The Influence of Mini-Car Occupant Restraint System Design Variables on the Crash Response of Passengers

HU Yu-mei[1] HE huan[1] FAN Ti-qiang[2] YE Yu-xi[1] XIAO Hui-fang[1]
[1.] The State Key Lab of Mechanical Transmission, Chongqing University, Chongqing,400044,China;
[2.]Chongqing Automotive Research Institution, Chongqing, 400039,China
hh198109@126.com

Abstract: In the frontal crash of mini-car, the passengers can easily get serious hurt, it is very important to optimize the occupant restraint system to protect the passengers. With the use of LS-DYNA,VPG etc, this paper builds the restraint system model of a mini-car containing the Hybird □ 50th dummy、seat、seatbelt and the steering system,Makes simulation compute to the sensitive design variables of the restraint system such as the seatbelt fabric stiffness、 retractor characteristics、 upper slipping position of seatbelt、seat cushion stiffness, gives out the corresponding passenger respond curve and human body injury value, sums up the regularitie between design variables and passenger protect efficiency, which can also be applied on the restraint system of other vehicle type and finally puts forward a set of design variables adaptive to this mini-car.
Keyword: Frontal Crash Restraint System Human Body Injury Weighted Injury LS-dyna

1. Preface

Occupant restraint system(including seatbelt and chair)and airbag are the two most effective safeguards in car crash, which can reduce the risk of passengers in front seat subjected to deadly injury by 45% and the risk of moderate injury by 50%. As the rate of reduced risk go beyond airbag's efficiency, it's very important to conduct a optimization on occupant restraint system, however, research in this field is only limited to optimize seatbelt, seat, airbag respectively. But if we start with system concept, combine seatbelt with seat, and seek the most excellent match on their mechanical characteristic and parameters,the performance of occupant restraint system can be highly improved. This paper try to optimize the variables of occupant restraint system using computer simulation, choosing variables base on the most excellent integration performance, exert the harmony and restraint capability of seatbelt and seat mostly, reduce the number of devastating test, minimize the exploration fee as well as shorten design period, enhance the technic level and performance of occupant restraint system ulteriorly.

2 Build the Model of Mini-Car Restraint System

2.1 The introduction of dummy

At present, a Hybird □ 50th male deformable dummy is required in the frontal impact, this dummy is designed by General Motors company in 1970s,and it's mainly used for simulating human biomechanic response in the frontal impact, It is designed to be disassemble, and it is consisted of head、neck、abdomen,、buttocks and limb. This model can not only accurately describe kinematics and dynamics characteristic of dummy during car crash, but also possess nice biological fidelity to provide exact dummy injury value. Therefore, this paper utilize this dummy to study the relationship between mini-car restraint system design variables and human body injury.

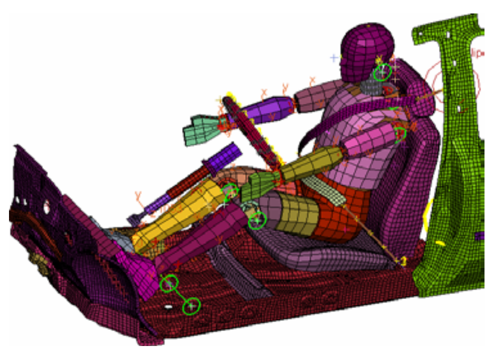

Fig1. Model of occupant restraint system

2.2 Build the Model of Occupant Restraint system

The occupant restraint system mentioned in this paper mainly consists of seatbelt system and seat , and the seatbelt system include fabric, sensor, retractor and slipring, pretension is needed if necessary; The seat is dispersed with solid element and its material is foam; floor and B pillar are simplified as rigid body. In this system, defining dummy and sear, 1D seatbelt element, dummy and chair, 2D seatbelt element and dummy is necessary. At the same time, it's also a must for us to define sensor type and trigger time to activate retractor. The model of occupant restraint system is shown in Fig.1

3 Simulation and validation of Mini-Car Restraint System

In the frontal crash of mini-car, the region before engine is the primary endergonic region, nevertheless, the stiff of cab especially the region nearby B pillar is much higher than the region before engine, And this region does not touch the rigid wall directly, therefore the deformation of cab is very small, in order to reduce compute time, this paper first conducts a simulation of the whole car and extract the longitudinal acceleration curve of lower part of B pillar, subsequently, this curve acts as an input and is imposed on the dummy reverse. comparison between occupant restraint system simulation results and whole car simulation results are shown from Fig. 2 to Fig. 4.

