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Vehicle Seat Structure Optimization in Front and Rear Impact

Yali Yang[*,1], Hao Chen[1], Ruoping Zhang[1], Haining Chen[1] and Xuhua Qiang[2]

[1]*College of Automotive Engineering, Shanghai University of Engineering Science, Shanghai, 201620, China*
[2]*Shanghai ShuangJie Technology Co., LTD., Shanghai 201804, China*

Abstract: Seat is one of the important parameters for occupant safety during an impact. The occupant injury characteristics are vital for better seat development. For improving occupant safety during impact, the research on the seat structure optimization in front and rear impact was conducted in this paper. Dummy-seat finite element simulation model was established and analyzed by using HyperMesh and LS-DYNA software. The model was verified with test data before further application. Then, the model was simulated to determine its performance on the head, chest and neck injury of the dummy in the frontal and rear impact. The simulation results showed that the original model cannot provide effective protection according to CNCAP regulation. Thus, modification should be carried out. On the basis of previous study, seat side plate, lower bracket under cushion, and back lock member were modified by implementing orthogonal experiment design method to determine the best option. The optimized solution $A_4B_2C_2$ was gained through range analysis and integrated balance method. After simulation, chest compression reduced 17.21%, 3ms resultant acceleration reduced 21.16%, dummy neck F_X decreased 15.44%, M_Z value decreased 3.13%, and backrest angle decreased 46.1%. It was indicated that the optimized structure can improve passenger protection. It was illustrated that the model based method combining HyperMesh and LS-DYNA was an effective way for seat development and for conducting occupant injury study.

Keywords: Front and rear impact, Occupant injuries, Orthogonal optimization, Seat.

1. INTRODUCTION

With the development of auto industry, the safety of the car has increasingly become an important research field for modern automobile development design [1, 2].

As an important safety component, vehicle seat is a hot spot in the study of automobile safety and it provides a decisive protection for passengers [3]. In 2011, Jin [4] systematically introduced the seat safety performance requirements pointing out that seat back should be strengthened, the cushion stiffness improved and headrest redesigned on low-speed crash protection. Yang [5] analyzed that insufficient stiffness of seat cushion is the cause of human body diving in rear collision which results in greater damage on the abdomen in 2012. According to the recent research status abroad, Nicolas [6] established finite element models of multi-body human body and seat to study the safety of the crew in rear crash. Masahide *et al*. [7] from Japan's Toyota motor crop studied occupant protection during the car crashes. Chen [8] established multi-rigid-body crash model to analyze the seat parameter effect on passenger injury during rear impact and optimize the seat structure. Wang [9] conducted research study on seat strength and stiffness in front crash and optimized seat to provide better passenger protection.

The seat safety research has laid emphasis on the strength of seat and body connection and seat features during frontal crash, and headrest safety and backrest strength in rear impact. Seat safety refers to the ability to prevent vehicle accidents effectively and to reduce the damage of occupants to a minimum at the time of the accident [10]. Research on vehicle seat in a front and rear collision mechanism of injury to the occupant can provide theoretical technical support for the seat design, research and development. It can improve vehicle passive safety performance in a collision and have greater significance in traffic safety [11-13].

Based on a domestic car seat, a seat-occupant finite element model was established by using HyperMesh and LS-DYNA simulation software to study the passenger injury characteristics during front and rear impact. The main purpose was to analyze the performance of the seat and the improvement and optimization of the structure, thus to improve dummy injury indicators to provide effective protection for occupants and also to provide a method for modern seat design and passenger protection evaluation.

2. DUMMY-SEAT MODEL ESTABLISHMENT AND ANALYSIS

2.1. Model Establishment

The CAD geometric model was imported to HyperMesh software and meshed according to engineering experience. In this model, the sheet metal parts using two-dimensional grid method were meshed by quadrilateral element and triangular element. Three-dimensional mesh was used in headrest, backrest, cushions and other special components. Belt model was the combination of one-dimensional multi-rigid-body seat belt element and two dimensional membrane elements. Model grid size was controlled at about 10 mm. Final mesh model is shown in Fig. (**1**).

