Hao Yumin,A Study on Child Occupant Accident Reconstruction,Automo tive Engineering,2009.31(12):525-528

[6] Liu Xueshu,Song Zhen huang,Yu Chang ji.Study on Basic Principle of Vehicle Crash[J].Tianjin Automobile,2004(3):p.22-25

[7] Mertz, H. Anthropomorphic test devices. Accidental Injury - Biomechanics and Prevention, Chapter 4. Ed. Alan Nahum and John Melvin. Pub. Springer-Verlag 1993

[8] MEYER E G and HAUT R C. The Effect of Impact Angle on Knee Tolerance to Rigid Impacts. Stapp Car Crash Journal. 2003.47: p.1-19

[9] KIRKISH S L, BEGEMAN P C and PARAVASTHU N S. Proposed Provisional Reference Values for the Humerus for Evaluation of Injury Potential. SAE Paper, No. 962416