From Fig.2 to Fig.4 we can conclude that: occupant restraint system simulation results and whole car simulation results are basically consistent, but the results of the restraint system simulation are ahead of whole car simulation, and the human injury value especially the impact force of knee is higher than whole car simulation results, this error is mainly from two aspects: firstly, this model neglects the deformation of front surrounding and front floor but simplified them as rigid; secondly, instrument board is missed in this model. Although some error exist in this model, the trend of this two results is nearly the same and the error on human body injury criterion is limited to 10 percentage, there's no doubt that it is feasible to make simulation with this model, and this model can be used in the following study.

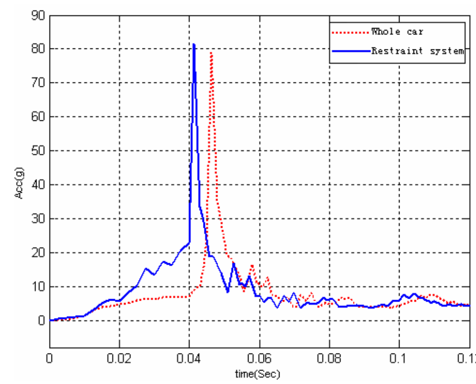

Fig 2. Compare of head resultant acceleration

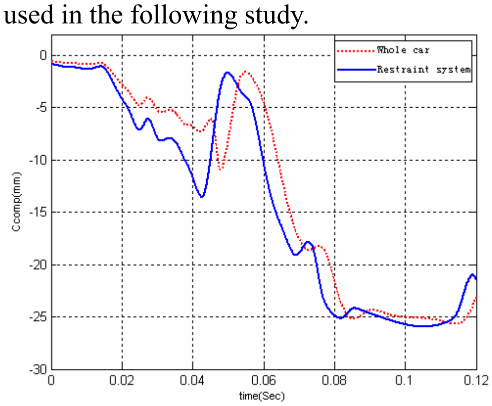

Fig 3. Compare of chest compression

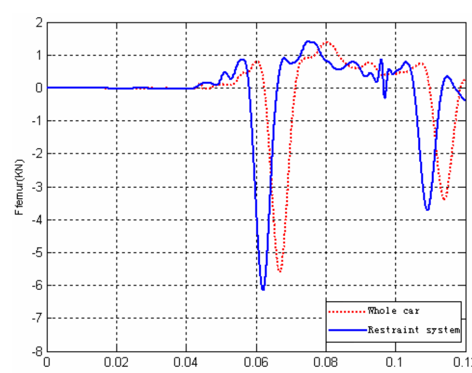

Fig 4. Compare of keen impact force

4 The relationship between restraint system design variables and human body injury

4.1The influence of seatbelt fabric stiffness

According to GB14166-93, the stiffness of fabric is the relative stretching rate of seatbelt when it is against a 11080N force. In practice, the different stiffness is acquired through adjusting the degree of tightness of fabric in the process of yarn melting glue coloration. Generally, the stiffness of fabric can(relative stretchion rate)vary from 5% to 23%. The fabric stiffness(relative stretchion rate) used for simulation in this paper deviates ±4% and ±8% when it is compared to original stiffness.the normalized simulation results judeged by CMVDR294 criterion are shown in Fig.5. When fabric relative stretching rate varies from 0 to -4%,both HIC value and Ffemur value decrease greatly, concomitant with the increase in Ccomp value; when fabric relative stretching rate vary from 0 to 4%,both HIC value and Ccomp value decrease slightly concomitant with the increase in Ffemur value;when fabric relative stretching rate varies beyond -4% to +4%, the detailed rules about HIC value, Ccomp value, Ffemur value are shown in Fig.5.From Fig.5 we can find out that: when the fabric stiffness increases in certain range(relative stretching rate decrease), the dummy especially it's shoulder and head can be well restricted to the seat, Thus the impact between the head and steering wheel, leg, frontal surrounding as well as steering pole can be avoided or lightened. When the fabric stiffness decreases in certain range and the dummy is not well restricted, the impact between leg and frontal surrounding as well as steering pole is aggravated.

