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Parameter Optimization of Child Restraint System Based on Orthogonal Experiment

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Abstract:

Background: According to the World Health Organization statistics, the traffic safety problem of the child occupant has gradually got the attention, the Child Restraint System provides the most direct protection for the children, so it’s design parameters have important effect on the safety of the children.

Objective: This paper is aimed to study the influence of the child restraint system’s (CRS) design parameters on the child occupant injury.

Method and Material: A frontal crash simulation model with an ISOFIX CRS was established under ECE R129 regulation, and the simulation results were verified with sled test. The influences of the friction coefficient between children’s safety belt and child dummy, the stiffness of children’s safety belt, the location of shoulder strap of children’s safety belt and the friction between child seat and car seat on injury parameters, such as head injury criterion (HIC15) values and chest resultant acceleration, were analyzed by using orthogonal experimental design.

Results: The hole position of seat belt shoulder strap has greatest effect on the WIC value and head displacement in X direction, it makes WIC value reduced by 7.2% compared with the original scheme, and the head displacement reduced by 1.4%.

Conclusions: The finite element method was adopted to analyze the influence of design parameters on the safety of children, geting the optimal scheme to reduce the injury parameters the children in a crash accident, and provide an important reference of the research and design in a further study.

Keywords: Design Parameter, ECE R129, Orthogonal Experiment

1 Introduction

Child occupant safety has become a hot spot of domestic and foreign researchers. Zeng Qingguo et al of South China University of Technology use the orthogonal method to optimize the parameters of CRS and get reliable and comprehensive evaluation [1]. Sherwood et al. [2] set up the parameters and level of the CRS, and found that the stiffness of the children's safety belt has the greatest impact on the children's injury.

In this paper, Q3 dummy FE model was used to develop the front sled test FE simulations with an ISOFIX CRS based on ECE R129 regulation, and passed test verification, at the same time, the influence of the CRS’S design parameters on the response of children in crash is analyzed using orthogonal experimental design.

2 Simulation Model of CRS in Frontal Impact

2.1 Establishment of simulation model

The prototype of the domestic seat in this paper is a ISOFIX CRS which passed the ECE R44 regulation, adapted to 1-8 years old children. The CRS is modeled with reverse engineering method, and being meshed in the finite element pre-processing software-Hypermesh, the grid number is 37286, the number of nodes is 35506. This paper established the frontal crash simulation model with the ISOFIX forward facing CRS under ECE R129 regulation, including Q3 dummy FE model, FE model of child seat, ECE test seat. Q3 dummy FE model is developed by the International child dummy working group in 1993, and the head, chest and lumber were conducted a series of calibration test [3]. Sharafat pointed out that Q3 dummy has more biologically reality, durability and repeatability compared to P3 dummy [4], so Q3 dummy can be used in front impact and side impact sled test as “multi direction” child dummy.

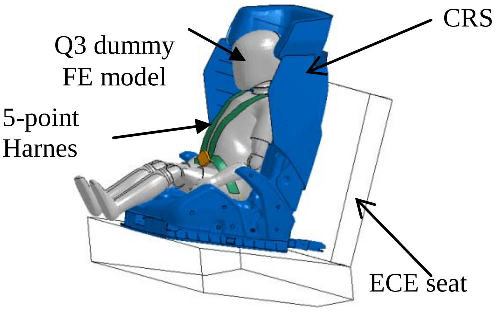


Figure1 Simulation model of CRS in frontal crash

The plastic material properties of child seat is tested by microcomputer control electronic universal testing machine and displacement extensometer, Figure 2 and figure 3 are the CRS'S material curve and the frontal sled acceleration of ECE R129 regulation.

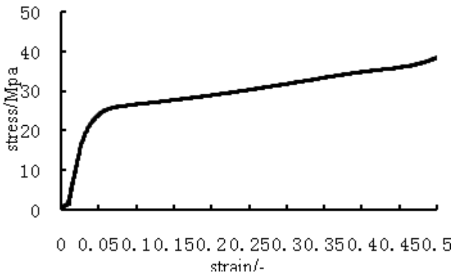


Figure 2 PP stress-strain curve

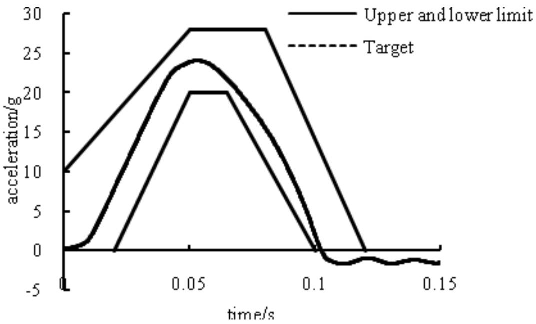
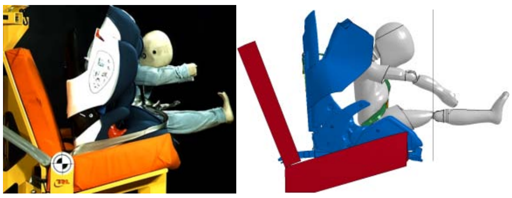