*Address correspondence to this author at the College of Automotive Engineering, Shanghai University of Engineering Science, No. 333 Longteng Road, Shanghai 201620, China; Tel: +86 13585901281;
E-mail: carolyn71@163.com

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a) FE model **b**) FE model with dummy

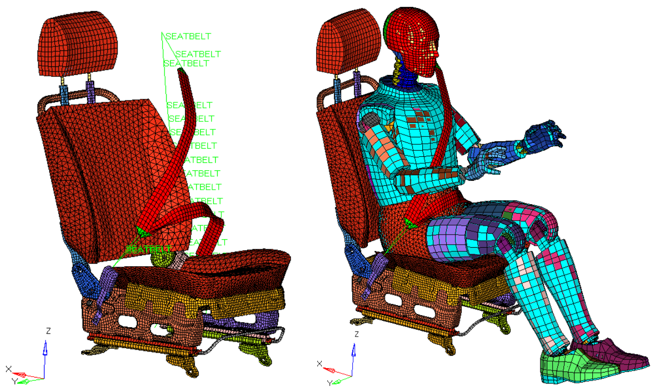

Fig. (1). FE model seat-dummy.

A total of 30954 nodes and 93421 elements were included in this model. And then, on the basis of this seat model to join Hybrid □, 50% male dummy completed the dummy-seat model as shown in Fig. (**1**).

2.2. Front and Rear Impact Setup

For front impact, the analysis was a low speed collision. In accordance with requirements of the low-speed collision, the collision speed was selected 50km/h, at X-axis negative direction. Collision time was 150ms. Acceleration curve is shown in Fig. (**2**), which was obtained by vehicle collision test. The chest compression, chest 3ms synthetic acceleration data were used as evaluation indexes.

For rear impact, the speed of rear collision was 50hm/h, in X direction. The remaining boundary conditions were the same as the frontal collision simulation. Seat acceleration curve is shown in Fig. (**3**), which was obtained by the collision test of the vehicle.

2.3. Model Verification

To verify the model, X direction acceleration curve of chest was used. The real test and simulation curves are shown in Fig. (**4**). Similar trend was observed in the curves with almost the same maximum time. The maximum X acceleration of simulation was 35.5g and that for the test was 40.53g. The difference was below 20%. The occupant

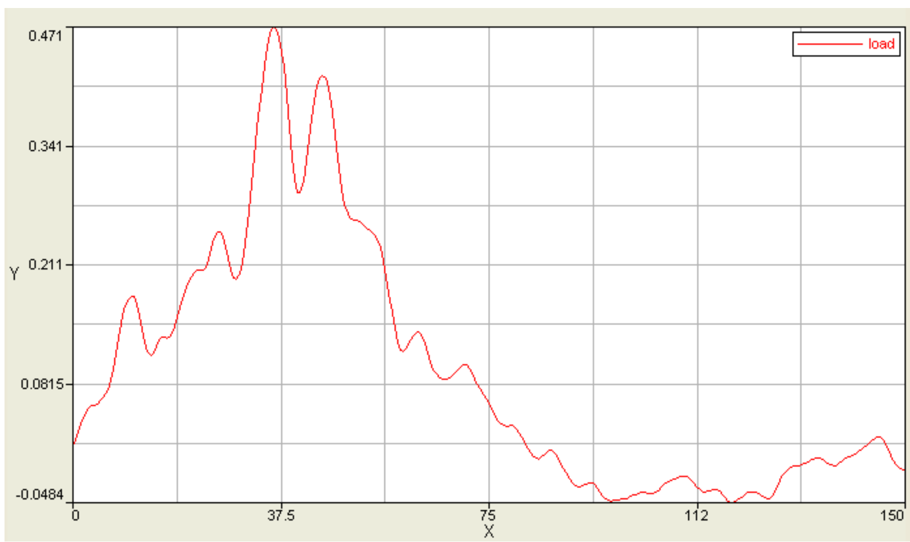

Fig. (2). Acceleration curve of front impact.

