DEVELOPMENT OF COMPUTER SIMULATION METHOD FOR SEAT OPTIMIZATION TO REDUCE NECK INJURY IN A LOW SPEED REAR IMPACT

Sung Chul Choi
Han Il Bae
Sung Jun Han
Si Yeol Kim
Hyundai Motor Co. & KIA Motors Corp
Korea
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ABSTRACT

Whiplash injuries caused by rear-end collisions have been issued by many researches or reports and car manufacturers has been trying to develop a seat to protect passengers from whiplash injuries. The main objective of this study is to present the computer simulation method for car seat optimization against whiplash injury. The study result assists designers to understand design parameters of a seat and active headrest(AHR) performance in relation to the rear-end collisions. Also, we examine how the dummy position (including the height) affects the injury indexes. The structural optimization is performed to obtain the optimal seat with AHR (Active Head Rest)by using the TNO BioRID-II dummy and MADYMO software[4].

INTRODUCTION

Many studies have been performed to protect or decrease the neck injury caused by rear-end collisions. Recently, there has been a movement that whiplash injuries due to rear-end collisions should be enforced more strictly by the law. The most of car makers have developed a seat with active head rest(AHR) to meet the requirements of the relevant laws. For this purpose, this study examined how the design parameters[1] of a seat affect the injury values, and optimize the design parameters to minimize neck injury in collision. Furthermore, we will study how the dummy position as a test variation affects the output such as contact time between head and headrest (HRCT), T1 acceleration, and neck injuries. Finally, we evaluate the influence of the seat cover material(cloth cover versus leather cover) on neck injury in collision.

DUMMY SETTING

According to IIHS Whiplash Sled Test Protocol, a dummy was placed at 20mm front and 50mm above from the H-point and the dummy is moved down [2] by 6mm below from the H-point.(Fig.1)[3] During the motion, the contact between the dummy and the seat must be defined. The seat cushion, seat back and frame will be deformed in compliance with the dummy motion. . To perform the whiplash simulation, the final coordinates of the nodes of seat structure model was recorded, in the last time step during computation.

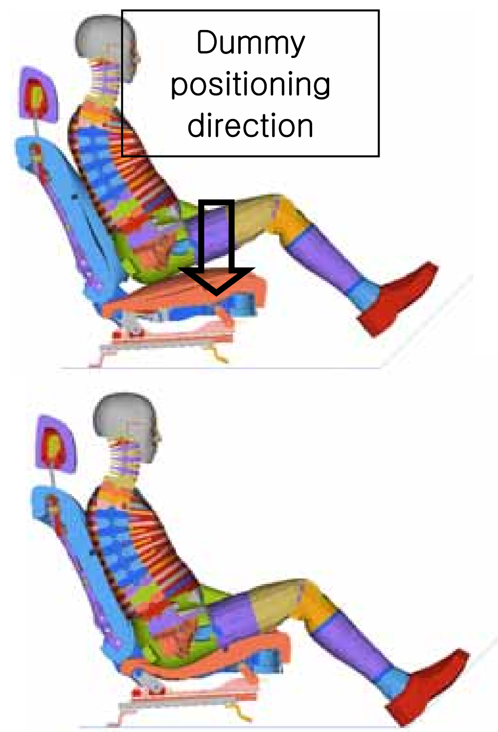


Fig.1 Dummy Setting

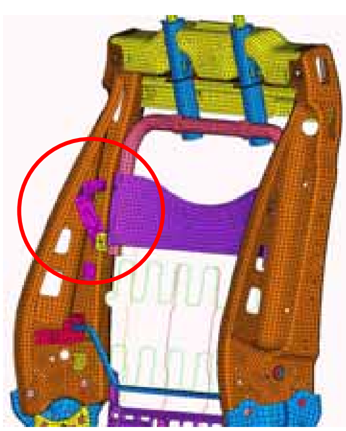
CONSTRUCTION OF THE MODEL

The overall composition information of the Rear Impact Simulation model(shown in Fig. 2) is summarized as the followings.[4]

