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Vehicle Front Structure Energy Absorbing Optimization in Frontal Impact

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Abstract: Energy absorption performance is one of the most important indexes in the vehicle safety during impact. Research on the car frontal structure energy performance and structure optimization was conducted in this paper. Whole vehicle model was established by HyperMesh and simulated in LS-DYNA. Simulation results indicated that modification was needed for the original structure to meet the industry requirements. Based on simplified whole vehicle model, orthogonal design optimization was implemented, including bumper cross beam material (A), bumper cross beam thickness (B), energy absorber groove distance (C), and front longitudinal beam groove number (D), with 3 levels for each factor. The best option was B3D1A3C3 which was gained by using range analysis and integrated balance method. Simulation results showed that both front and total energy absorptions were improved. The optimized structure increased front energy absorption to 51.1%, which can meet the industry requirement.

Keywords: Energy absorbing, Front structure, Optimization, Orthogonal design, Model establishment, Model verification.

1. INTRODUCTION

In the field of automotive engineering, safety, energy conservation, environmental protection is considered to be the three main themes for the future of automotive industry development. With the increase of vehicle volume, more and more attention has been put on traffic safety, and the vehicle collision accidents are inevitable in the current scientific level. Furthermore, with the increasingly fierce competition in the national automobile makers, traffic safety has become a focus for many research institutes [1, 2].

Among the crash patterns, frontal impact is the most common one, which accounts for about 40% of all crash accidents [3]. Most of the automobile frames are nowadays commonly designed with thin-walled structure, which can absorb energy through deformation in the collision process. In frontal impact, the front portion of car body is the main energy absorbing area. The more the energy is absorbed, the safer the occupant is. The main energy absorbing parts are the thin-wall parts, bumper, frontal longitudinal beam, engine hood and so on [4-6].

Research on the front structure and energy absorption performance during impact was focused on using precision model and algorithm. Zhang *et al*. (2007) [7] presented a new genetic algorithm based on stepwise regression method for multi-objective optimization for car crash. Wang *et al*. (2010) [8] studied the effect of material strain rate on vehicle acceleration and energy absorption. Cheng *et al*. (2011) [9] optimized front bumper to improve energy absorption performance of passenger car. Zhou *et al*. (2009) [10] conducted orthogonal optimization on front portion part thickness for energy absorption improvement. Wang *et al*. (2013) [11] studied the effect of thin-walled straight beam structure on the energy absorption performance by using FE method.

Energy absorption performance is one of the most important indexes in the vehicle safety during impact. Research on the car frontal structure energy performance and structure optimization was conducted in this paper, by HyperMesh and LS-DYNA software. And orthogonal design optimization was implemented to determine best structure for high performance on energy absorption.

2. MODELS

2.1. Model Establishment

The body CAD model was established by CATIA software. The CAD model was transferred into HyperMesh software for geometry healing and meshing. The final whole vehicle model was shown in Fig. (**1**). The car consists of 666 parts. The total mass was 1580 kg. The total element was 908702 with 870742 nodes.

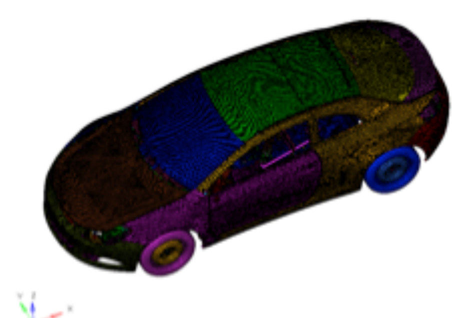

Fig. (1). Whole vehicle model.

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2.2. Model Verification

According to CNCAP regulation [12], vehicle initial X direction velocity should be 50 km/h for 100% frontal impact with rigid wall. The impact time was 80 ms. Impact simulation was conducted in LS-DYNA.