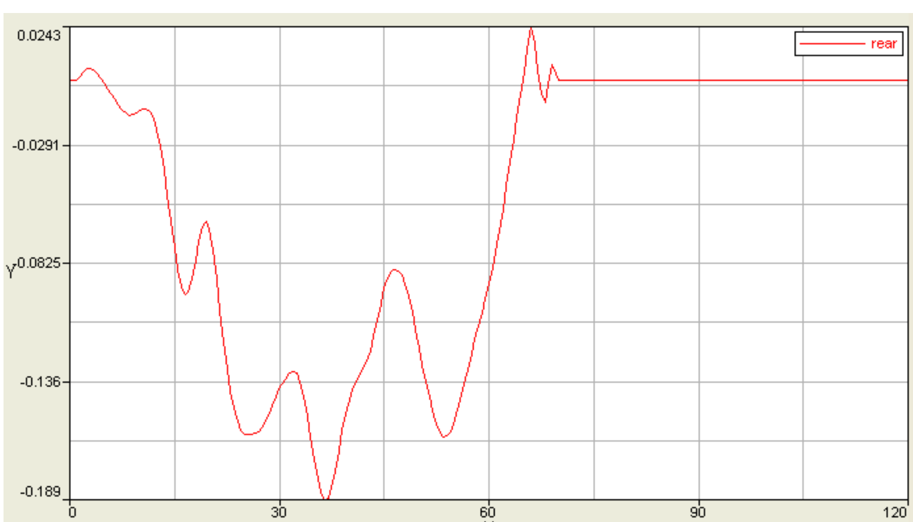

Fig. (3). Acceleration curve of rear impact.

protection performance of simulation was valid which indicated that the model can be used for simulation [14].

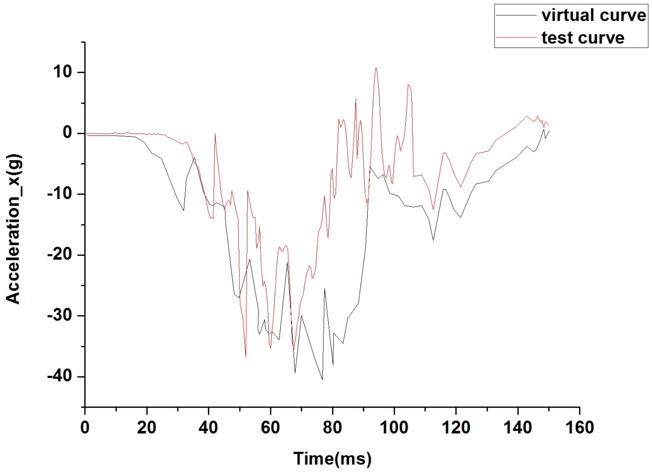

Fig. (4). Chest X acceleration curves of test and simulation.

3. OCCUPANT INJURY ANALYSIS

3.1. Frontal Impact

Fig. (**5**) shows that the maximum amount of chest compression was 63.84mm which was higher than the CNCAP requirement (50mm), and the value higher than 50mm period was about 50ms leading to a large amount of dummy chest compression resulting in more serious injuries in chest. 3ms synthesis acceleration of chest was 24.67g Fig. (**6**), meeting CNCAP requirement. Results indicated that modification should be carried out to optimize seat for better front injury protection.

3.2. Rear Impact

As shown in Fig. (**7**), dummy neck X to a maximum force FX was 881N. The value was greater than zero starting at around 104ms, and was largely changed. The neck X-force FX was over 730N (CNCAP value) and had a longer duration with more than 15ms. This showed that there was larger impact force acting on the dummy neck over a long period of time which could cause greater harm to the dummy neck. Optimization was needed to meet the requirement.

For Z-torque M_Z (12.13N·m), the value was greater than 0 after 102ms which could cause some dummy neck injury as shown in Fig. (**8**).

With the increase in the force of the backrest, the backrest angle was increased Fig. (**9**). The maximum change of the backrest angle was 22.97°, which could be further optimized.

4. SEAT STRUCTURE ORTHOGONAL DESIGN OPTIMIZATION

4.1. Orthogonal Design Arrangement

Based on the previous study of Chen [15], the seat structure was modified through three aspects, seat side plate, the lower bracket under cushion and back lock member, by combining the stress analysis during front and rear impact simulation, and industry engineering experience. The factors and level of each factor are shown in Table **1**. And a mixed orthogonal table $L_8(4X2^2)$ is shown in Table **2**.