1) Solver : MADYMO Ver. 6.2.2
2) BioRID-II Facet Dummy Model Ver. 1.2
3) FE Seat Model
   - Number of Node: 103000(approximately)
   - Number of Element: 140,000(Solid 70,000)
4) Time Step: 1E-07 (FE Time Step)
   Time End: (180msec)
5) Dummy to Seat Contact
   - FE.FE Contact
   - Surface to Surface
   - Master: Dummy Fe Group
   - Slave: Seat Fe Group
6) FE Seat to FE Seat Contact
   - FE.FE Contact
   - Surface to Surface
   - Master: Steel Part
   - Slave: Foam Part

Fig.2 Whiplash Simulation Model

To generate an active link mechanism, the body and joint are defined after constructing the multi-body(MB) system and then connecting the FE mesh with the body. Two MB systems are defined for modeling of the left and right link. Each MB system consists of three bodies, which are a free joint and two revolute joints.(Fig. 3) Some elements of FE mesh are supported to each body



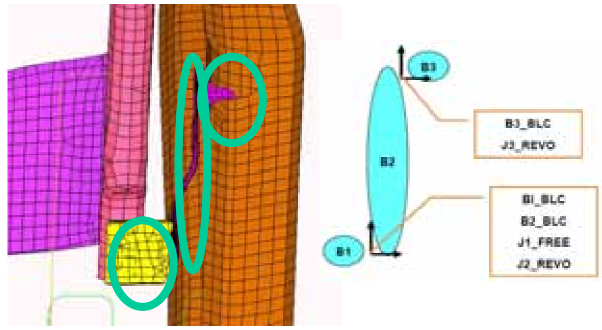


Fig. 3 Construction of the active headrest

The sled pulse proposed by the IIHS(Fig.4) is applied to the simulation and the seat performance is evaluated following the IIHS evaluation rules.

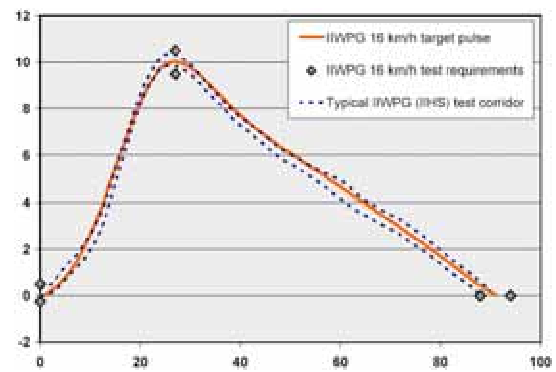
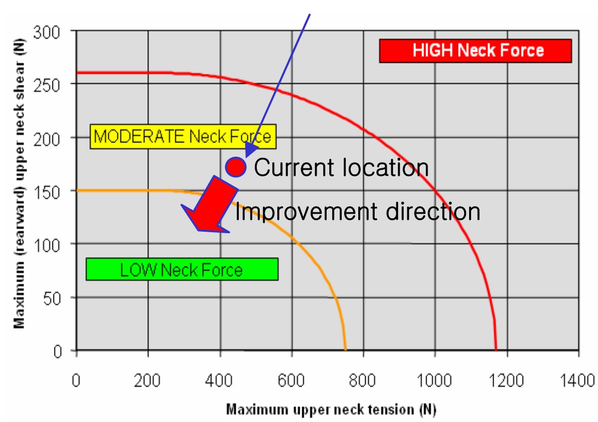