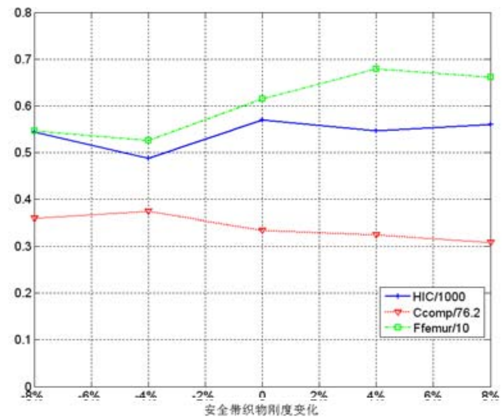

Fig.5 Influence of seatbelt fabric stiffness on human body injury

4.2The influence of retractor lock characters

After the retractor is locked, fabric will still be pulled out due to some factors such as the delay of locking retractor, "the scroll effect", seatbelt elongate deformation and so on. According to GB14166-93, when the acceleration of sensor attached to car equals to 0.75g, the pull out length of retractor fabric should less than 25mm; when the acceleration of sensor attached to seatblet equals to 2g, the pull out length of retractor fabric should less than 50mm.The pulled out length of locked retractor used for simulation in this paper deviates ±10mm and ±20mm from original length, simulated results normalized according to the CMVDR294 criterion are shown in Fig.6. When the length of fabric be pulled out varies from 0 to -10mm, HIC value decreases greatly and Ffemur value decreases slightly, along with the increase of Ccomp value; when length of fabric be pulled out vary from 0 to 10mm, HIC value increases greatly, both Ccomp value and Ffemur value increase slightly; when length of fabric be pulled out beyond -10mm to 10mm, detailed rules about HIC value, Ccomp value, Ffemur value are shown in Fig.6.From Fig.6 we can find out that: when the length of fabric be pulled out decreases in certain range, the dummy especially it's shoulder and head can be well restricted to the seat, thus avoid or lighten the impact between head and steering wheel, leg and frontal surround as well as steering pole; when the length of fabric be pulled out increases in certain

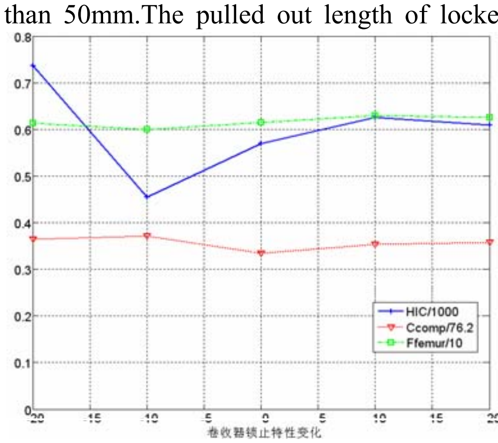

Fig6.Influence of retractor lock characters on human body injury

range, the dummy is trend to slip downward so the impact between leg and frontal surround as well as steering pole is aggravated, which also arise a wallop between aiguillette and chest.

4.3The influence of upper hanging position of seatbelt

Seatbelt upper hanging point is the hanging position of seatbelt on the upper end of B-pillar. Seatbelt upper hanging point used for simulation in this paper deviates ±25mm and ±50mm from the original position, the simulated results normalized with CMVDR294 criterion are shown in Fig.7. From Fig.7 we can find out that: compared to original car, when the downward offset value of seatbelt upper hanging position varies from 0 to 25mm, both HIC value and Ffemur value decreases greatly along with the increase in Ccomp value; when the upward offset value of seatbelt upper hanging point vary from 0 to -25mm, both HIC value and Ccomp value will increase greatly along with decrease in Ffemur value; when the offset value of seatbelt upper hanging point beyond -25mm to 25mm, the detailed rules about HIC value, Ccomp value, Ffemur value are shown in Fig.7. From Fig.7 we can find out that: when the upper hanging point of seatbelt offsets downward in certain range, the dummy especially its shoulder and head can be well restricted to the seat, thus the impact between head and steering wheel, leg and frontal surround as well as steering pole will be avoided and lightened;when the upper hang point of seatbelt offsets upward in certain range, the dummy is lack of restriction so the impact between leg and frontal surround as well as steering pole will be aggravated, which also arise a wallop between aiguillette and chest.