4.2. Orthogonal Analysis

Based on the experimental arrangement, specific modification was carried out to establish the corresponding

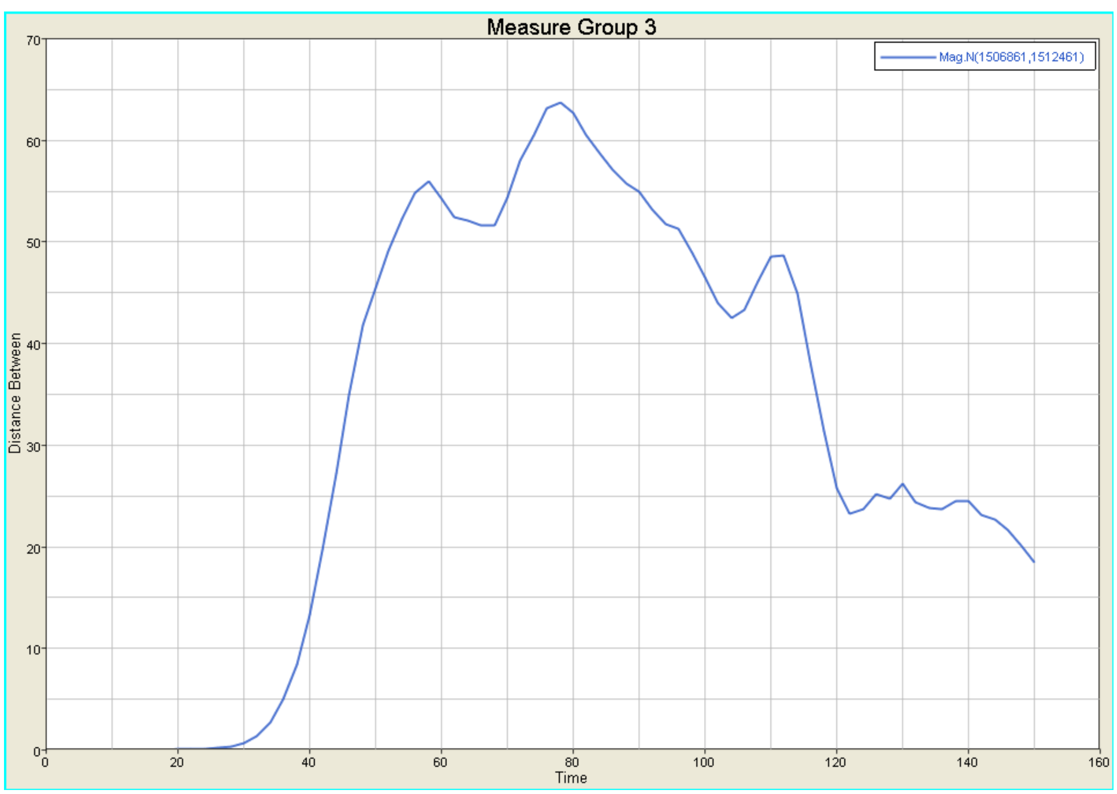

Fig. (5). Chest compression of dummy (mm).