Fig. 3 Sled Pulse

BASE RUN RESULTS

	Seat Design Evaluation	
	HRCT (<70msec)	T1 Acc. (<9.5g)
Results	72msec	7.55g

	Neck Force		
	Fx(+) [N]	Fz(+) [N]	Level
Results	176.0	428.7	Moderate



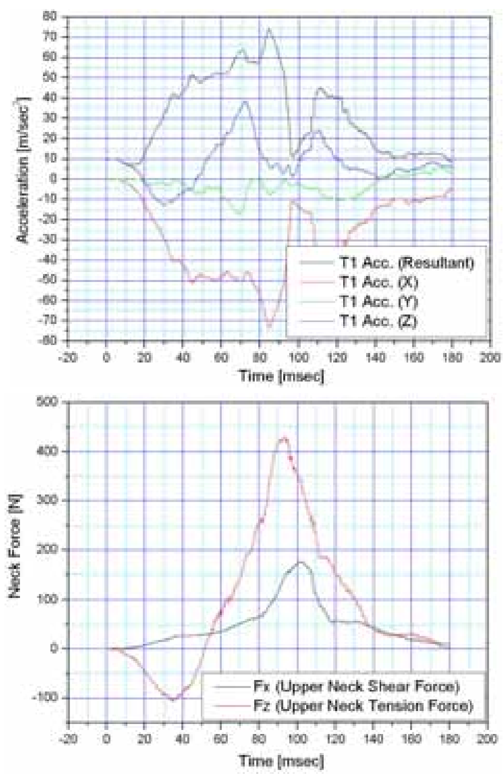


Fig. 4 Seat Dynamic evaluation result

The results of the base run are shown in Fig.4. Since the T1 acceleration is less than 9.5g(IIHS requirement), the current seat design meets the IIHS requirement, however the evaluation of neck injuries ranks moderate.

REVIEW OF THE PARAMETER TO IMPROVE

Table.1 Seat Design Variables

Variable	Variable Level		
Dummy Position(in Z-Axis)	A1	A2	
Thickness of Panel	B1	B2	B3
Head Rest Position	C1	C2	C3
Spring Constant of Active Head rest	D1	D2	D3
Height of Head Rest	E1	E2	E3
Stiffness of Head Rest Pole	F1	F2	F3
Direction of Active Head Rest Spring	G1	G2	G3
Stiffness of Seat Back Spring	H1	H2	H3
Dummy Position(in X-Axis) (Noise Factor)	N1	N2	