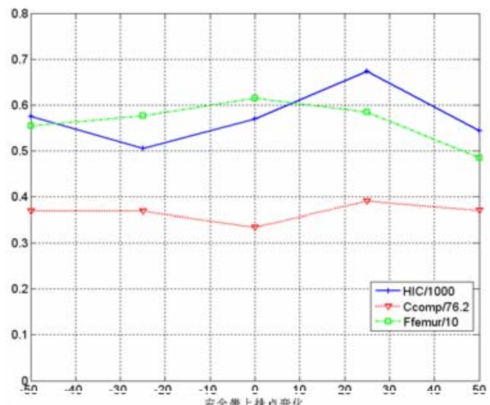

Fig7.Influence of seatbelt upper hanging position on human body injury

4.4The influence of seat cushion stiffness

According to GB14166-93, the seat cushion stiffness is defined as the quotient of 470N divided by the cushion's sink value when it is against a force of 470N. the seat cushion stiffness used for simulation in this paper deviate ±4N/mm and ±8N/mm from original stiffness, the simulated results normalized with CMVDR294 criterion are shown in Fig.8. When the cushion stiffness varies from 0 to -4N/mm, the HIC value decreases greatly while Ffemur value decreases slightly, along with increase in Ccomp value; when the cushion stiffness varies from 0 to 4N/mm, both HIC value and Ccomp value increase in certain degree, along with the decrease in Ffemur value; when the cushion stiffness varies beyond -4N/mm to 4N/mm, detailed rules about HIC value, Ccomp value, Ffemur value are shown in Fig.8. From Fig.8 we can find out that: when the seat cushion stiffness decreases in certain range, the absorbing energy capability of seat cushion will be improved, so the damage of head and leg will be decreased; when seat cushion stiffness increases in certain range, the absorbing energy capability of seat cushion will be reduced in certain degree, the dummy can't move toward the direction in which wallop can be avoided, and the damage to human's head and chest is aggravated, but the injury of human's leg

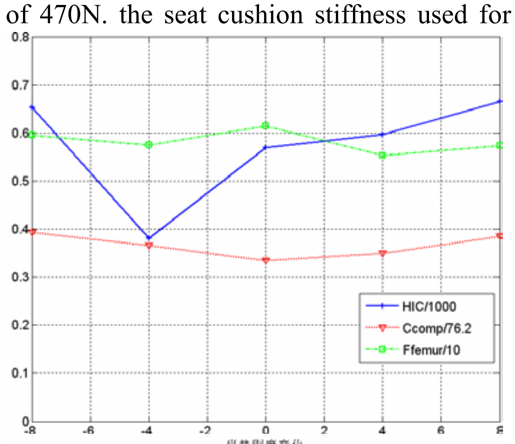

Fig8. Influence of seat cushion stiffness on human body injury

avoided lightened.

5 Optimization of Mini-Car Restraint System

This paper adopts Weighted Injury Criterion mentioned in reference 3 to fully evaluate the protection performance of restraint system, and makes it the objective function to optimize the restraint system. The smaller the WIC is ,the better protection performance of restraint system will be.

$$WIC = 0.6\left(\frac{HIC_{36}}{1000}\right) + 0.35\left(\frac{C_{comp}}{0.0762}\right) + 0.05F_{femur}/10$$

Basing on the Weighted Injury Criterion and following the relationship between restraint system design variables mentioned above and human body injury, the final decided design variables are: stretch rate of fabric decreases by 4%, pull out rate of fabric after retractor locked decreases by 10mm, upper anchor of seatbelt move downward by 25mm, seat cushion stiffness decreases by 4N/mm. Simulation results between different structures are shown in Fig.9 to Fig.11, the dynamic simulation process are shown in Fig.12 to Fig.15.