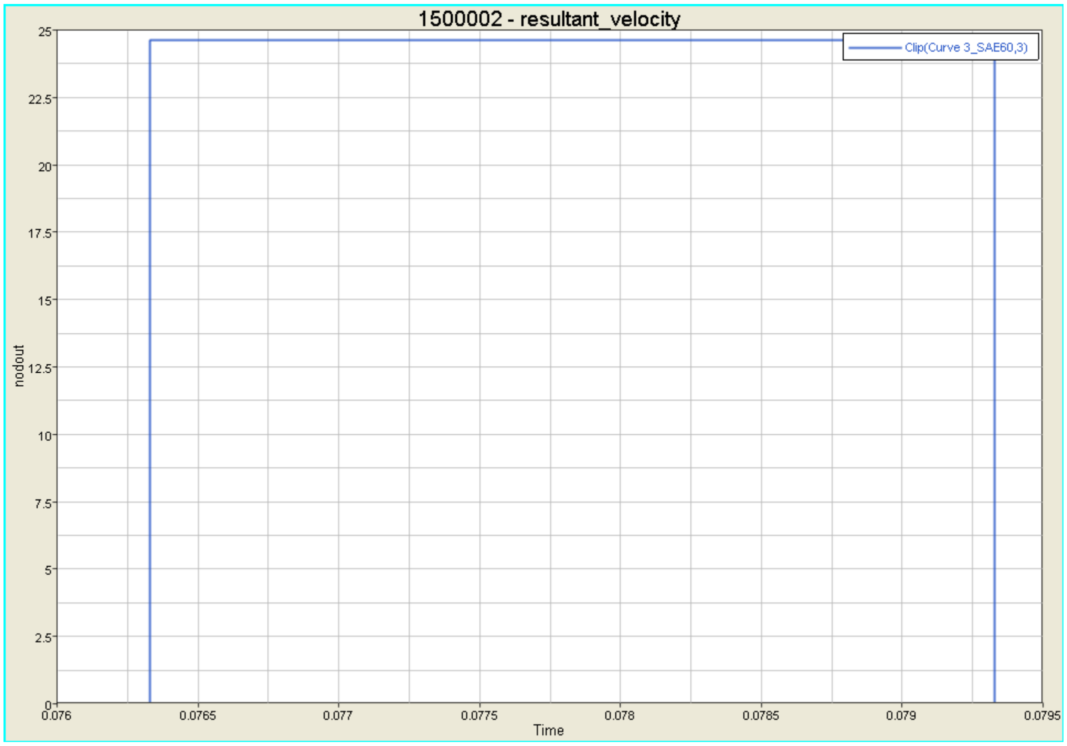

Fig. (6). 3ms synthetic acceleration of chest (g).

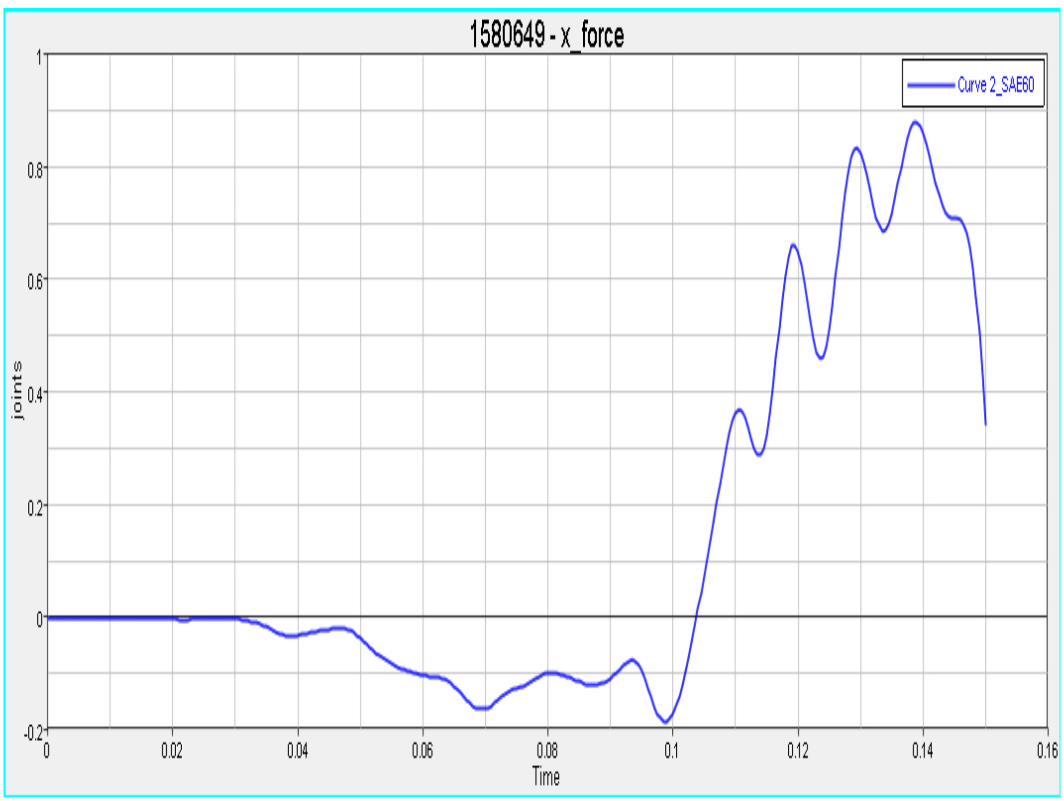

Fig. (7). Curve of X force of dummy neck (N).

model. All the modes were simulated in front and rear impact. The simulation results are shown in Table **3**. Results indicated that the occupant injury was reduced after different modification.

In order to determine the primary and secondary sequence of each factor, range analysis was applied. The simulation experiment data and range R, and the referred range R′ are shown in Table **4**.