※ ◯ : Base Run

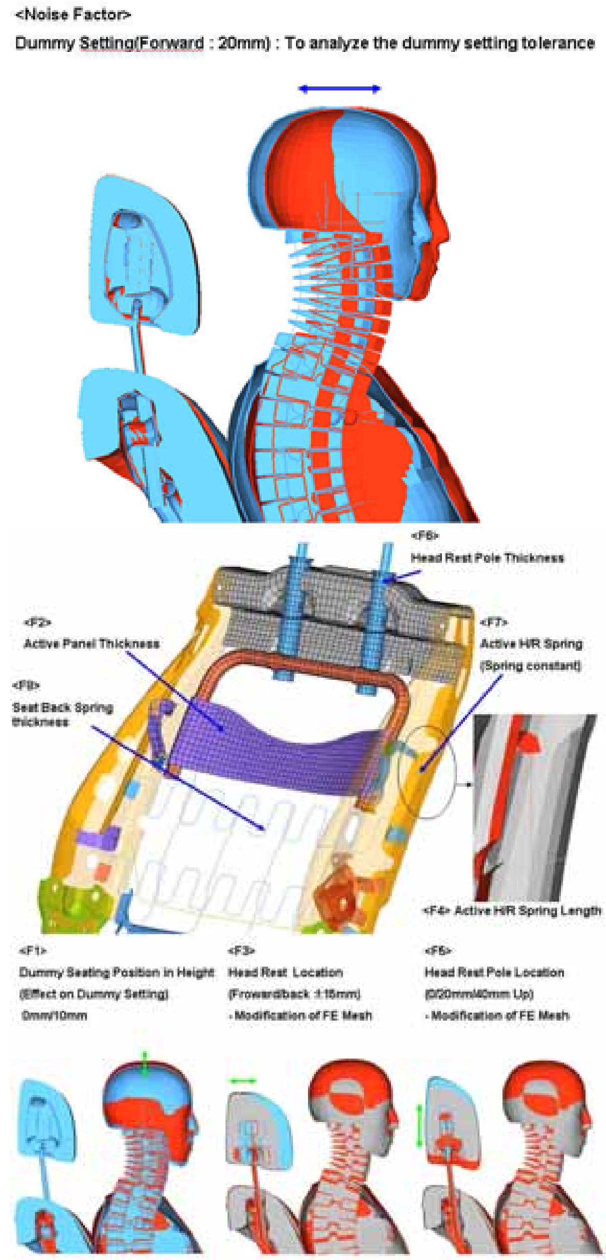


Fig. 4 Seat Design Variables

To improve the performance of a seat, the seat design variables are chosen as shown in Table.1. And the dummy position in X-Axis is selected as a noise factor. The reason for selecting the dummy position as noise factor is that the dummy position can be altered easily during test setup process, and by the seat material. An L18 Taguchi-style Design of Experiments (DOE) with eight factors is used to optimize the seat design to minimize neck injuries. Totally, 36 Runs are being conducted Results of T1 X Acc. Peak, HRCT (Head Restraint Contact Time), Upper Neck Force X Peak, Upper Neck Moment Y Peak will be analyzed to minimize each response. L18 Orthogonal Array[5] is shown in Table 2.

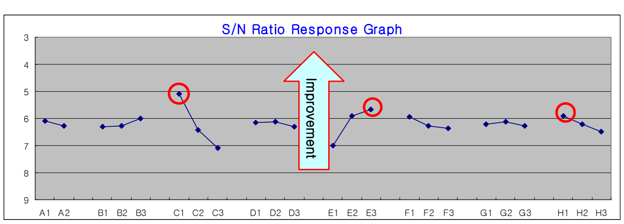
Table.2 Taguchi DOE Matrix

Noise 0	Dummy Position : Base							
	A	B	C	D	E	F	G	H
1	1	1	1	1	1	1	1	1
2	1	1	2	2	2	2	2	2
3	1	1	3	3	3	3	3	3
4	1	2	1	2	2	2	3	3
5	1	2	2	3	3	3	1	1
6	1	2	3	1	1	1	2	2
7	1	3	1	1	1	3	2	3
8	1	3	2	2	2	1	3	1
9	1	3	3	3	3	2	1	2
10	2	1	1	3	3	2	2	1
11	2	1	2	1	1	3	3	2
12	2	1	3	2	2	1	1	3
13	2	2	1	3	3	1	3	2
14	2	2	2	1	1	2	1	3
15	2	2	3	2	2	3	2	1
16	2	3	1	2	2	3	1	2
17	2	3	2	3	3	1	2	3
18	2	3	3	1	1	2	3	1

Noise 1	Dummy Position : Base + 20mm							
	A	B	C	D	E	F	G	H
1	1	1	1	1	1	1	1	1
2	1	1	2	2	2	2	2	2
3	1	1	3	3	3	3	3	3
4	1	2	1	2	2	2	3	3
5	1	2	2	3	3	3	1	1
6	1	2	3	1	1	1	2	2
7	1	3	1	1	1	3	2	3
8	1	3	2	2	2	1	3	1
9	1	3	3	3	3	2	1	2
10	2	1	1	3	3	2	2	1
11	2	1	2	1	1	3	3	2
12	2	1	3	2	2	1	1	3
13	2	2	1	3	3	1	3	2
14	2	2	2	1	1	2	1	3
15	2	2	3	2	2	3	2	1
16	2	3	1	2	2	3	1	2
17	2	3	2	3	3	1	2	3
18	2	3	3	1	1	2	3	1

The response analysis and S/N(Signal to Noise) analysis for each outputs are conducted according to the DOE matrix(shown in Table.2). It is desirable to minimize the dispersion of each output that S/N value is near in 0(zero) and it is good that the response value is low because it has smaller the better characteristics. Thus, the simulation will be performed to optimize the seat with those two objectives satisfied.