The energy curve during impact was shown in Fig. (**2**). The total energy curve was constant, which was consistent with the law of energy conservation. The hourglass energy accounted for to 2.94% of the total energy, which was lower than the industry rated value of 3.0%. It was indicated that the simulation result was valid for impact analysis.

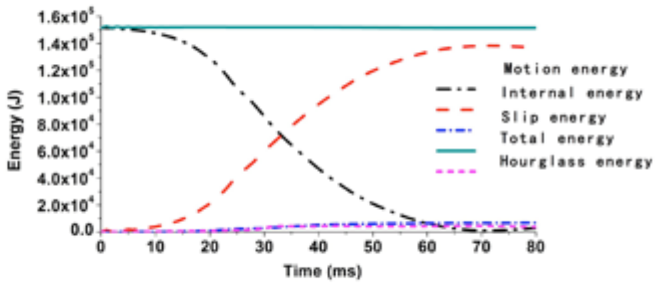

Fig. (2). Energy curve during impact.

3. ENERGY ABSORPTION PERFORMANCE

To understand the energy absorption feature, the whole vehicle model was simulated for 100% frontal impact. Table **1** shows the energy absorption for parts in the front portion of car. The energy absorption was concentrated in the front portion. Bumper cross member, energy absorption box, longitudinal beam, and sub-frame assemble were the main energy absorbing parts, which accounted for 49.78% of the total vehicle energy absorption. This value was lower than the regulation requirement of 50% [13]. Thus, modification should be done in the frontal portion to improve energy absorption performance, and to enhance cab safety.

Table 1. Energy absorption in the whole vehicle model.

Part	Energy/J	Percent/%
Bumper cover	6407.4	4.63%
Radiator	3915.4	2.83%
Bumper cross beam	7227.62	5.23%
Energy absorber	8782.24	6.35%
Front longitudinal beam	25508.3	18.45%
Hood	5031.18	3.64%
Front wall	3467.41	2.51%
Fender	660.75	0.48%
Power train	16.01	0.01%
Sub-frame	27307.96	19.75%
Guard plate	1433.97	1.04%
Door	164.64	0.12%
Floor	7589.47	5.49%
Steering system	2394.560	1.73%

B column Acceleration was another effective parameter to evaluate vehicle deceleration during impact. The B column acceleration was shown in Fig. (**3**). Imaginary line represent left side, and dot-dash line represent right side. The full line was the equivalent dual-trapezoids curve. The deceleration curve was relatively smooth, with maximum value of 34.2 g, which can be further reduced.

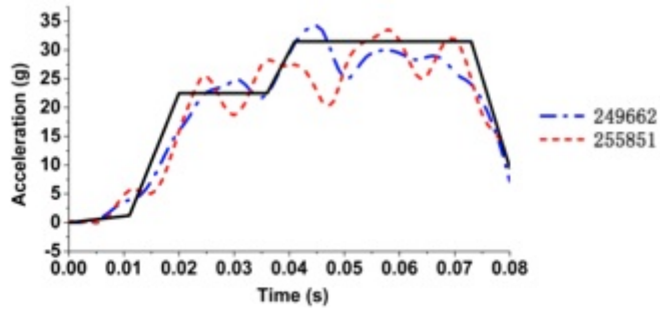

Fig. (3). B column acceleration during impact.

4. FRONTAL STRUCTURE ORTHOGONAL OPTIMIZATION

4.1. Model simplifying

During orthogonal design, enormous calculation should be done if using whole vehicle model. To improve simulation efficiency, the simplified model was used.

During impact, the front portion was the main energy absorbing area, accounting for more than 85% (Table **1**). Little deformation was observed after B column. The structure after column B can be replaced by using mass point, which was connected with side wall and floor with rbe2 rigid element. The mass point shared the same coordinates with the original model. The simplified model is shown in Fig. (**4**).