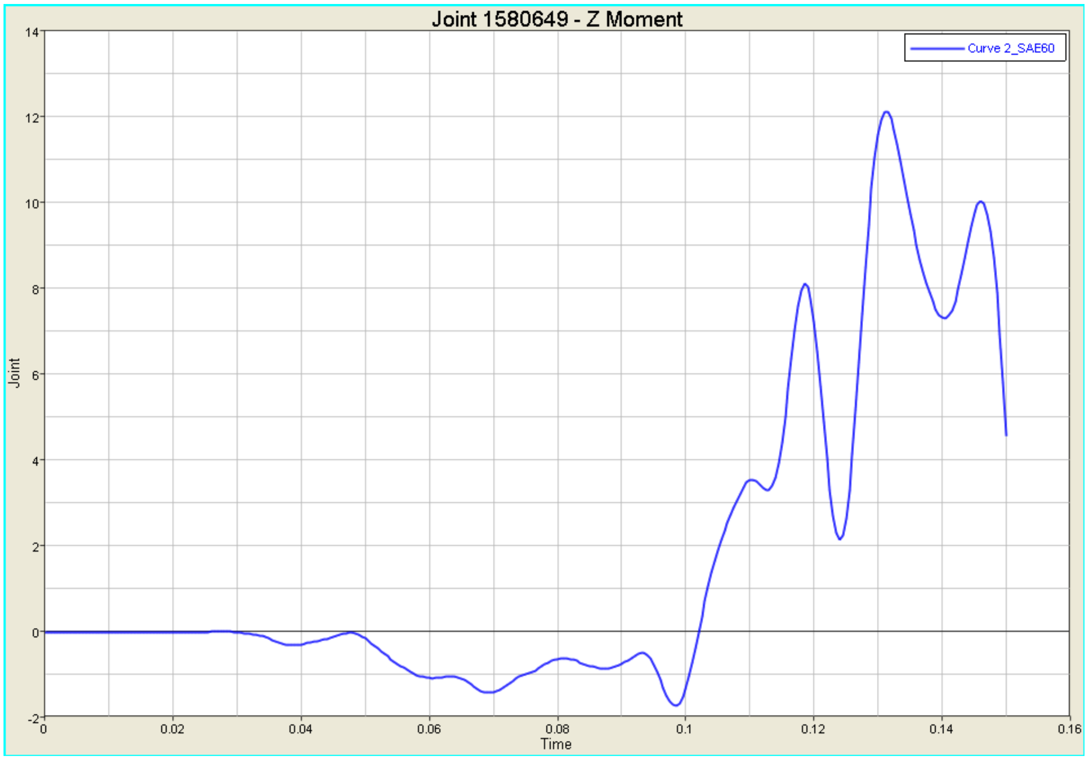

Fig. (8). Curve of Z moment of dummy neck (N·m).