The results for HRCT(Head & Headrest Contact Time) is as follows. Of the variables tested, the headrest fore/after position(Factor 3) and the upper/ lower position of the headrest(Factor 5) as the geometry parameter had the greatest effect on HRCT(Head & HeadRest Contact Time) as shown in Figure 5.



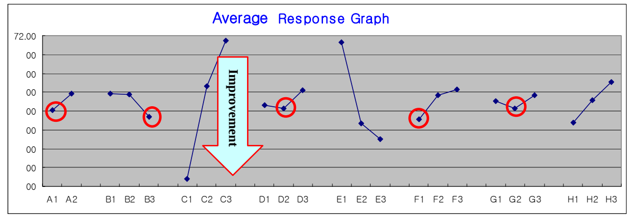


Fig. 5 Results for HRCT

The combination of the variables to minimize HRCT is shown in Table 3.

Table 3. Combination of the variables for HRCT

	A	B	C	D	E	F	G	H
Base	1	2	2	2	1	2	2	2
Opt.	1	3	1	2	3	1	2	1

The results for T1 acceleration is as follows.

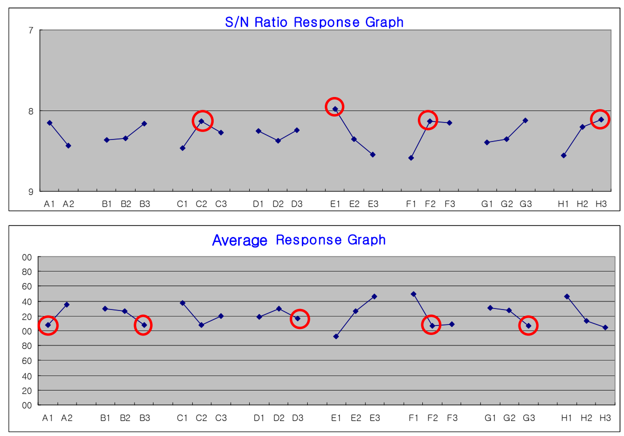


Fig. 6 Results for T1 Acceleration

Of the variables tested, the upper/ lower position of the headrest(Factor 5) as the geometry parameter and the stiffness of the seat back spring (Factor 8) had the greatest effect on T1 Acceleration as shown in Figure 6. The combination of the variables to minimize T1 Acceleration is in shown Table 4.

Table 4. Combination of the variables for T1 Acc.

	A	B	C	D	E	F	G	H
Base	1	2	2	2	1	2	2	2
Opt.	1	3	2	3	1	2	3	3

The results for neck shear are shown in Figure 7. Among the variables tested, the headrest fore/after position (Factor 3), the upper/ lower position of the headrest (Factor 5) as the geometry parameter and the stiffness of the head rest pole (Factor 6) had the greatest effect on neck shear.

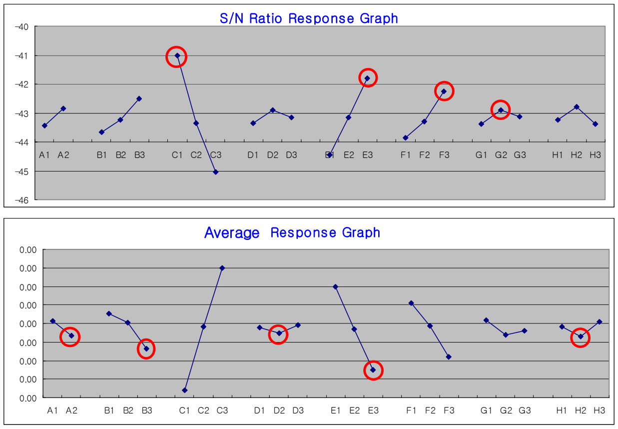


Fig. 7 Results for Neck Shear

The combination of the variables to minimize neck shear is in shown Table 5.

Table 5. Combination of the variables for neck shear

	A	B	C	D	E	F	G	H
Base	1	2	2	2	1	2	2	2
Opt.	2	3	1	2	3	3	2	2

The results for neck tension is shown in Figure 8. Of the variables tested, the headrest fore/after position (Factor 3), the upper/ lower position of the headrest (Factor 5) as the geometry parameter and the stiffness of the seat back spring (Factor 8) had the greatest effect on neck tension.