Figure 3 Frontal sled acceleration of ECE R129 regulation

2.2 Verification of simulation model

The validity of the simulation model of CRS is verified by comparing with the test results of the sled impact test, including the kinematic response and the damage parameter values of the child occupant. Figure 4 is dummy's dynamic actions at different time in the test and simulation, the figure can be seen that the dummy's dynamic actions in simulation is basically the same as test, at 120ms, the bending angle of head in test is larger than simulation, and the entire face almost contacts to the abdomen.



90ms

120ms

Figure 4 Dummy's dynamic actions in the test and simulation

Figure 5 and figure 6 are the comparison of chest resultant acceleration curve and chest vertical acceleration curve between simulation and sled test, Simulation and sled test curve are quite close in the pulse width, shape trend and peak range, the deviation of peak value are both within 5%, so it can be considered that the FE model is accurate, the prediction of chest acceleration response basically meets the requirements.

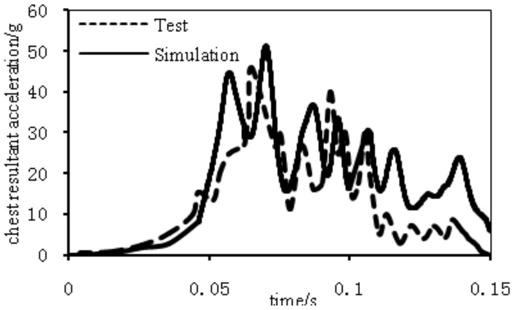


Figure 5 Chest resultant acceleration

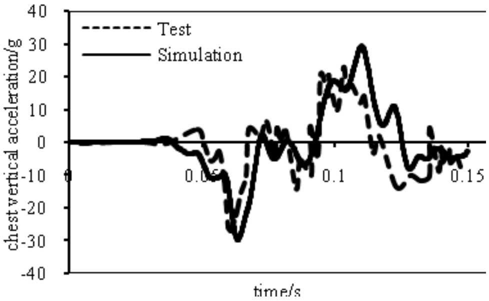


Figure 6 Chest vertical acceleration

The damage index value of the head's maximum displacement in X direction, chest resultant acceleration and chest vertical acceleration are shown in table 1 below, the results of test and simulation are also shown in the same table. The simulation and test results are close to each other and the damage value of results are all less than the index value.

Table 1 Damage value of simulation and test

	Head's maximum displacement in X direction /mm	Chest resultant acceleration (3ms)/g	Chest vertical acceleration (3ms)/g
index value	550	55	30
test	549	43.7	23.8
simulation	543	48.3	27

3 orthogonal experiment design

Orthogonal experiment design is one of the common methods in many experimental design methods, it is the method of designing the multifactor optimization.

This paper employs orthogonal experiment design method to make a orthogonal table L9(34) with four factors and three levels for the friction between seat belt and dummy (level:0.2~0.8), seat belt stiffness (level:0.5~2), the hole position of seat belt shoulder strap (level: upper hole~ lower hole) and the friction between child seat and ECE seat cushion (level:0.2~0.8), as is shown in table 2.

Table 2 Factor and level table

Factor	level1	level2	level3
A the friction between seat belt and dummy	0.2	0.5	0.8
B seat belt stiffness	0.5	1	2
C the hole position of seat belt shoulder strap	upper hole	middle hole	lower hole
D the friction between child seat and ECE seat cushion	0.2	0.5	0.8

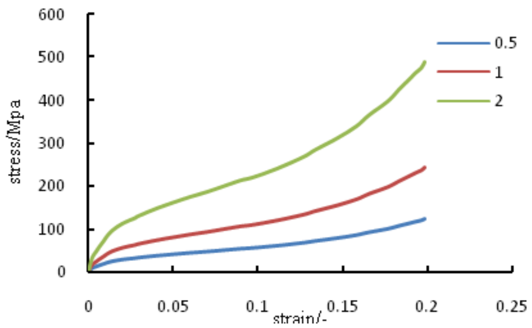


Figure 7 seat belt stress-strain curve

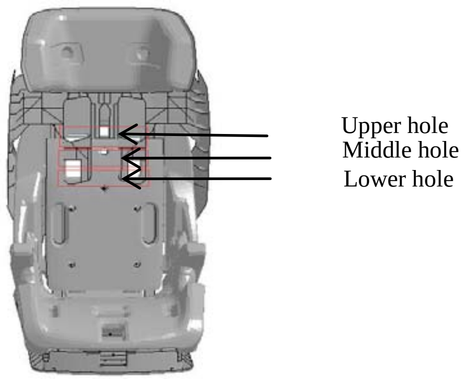


Figure 8 Hole position of seat belt shoulder strap

In front collision accident, child occupant's injury part relates to head, chest, neck, and so on, in Europe, the newest child restraint system regulation ECE R129 explicitly selects head and chest as the evaluation index, so in this paper, according to the WIC which represents positive impact damage assessment [5], the head and chest injury index(head injury criterion HIC15、head resultant acceleration aH and chest resultant acceleration aT) is regularization weighted. The smaller the WIC value, the better protect performance of the CRS.

