A Study of Restraint System Optimisation for Child Dummy Injuries in Offset Frontal Crash Test

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I. INTRODUCTION

In the last several decades, advancements in occupant protection in motor vehicles have been made not only for adults, but also for children. As one measure to help improve the safety of child occupants, in 1981 the EU enacted ECE R44 to specify safety criteria for child seats. The European New Car Assessment Program (Euro NCAP) began assessing child occupant protection performance from 2003. With the introduction of several new child dummies, Euro NCAP and the Korean New Car Assessment Program (KNCAP) have also announced plans to adopt the six-year-old Q6 dummy and the ten-year-old Q10 dummy from 2016 and 2017 respectively [1-2]. In this paper, we focus on the injury potential of Q6 and Q10 child dummies in 64 kph, 40% offset frontal crash test of a small passenger vehicle. The whole procedure is designed with Design for Six Sigma (DFSS) analysis. Sled testing of both dummies was conducted with different restraint systems settled by control factors of DFSS. Dummy injury values were evaluated as a result of sled tests. This paper describes the important factors and combination of these factors for optimised performance in terms of Q6 and Q10 dummy injury values through DFSS case study by sled tests.

II. METHOD

By using DFSS analysis method, four control factors that can affect Q6 and Q10 dummy injury values were set to Child Restraint System (CRS), Seatbelt Retractor Pretensioner (RPT), Belt position and Dynamic Locking Tongue (DLT), as shown in Table I.

TABLE I
CONTROL FACTORS

Level	Control factors			
	CRS	Seatbelt RPT	Belt position	DLT
Level 1	A	4kN+1kN(DLL)	Lower	Yes
Level 2	B	5.5kN(CLL)	Mid	No
Level 3	C	Non RPT	Upper	

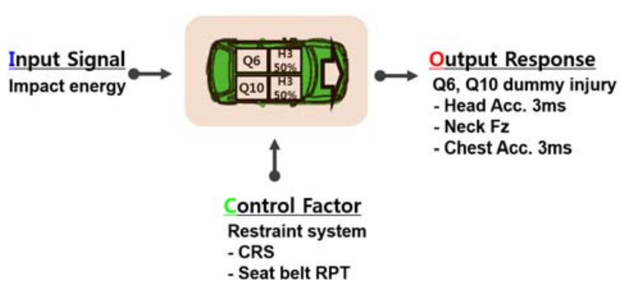

Fig. 1. P-Diagram.

The CRS selected includes three popular CRS models which have ISOFIX attachments to fix CRS to the ISOFIX anchorages in the rear seat of the vehicle, and adjustable head-rests supporting the shoulder-belt. Variations of seatbelt RPT are Non-RPT, 4kN+1kN Digressive load limiter (DLL) and 5.5kN Constant load limiter (CLL), in order to compare injury values applied to these restraint systems. Shoulder-belt position was adjusted by the position of CRS's head-rest, which was set mid-head-rest position as recommended by the manufacturer of the CRS. Lower and upper shoulder-belt position were defined as 20 mm lower and 20 mm higher than mid–head–rest height. Fig. 1 shows the P-Diagram, which is a schematic diagram that encompasses signal factor, control factor and response variable. Three injury values – 3ms Head acceleration, 3ms Chest acceleration and Axial Neck Force (Fz) – were evaluated in this study.

III. INITIAL FINDINGS

The sled test pulse used in this study was well correlated with a 64 kph, 40% offset frontal impact vehicle test pulse within 10% in peak acceleration. Table II shows the injury values (normalised to the baseline condition) from the sled test results, conducted in accordance with L9 orthogonal array, which is an experimental design proposed by Taguchi and composed by using the combination of control factors in Table I. These nine tests in Table II represent 54 tests. As a result of the 'Analysis Variance', the 'Contribution Rate' in each factor shows the influence of the restraint system variables on the dummy injury values (Table III). CRS model and seatbelt RPT variables made a significant contribution to dummy injury values, while shoulder-belt position and DLT did not have a significant effect on the injury values.

TABLE II
TEST MATRIX (L9) AND RESULT

No.	Control factor				Injury					
	CRS	Seat belt RPT	Belt Position	DLT	Head acc. 3ms		Chest acc. 3ms		Neck Fz	
					Q6	Q10	Q6	Q10	Q6	Q10
Baseline	3	3	2	2	1.00	1.00	1.00	1.00	1.00	1.00
1	1	3	1	1	1.09	1.17	0.92	1.07	1.09	1.17
2	1	1	2	2	0.77	0.81	0.76	0.72	0.77	0.81
3	1	2	3	2	0.82	0.83	0.81	0.78	0.82	0.83
4	2	3	3	2	1.10	1.16	0.87	1.05	1.10	1.16
5	2	1	1	2	0.88	0.92	0.79	0.81	0.88	0.92
6	2	2	2	1	0.92	1.05	0.83	0.93	0.92	1.05
7	3	3	2	2	1.00	1.00	1.00	1.00	1.00	1.00
8	3	1	3	1	0.80	0.84	0.77	0.57	0.80	0.84
9	3	2	1	2	0.80	0.85	0.78	0.75	0.80	0.85
Best Q6/10	3/3	1/1	3/3	1/2	0.77	0.57	0.82	0.47	0.80	0.78
Validation	3/3	1/1	3/3	1/2	0.75	0.58	0.81	0.43	0.77	0.70