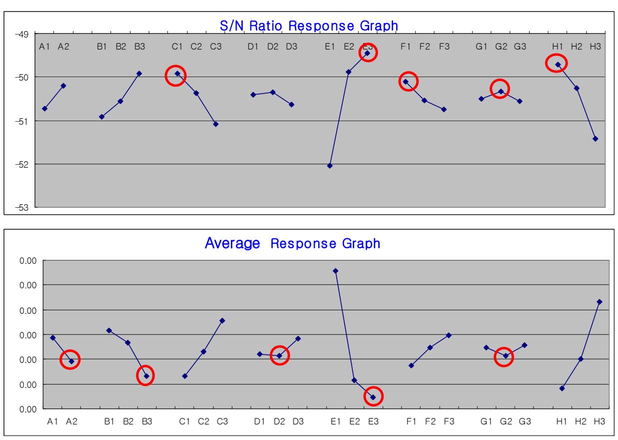


Fig. 8 Results for Neck Tension

The combination of the variables to minimize neck shear is shown in Table 6.

Table 6. Combination of the variables for neck tension

	A	B	C	D	E	F	G	H
Base	1	2	2	2	1	2	2	2
Opt.	2	3	1	2	3	1	2	1

The Simulation is performed for 4 combinations(to minimize each output) and the results are obtained as follows.

Factor (Target)	Contact Time (< 70msec)	T1 Acc. (< 9.5g)	Shear	Tension
Base	72msec	7.55g	176N	428.7N
Case 1 (Contact Time Opt.)	58msec	8.28g	140.1N	309.9N
Case 2 (T1 Opt.)	76msec	7.21g	149.4N	454.86N
Case 3 (Shear Opt.)	52msec	8.94g	111.7N	307.6N
Case 4 (Tension Opt.)	51msec	8.19g	128.0N	326.0N

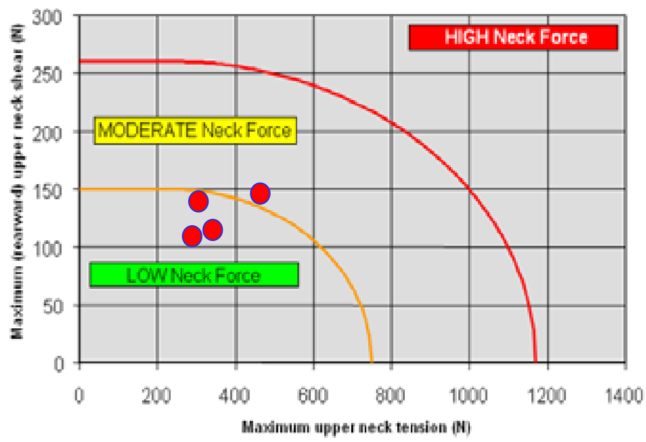
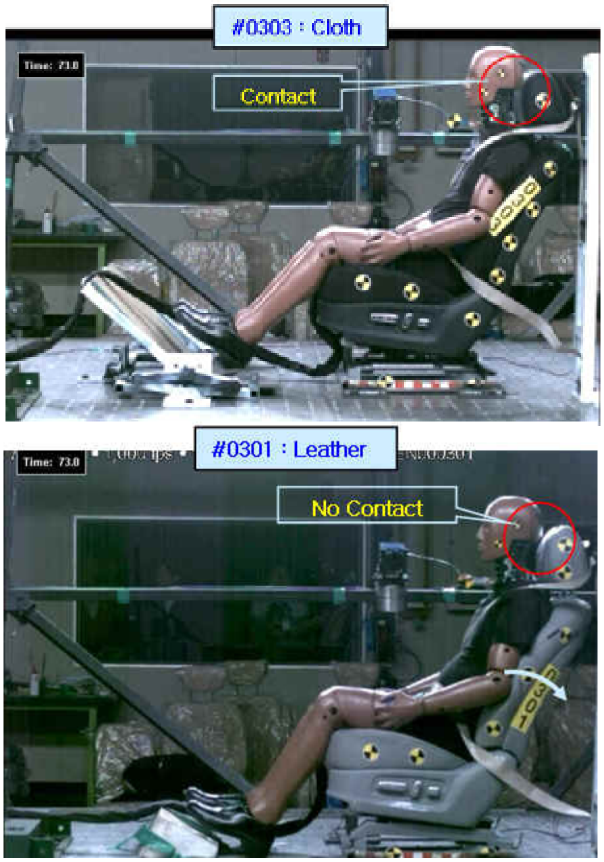