$$\mathrm{WIC} = 0.35\left(\frac{\mathrm{HIC}_{15}}{1000}\right) + 0.35\left(\frac{a_H}{705.6g}\right) + 0.3\left(\frac{a_T}{588g}\right) \qquad (1)$$

In formula（1），$HIC_{15} \le 570$, $a_H \le 60g$，$a_T \le 55g$。

The comprehensive test needs to be carried out 34=81 test, and orthogonal table L9(34) requires for nine tests, the specific test combination is shown in table 3.

Table 3 Orthogonal experiment design table

Test No.	Factor				HIC15	aH/g	aT/g	DH,X/ mm	I
Item	A	B	C	D					
1	1	1	1	1	313	57	47	552	0.162
2	1	2	2	2	302	55.2	50	548	0.159
3	1	3	3	3	365	59	60	553	0.188
4	2	1	2	3	280	54.6	49.5	547	0.150
5	2	2	3	1	352	58	57	549	0.181
6	2	3	1	2	345	58	55	541	0.178
7	3	1	3	2	286	59.9	54.8	585	0.158
8	3	2	1	3	339.6	58	49	541	0.173
9	3	3	2	1	288	54.2	49.3	535	0.153
original	1	2	1	1	322	56	48.3	543	0.165

After nine times of simulation, the head displacement in X direction and comprehensive damage index WIC are obtained, it can be seen that the WIC value of test 4 is smallest, test 9 is second, but the head displacement of test 9 is smallest, so it is necessary to carry out sensitivity analysis. The WIC value of 4 is reduced by 2%

compared with the WIC value of teat 9, the head displacement of test 4 is 2.2% higher than that of test 9. Therefore, the optimal scheme is test 9, the A3B3C2D1 scheme is the best, the corresponding parameters selects the friction between seat belt and dummy as 0.8, seat belt stiffness as 2, the hole position of seat belt shoulder strap as middle hole, the friction between child seat and ECE seat cushion as 0.2.

Form the effect curve shown in figure 9, we can have a more intuitive understanding of the impact of each factor on the test results, factors C and D have minimum values in the second level, factor A has minimum value in the third level, with the increasing of factor B, the WIC value is also increasing. From the graph below, we can see that the influence of factor C on WIC value and head displacement in X direction is the biggest, and the influence of factor B on head displacement in X direction is the second, the other factors are relatively smaller.

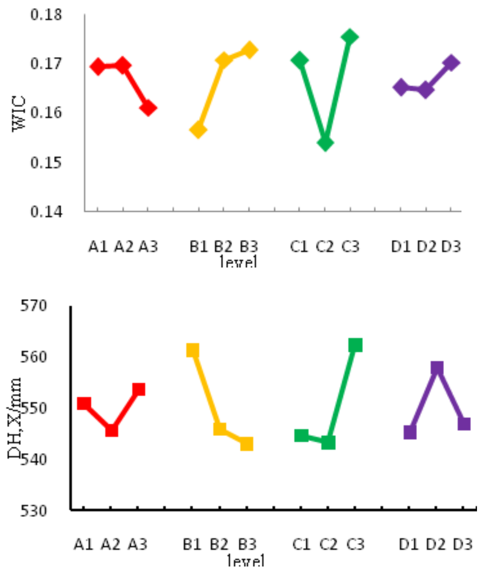


Figure 9 effect curve

4 Discussion

Each design parameter has its own range of values, there is interaction effect between these parameters, and the whole system has strong noise and nonlinear, the objective function is time consuming and large amount of calculation, in order to quickly and effectively carry out the optimization design for the protection of CRS, in this chapter, we take the interaction effect among the factors and noise and nonlinear of system into consideration, applying orthogonal experiment design method to analyze the all factors.

5 Conclusion

1) The hole position of seat belt shoulder strap and seat belt stiffness have great effect on the WIC value and head displacement in X direction.

2) The hole position of seat belt shoulder strap should be designed to parallel to the children’s shoulder to reduce the head maximum displacement in X direction.

3) Orthogonal experiment design method can be used for safety evaluation of CRS. The dummy’s damage value (head HIC15 value, chest resultant acceleration and chest vertical acceleration) of optimized design scheme are lower than regulation limit, and the WIC value is better than original scheme. In this paper, the optimization method of the CRS has important reference value for the protection of children.

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