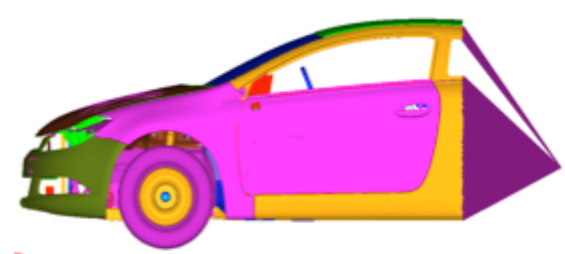

Fig. (4). Simplified vehicle model.

The simplified model was analyzed to verify its validation. Figs. (**5**, **6**) show the total energy and B column acceleration curve compared with original whole vehicle model.

The simplified model had almost the same amount of energy absorption (134786 J), i.e. only 1.6% lower than the original model. The same trend was observed in B column acceleration. The differences of maximum value between simplified and original models were lower than 3%. Thus, the mass element can be used to represent the non-deformation area, to conduct high efficiency impact analysis.

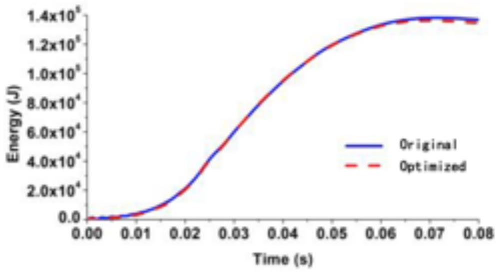

Fig. (5). Energy curve for original and simplified models.

4.2. Orthogonal Optimization

The main optimizing target was to increase front portion energy absorption, and reduce B column acceleration peak value. Thus, four factors were included, which are bumper cross beam material (yield strength (SIGY)), bumper cross beam thickness (inner and outer), energy absorber groove distance, and front longitudinal beam groove number. Each factor had 3 levels, shown in Table **2**.

Table 2. Orthogonal design factors and levels.

Factor		Level 1	Level 2	Level 3
A	SIGY /MPa	240	358	587
B	Thickness/mm	1.0/1.5	1.2/1.8	2.0/2.5
C	Groove distance/mm	0	25	45
D	Groove number	1	2	3

The orthogonal experiment table is shown in Table **3**. For different combination, front energy absorption and B column acceleration peak value was used for impact simulation analysis.

To determine the best option, range analysis was used. Mean value K and range value R were calculated, as shown in Tables **4** and **5**.

For energy absorption, the factor sequence from high to low were thickness (B), groove number (D), SIGY (A) and groove distance (D). Factor B and D had higher effect. Energy absorption increased with A and B, and decreased with D. Thus, the best option for energy absorption was B3D1A3C2.

Table 3. $L_9(3^4)$ orthogonal design and results.

Experiment	Front Energy Absorption (J)	B Column Acceleration Peak Value (g)
A1B1C1D1	66980.39	33.2317
A1B2C2D2	67198.70	32.0527
A1B3C3D3	67692.48	31.532
A2B1C3D1	66877.18	33.9209
A2B2C3D1	68316.26	32.5389
A2B3C1D2	68820.89	31.5258
A3B1C3D2	66878.51	31.3263
A3B2C1D3	66687.63	31.7574
A3B3C2D1	70665.78	33.128

For B column acceleration peak value, the sequence was D-C-B-A. And the best option was D2C3B3A3.

As a multi-objective optimization, integrated balance method was used for the final optimization choice. As the main target was energy absorption, the factor sequence should be B-D-A-C. Based on the value and range, the optimization option was B3D1A3C3.

4.3. Performance of Optimized Structure on Energy Absorption

Modification was done according to the best option B3D1A3C3. Then, simulation was conducted in LS-DYNA, to compare its performance with original model, as shown in Table **6**.

Compared with original model, optimized structure increased front portion energy (2.97%) and total energy absorption (2.84%), without significant difference. The front energy absorption percentage was increased to 51.1%, which can meet the industry requirement. It was illustrated that the optimization was effective.