Fig. 8 Results for each combination

The case 4 is found to be the best combination of the variables to satisfy the requirement for HRCT and T1 Acceleration and also to be capable of minimizing neck shear and tension.

REVIEW OF THE PARAMETER TO AFFECT THE PERFORMANCE

To review the results of the case 4 described above, the headrest fore/aft position (Factor 3) and the upper/ lower position of the headrest (Factor 5) as the geometry parameters, have the greatest effect on all results. If these variables are fixed, Factor 3 and Factor 5 can be considered as the dummy setting variation. Therefore the dummy setting variation is supposed to be the decisive factors in test. As an example, depending on the seat cover material, the difference of the dummy setting is occurred in test which leads to the difference of the results. Thus, this effect on the test condition and the corresponding results are analyzed by using the computer simulation. The trend of the dummy behavior and the change of the neck injury, respectively, is compared between the simulation and the test even if the condition of the seat model isn't identical to one of the real seat used in test.



Test No.	Type	Bio-RID Hip point	Pelvic Angle	HRCT	T1	Fx(+)	Fz (+)	Neck Force
UNIT		mm	degree	ms	G	N	N	Rating
REF		X/Z	26.5±2.5	70	9.5	100	600	
0301	leather	215/315	27.9	87.3	11.27	106.8	633.4	MODERATE
0302	leather	211.5/319.7	27.8	81	9.82	94.45	563.3	LOW
0303	cloth	210.2/313.7	26.7	67	11.38	65.9	408.6	LOW

Fig. 9 Results of the test

The dummy is positioned differently in X-Axis and Z-Axis depending on the seat cover material(cloth and leather), because the leather is more durable than the cloth. In sled test #0303(For the cloth type), the backward motion of the dummy deformed the seat back foam easily and locally and operated the active headrest early. In the case of the leather type, the backward motion of the dummy deformed the seat back foam totally and so the seat back is firstly declined before the active headrest operates. After all, this phenomenon increases the contact time between head and headrest. To be expressed by the simulation model, the characteristics of the seat foam and the contact friction between dummy and seat back and between the dummy and seat cushion are applied differently to each model. The contact friction of the leather type is supposed to be larger than that of the cloth type. The foam material characteristics of the cloth type cover, is presumed to be softer in relative manner.