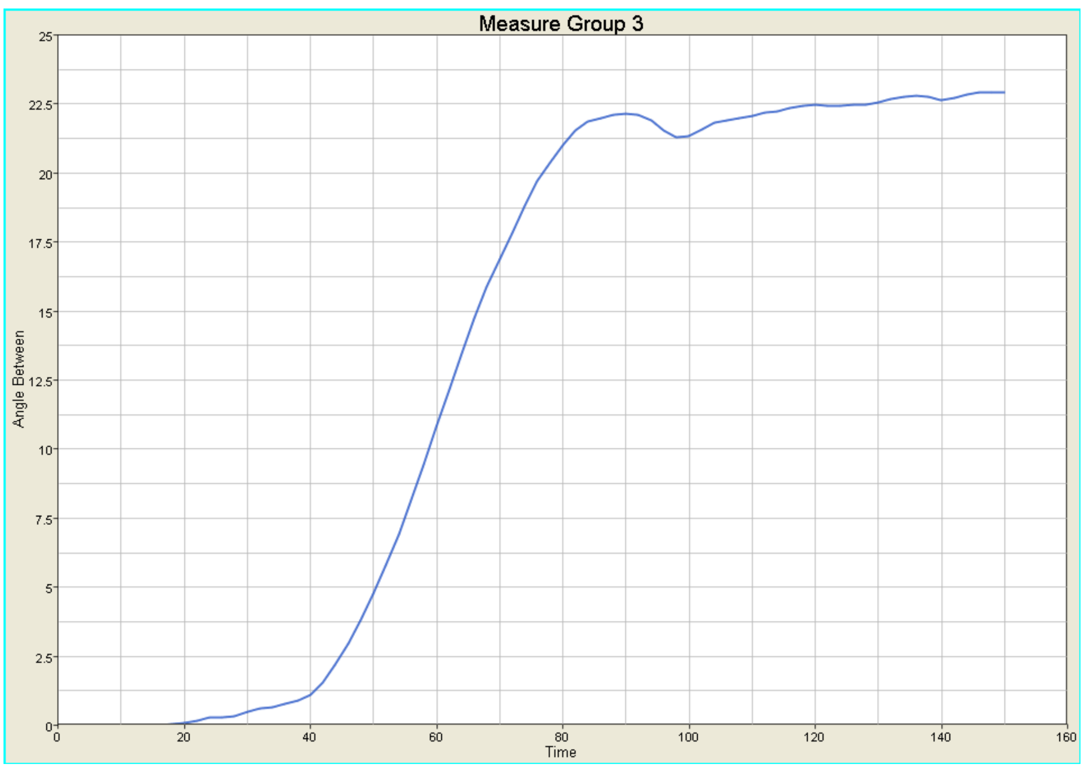

Fig. (9). Angle change of backrest (°).

For chest compression, the sequence was C-A-B, with the best combination of $A_2B_1C_1$. For 3ms synthetic acceleration, the sequence was B-C-A, with the best combination of $A_4B_2C_2$. It is indicated that the lower portion had relatively important effect on chest compression and 3ms synthetic acceleration.

For neck F_x, the influence order was A-C-B, with the best group $A_2B_1C_1$. For Neck M_Z, the order was A-B-C, with the best group $A_4B_1C_1$. It was illustrated that the back lock member had major effect on occupant neck injury.

To determine the optimized option, integrated balance method was used. According to the simulation results, 3

Table 1. Factor and level of this orthogonal table.

	Factor	Level 1	Level 2	Level 3	Level 4
A	Back lock member	142 mm	221 mm	269 mm	Using left structure to replace right
B	Side plate	2 holes	no holes		
C	Lower bracket	Original structure	Arc transit		

Table 2. Orthogonal table of L8 (4×2^2).

Experiment Number	A	B	C	Experiment Combination
1	1	1	1	A1B1C1
2	1	2	2	A1B2C2
3	2	1	2	A2B1C2
4	2	2	1	A2B2C1
5	3	1	1	A3B1C1
6	3	2	2	A3B2C2
7	4	1	2	A4B1C2
8	4	2	1	A4B2C1

Table 3. Simulation results.

		Chest Compression/mm	3 ms Synthetic Acceleration/g	Neck F_x/N	Neck M_Z/N·m
1	A1B1C1	63.84	24.67	881	12.13
2	A1B2C2	62.99	22.45	868	12.35
3	A2B1C2	57.19	20.83	773.26	14.65
4	A2B2C1	54.34	21.06	765.05	16.25
5	A3B1C1	50.52	23.56	740.65	10.84
6	A3B2C2	64.00	19.65	848	16.15
7	A4B1C2	64.39	20.76	789.49	11.08
8	A4B2C1	61.28	20.24	767.25	11.21

factors had different sequence on the selected occupant injury index. Factor A had larger effect on neck F_x and M_z. A_4 had the best overall performance. Factor B had larger effect on 3ms synthetic acceleration, and the best option was B_2. Factor C had larger effect on chest compression, with the best option C_2. Therefore, the optimized solution was $A_4B_2C_2$.

4.3. Occupant Protection Performance of Optimized Model

On the basis of the improvement structure, the optimized seat finite element model was established. Improved model analysis was carried out again in LS-DYNA, and compared with the simulation results of the original model. Chest compression, 3ms resultant acceleration, neck X-force, Z-moment and seat back angle were compared before and after optimization, as listed in Table **5**.

As shown in Table **4**, the dummy injury indicators decreased obviously. Among them, the backrest angle, chest compression and 3ms synthetic acceleration decreased 17.21% and 21.16%, respectively. This was due to the increase in optimized sides' strength, so that the seat could withstand a greater impact in front collision. Due to the modification on back lock member and center hinge, the seat can reduce force and torque on neck. The dummy neck F_X decreased 15.44%, M_Z value decreased 3.13%, and its angle variation also decreased. The dummy rebound decreased when impacted by an external force. Results illustrate that the optimized structure can improve occupant protection during front and rear impact.

CONCLUSION

(1) Dummy-seat model was established by HyperMesh and LS-DYNA software. Analysis was conducted to determine the performance of seat in dummy protection during front and rear impact. Results

Table 4. Analysis of simulation results.