B column acceleration fluctuation range was reduced, as shown in Fig. (**7**). And the peak value time was move backwards, and the value reduced by 10.1%, which illustrated the improved performance on acceleration response during impact.

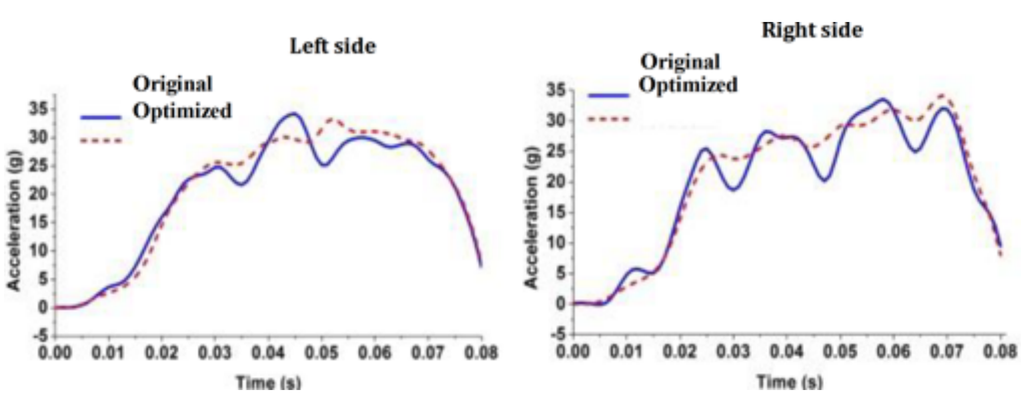

Fig. (6). B column acceleration for original and simplified models.

Table 4. Energy absorption value and range.

Level	A	B	C	D
K_1	67290.5	66912.0	67496.3	68654.1
K_2	68004.8	67400.9	68247.2	67632.7
K_3	68077.3	69059.7	67629.1	67085.8
R	786.79	2147.69	750.92	1568.38

Table 5. B column acceleration peak value and range.

Level	A	B	C	D
K_1	32.27	32.83	32.17	32.97
K_2	32.66	32.12	33.03	31.63
K_3	32.07	32.06	31.80	32.40
R	0.59	0.76	1.23	1.33

Table 6. Energy absorption before and after optimizing.

	Front /J	Total/J	Percent/%
Original	68826.12	138260	49.8
Optimized	70871.73	138653	51.1

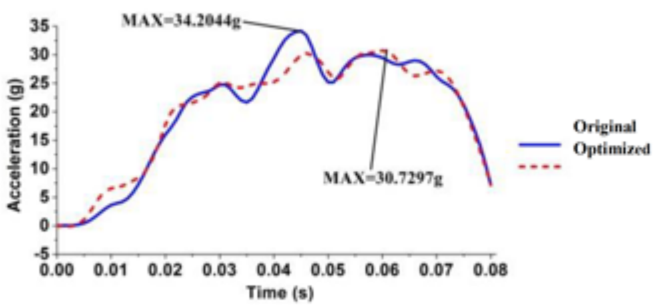

Fig. (7). B column acceleration for original and optimized models.

CONCLUSION

In this paper, the vehicle front structure energy absorption performance was studied, and orthogonal optimization was implemented to improve structure energy absorbing.

Simulation results indicated that modification was needed for the original structure to meet the industry requirements. Based on simplified whole vehicle model, orthogonal design optimization was implemented, including bumper cross beam material (A), bumper cross beam thickness (B), energy absorber groove distance (C), and front longitudinal beam groove number (D). The best option was B3D1A3C3 which was gained by using range analysis and integrated balance method. Simulation results showed that both front and total energy absorptions were improved. The optimized structure increased front energy absorption by to 51.1%, which can meet the industry requirement.

CONFLICT OF INTEREST

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

ACKNOWLEDGEMENTS

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