TABLE III
CONTRIBUTION RATE FOR Q6 AND Q10

Output response	Control factor	Contribution (%)	
		Q6	Q10
Head Resultant Acc.3ms	CRS	15	15
	Seatbelt RPT	82	82
	Belt position	0	1
	DLT	3	2
Neck Fz	CRS	30	27
	Seatbelt RPT	28	65
	Belt position	23	1
	DLT	19	7
Chest Resultant Acc. 3ms	CRS	8	30
	Seatbelt RPT	88	69
	Belt position	4	1
	DLT	0	0

Fig. 2, below, shows the 'Main Effect Plots', which display injury variation in accordance with level of control factor. The best overall performance achieved with the Q6 dummy was a case that was evaluated in sled test with CRS C, 4.0kN+1.0kN DLL seatbelt, shoulder upper belt position and non-DLT. This same restraint combination, with DLT, produced the best performance achieved with the Q10 dummy.

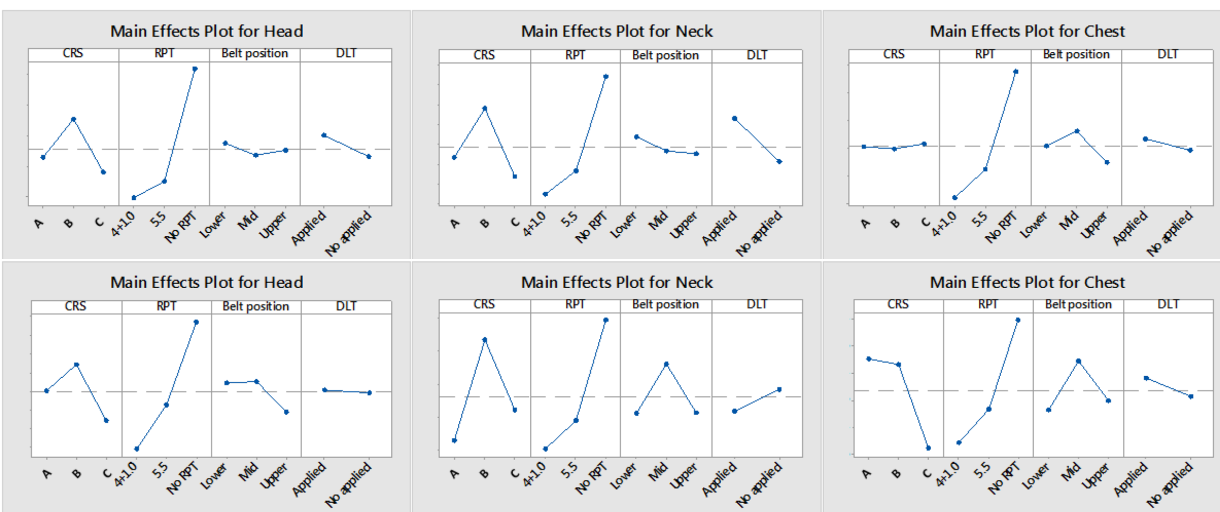

Fig. 2 Main Effect Plots of Q6 and Q10 dummies using DFSS analysis method

IV. DISCUSSION

To improve Q6 and Q10 dummy injury values in a 64 kph, 40% offset frontal crash test of a small passenger vehicle, 10 sled tests were performed based on the DFSS analysis method in order to find the best combination of the restraint variables studied. Seatbelt RPT and CRS are dominant control factors to affect the performance of the Q6 and Q10 child dummies in the rear seat, as described in Table III and Fig. 2. The injury values with seatbelt RPT are not only improved compared to the case without seatbelt RPT, but the performance is also improved with a seatbelt-DLL type load limiter, rather than CLL type load limiter. Moreover, A and C CRS models evaluated had relatively better injury values than the CRS B. Consequentially, the best case for Q6 and Q10 child dummy injury values in Table II bottom line shows 22% improved injury values for Q6 and 43% improved injury values for Q10 as compared with the baseline condition. This was confirmed by a small size passenger vehicle validation test. This paper provides a design guideline to select a restraint system to improve Q6 and Q10 child dummy injury values in rear seat in the Euro NCAP and KNCAP 64 kph, 40% offset frontal crash test mode.

V. REFERENCES

[1] Euro NCAP, Child occupant protection v7.0, 2015.
[2] Korea Ministry of Land, Infrastructure and Transport, KNCAP Updated status, 2015.