Parameter	K_i	A	B	C
Chest compression	K_1	126.83	232.94	229.98
	K_2	111.53	242.61	248.57
	K_3	114.52		
	K_4	122.67		
	R	7.65	2.42	3.90
	R′	4.87	3.43	5.53
3ms synthetic acceleration	K_1	47.12	89.82	89.53
	K_2	41.89	83.4	83.69
	K_3	43.21		
	K_4	41		
	R	3.06	1.61	1.46
	R′	1.95	2.78	2.07
Neck F_x	K_1	1749	3184.4	3153.95
	K_2	1538.31	3284.3	3278.75
	K_3	1588.65		
	K_4	1556.74		
	R	105.35	15.98	31.2
	R′	67.05	22.68	44.30
Neck M_z	K_1	24.48	48.7	50.43
	K_2	30.9	55.96	54.23
	K_3	26.99		
	K_4	22.29		
	R	4.31	1.82	0.95
	R′	2.74	2.58	1.35

Table 5. Comparison before and after optimization.

Index	Original	Optimized	Difference	Rate of Change
Chest compression/mm	63.84	52.85	10.99	17.21%
3ms synthetic acceleration/g	24.67g	19.45g	5.22	21.16%
F_X/N	881	745	136	15.44%
M_Z/N·m	12.13	11.75	0.38	3.13%
Backrest angle/°	22.97	12.38	10.59	46.10%

indicated that the structure needed modification to ensure passenger protection.

(2) The seat structure was modified through orthogonal experiment design and the best optimization option was $A_4B_2C_2$.

(3) It was indicated that the optimized structure can improve passenger protection. Chest compression reduced 17.21%, 3ms resultant acceleration reduced 21.16%, dummy neck F_X decreased 15.44%, M_Z value decreased 3.13%, and backrest angle decreased 46.1%.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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REFERENCES

[1] China Communications and Transportation Association. Chinese Transportation Yearbook. People's Communications Press: Beijing, China, 2012, pp. 83-115.

[2] H. Chen, "Structural design and finite element simulation of automobile driver seat", M.S. thesis, Northeastern University, Shenyang, China, 2010.

[3] Q.H. Li, J.P. Li, and S.H. Li, "Finite element analysis and test study about sled impact test of automobile seat", *Automobile Technology*, vol. 5, pp. 30-34, 2007.

[4] J.X. Jin, "Research on headrest and wield stripes performance and improvement of a car seat", M.S. thesis, Jilin University, Changchun, China, 2011.

[5] H.Y. Yang, "Prevent and stripes for the optimization design of the safety seat research", M.S. thesis, Hunan University, Changsha, China, 2012.

[6] N. Bourdet and R. Willinger, "Human body-car seat coupling under rear impact", In: Infats Proceedings of the, International Forum of Automotive Traffic Safety, 2005.

[7] M. Sawada, and J. Hasegawa, "Development of New Whiplash Prevention Seat", In: 19th International Technical Conference on the Enhanced Safety of Vehicles, 2005.

[8] J. Chen, "The research of passenger's injury and improvement during the rear-end collision", M.S. thesis, Wuhan University of Science and Technology, Wuhan, China, 2013.

[9] H.B. Wang, "Analysis of strength and stiffness for automotive seat on front crash", M.S. thesis, Hunan University, Changsha, China, 2012

[10] D.F. Wang, "A study on the impact safety of commercial vehicle cab and its improvement", *Automotive Engineering*, vol.1, pp. 34-36, 2011.

[11] H.Q. Long, J.H. Chen, and Y.X. Wu, "Application of CAE in development of automotive seat frame", *Computer Aided Engineering*, vol. 20, pp. 112-115, 2011.

[12] M.K. Shin, and K.J. Park, "Occupant analysis and seat design to reduce neck injury from rear end impact", *International Journal of Crashworthiness*, vol. 8, pp. 573-581, 2003.

[13] D.J. Chen, D.C. Fu, and H.H. Wang, "Lightweight design of car seats", *Mechanical Science and Technology for Aerospace Engineering*, vol. 30, pp. 26-32, 2011.

[14] L.J. Hu, "Study on automobile side impact and safety for the occupant protection", M.S. thesis, Liaoning Institution of Technology, Jinzhou, China, 2007.

[15] H.N. Chen, H. Chen, and L.J. Wang, "Analysis of vehicle seat and research on structure optimization in front and rear impact", *World Journal of Engineering & Technology*, vol. 2, pp. 78-85, 2014.

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