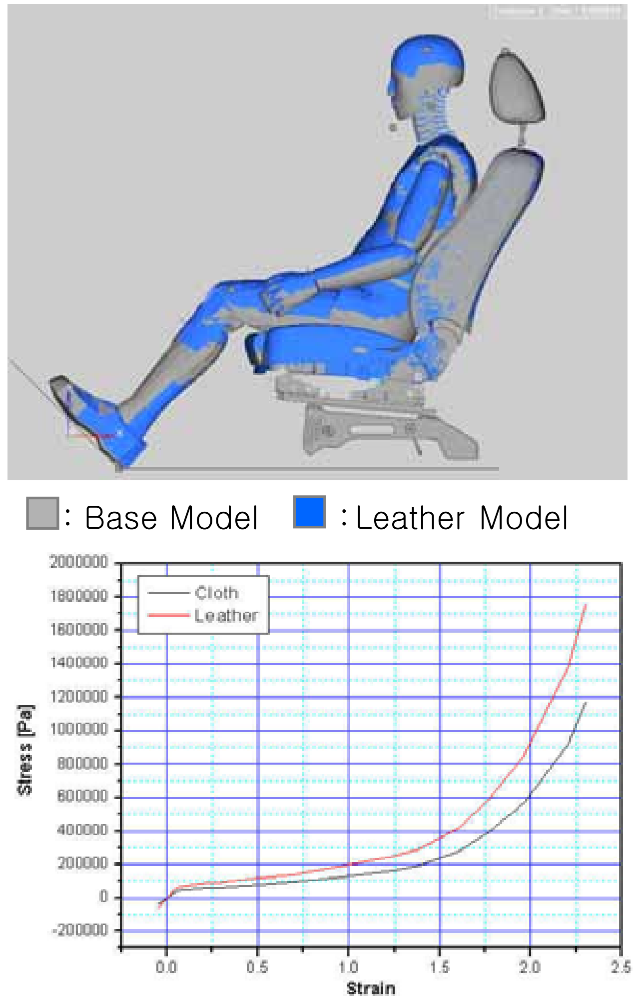


Fig. 10 Comparison of the Model and the foam material characteristics

To make the similar condition comparing the test, the dummy position(leather type) is adjusted in 5 mm higher than the base model.

The simulation is done in accordance with the above condition. The contact time between head and headrest is delayed noticeably and the rating for neck shear and tension is changed. Therefore, the results indicates that to change the seat material(for example, seat cover) and to obtain the identical performance with the baseline design, additional changes of the seat materials on top of the changed material and the structural changes are essential.

		Condition	HRCT	T1	Fx(+)	Fz (+)	Neck Force
	UNIT		msec	G	N	N	Rating
	REF		70	9.5	100	600	
Results	Base	Base (Cloth)	70	11.46	82.07	446.4	Low
	Leather	Base H-point + 5mm & Friction ↑	94	11.24	159	478	MODERATE

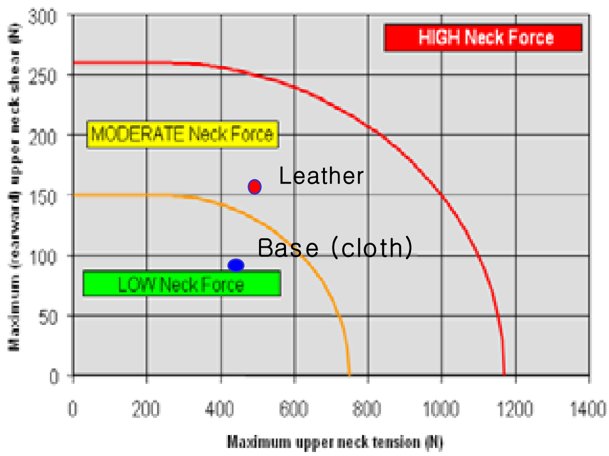


Fig. 11 Results for each type(cloth & leather cover)

CONCLUSIONS

This research performed a case study to obtain the optimized seat with AHR (Active Head Rest)by using BioRID-II dummy and showed a choice of the design factor affecting the neck injuries, T1 Acceleration and HRCT. And the sensitivity of each factor for the outputs is analyzed. It is confirmed that the test setting variation affects the outputs highly and the change of the seat cover or foam material also affect the test condition. Through the simulation following conclusion can be reached,

1) The headrest fore/after position (Factor 3), and the upper/ lower position of the headrest (Factor 5) as the geometry parameter had the greatest effect on the output.

2) Except the geometry parameter, the neck shear respond to the stiffness of the headrest pole sensitively and the neck tension respond to the stiffness of the seat back spring sensitively.

3) It is confirmed that the test setting variation affects the outputs highly and the change of the seat cover or foam material also affect the test condition. Therefore the exact test setting(maintaining the test condition settled) is necessary to evaluate the seat performance accurately.

4) Because the test results can be changed easily according to the test condition, the robust seat design (for backset and height) overcoming the test setup variation is essential.

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