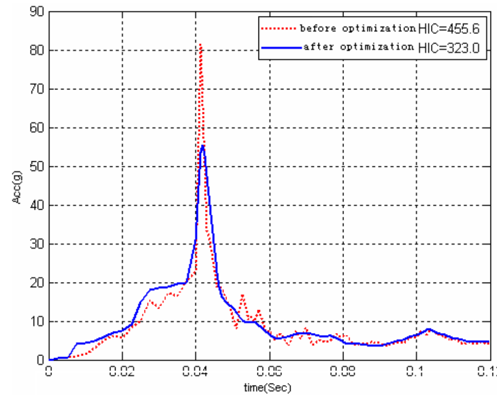

Fig9.Head resultant acceleration beforeand after optimization

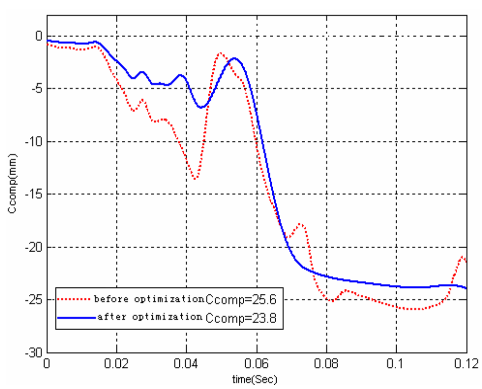

Fig10. Chest compression before and after optimization

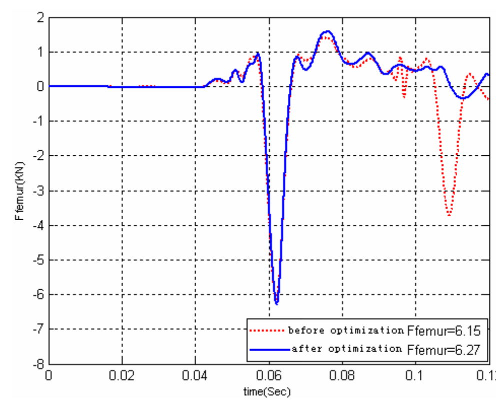

Fig11. Keen impact force before and after optimization

From Fig.9 to Fig.11 we can come to the following conclusions: head resultant acceleration and chest compression reduce greatly after optimization and the Weighted Injury value drops from 0.334 to 0.421and the protection performance of restraint system is improve greatly.

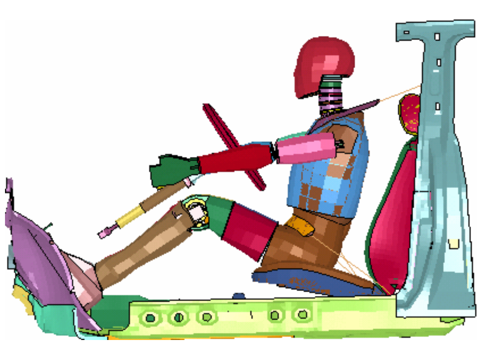

Fig 12. Time 30ms

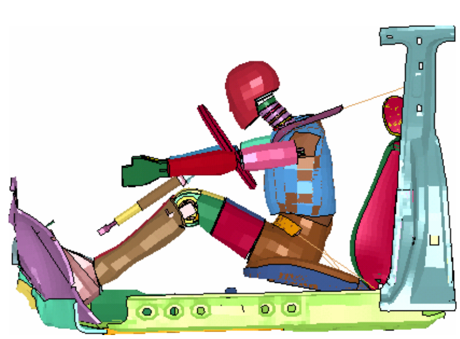

Fig 13.Time 60ms

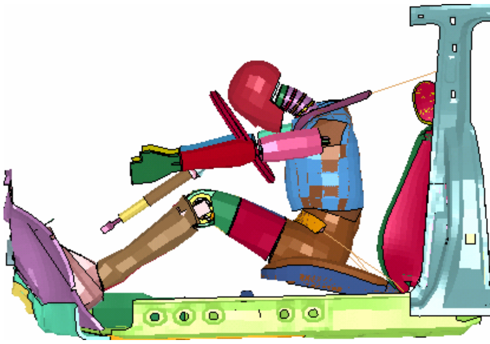
Fig 14. Time 90ms

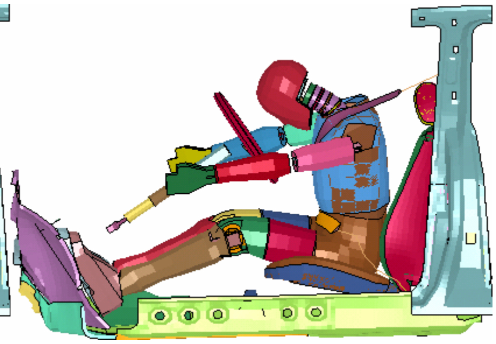
Fig 15. Time 120ms

6 Conclusion

(1) Separating the restraint system model from whole car model, and useing the longitudinal acceleration curve of lower B pillar as the input of restraint system, the simulation results of human injury value deviates less than 10% from the whole car model, thus it is feasible to use this model for the subsequent study, the model not only meets project precision requirement, but also consumes less time in optimizing process than the whole car model.

(2) Making simulation computer on the sensitivity design variables of restraint system, and illustrating rules and relationship between design variables and human injury, will be of referential significance in optimization design of occupant restraint system.

(3) Based on the Weighted Injury Criterion, an optimization on the restraint system has been conducted, a decrease of WIC up to 21% has been obtained, the protection capability of restraint system has been enhanced, which indicates that our study on occupant protection is efficient.

References:

[1] Zhang junyuan, A Study on the Optimzation of Seat Belt Restraint Effectiveness Based on Stochastic Simulation.Automobile Engeering.2004(3):p311

[2] Xiao fan, Numeration of Occupant with Restriction System's Dynamic Response in Frontal Impact. Journal of Tongji University.2004(9):p1222-p1224

[3] Viano DC,Arepally S. Assessing the Safety Performance of Occupant Restraint System. SAE Paper No. 902328

[4] Livermore-Software,LS-DYNA Keyword User's Manual,970 ed. Livermore: Livermore Software Technology Corporation, 2003