A STUDY ON INVISIBLE KNEE AIRBAG CUSHION FOLDING DESIGN USING DOE (DESIGN OF EXPERIMENTAL) METHOD

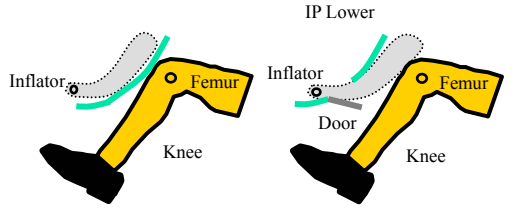
Soongu Hong
Hunhee Jung
Byungryong Cho
Ikwhan Kim
Hyundai MOBIS
Korea
Paper Number 07-0274

ABSTRACT

Recently, the application and development of knee airbag module into the vehicle are increasing to achieve a good rating during EuroNCAP and IIHS test. Also, EuroNCAP and IIHS press the automotive company to equip knee airbag module to improve occupant knee injury and give some benefit regarding knee airbag equipped vehicles at barrier test. (1) Therefore, the invisible knee airbag module has been independently developed through design, simulation, static deployment test and knee impact test. But it was very difficult to position the knee cushion in case of short space between IP lower panel and knee surface. To overcome this problem and optimize knee airbag cushion shape, DOE (Design Of Experimental) method has been applied on knee airbag cushion folding methodology and cushion inner shape using by blow test. But it was presented just knee airbag folding DOE in this paper and verification test results are presented.
A good relationship between DOE result and previous study (=trial & error method) for knee airbag folding process has been found in this study.

INTRODUCTION

The majority of occupant injuries are caused by frontal crashes and the distribution of seriously injured occupants in frontal crashes is 69% in Europe. Also, in previous research, 17% of distribution lies in side crashes, 9% in rollover and 3% in rear crashes (2). The knee is one of the more frequently injured parts of the lower limbs with femur and patella fractures that represent 34% of lower limb injuries in a UK research report. (2, 3) Mark R.Socher et al(4) studied the injury pattern of knee, thigh and hip in frontal crashes and the results show that hip injuries tend be more debilitating than knee and thigh injuries. Hip injuries occurred more frequently to drivers than to passengers, to heavier and taller occupants than lighter, smaller occupants, to males than to females and to unbelted occupants than to belted occupants. Some companies also presented papers for knee airbag development. Raj S. Roychoudhury, James K. Conlee et al (5) developed a blow molded active plastic kneebolster using TPO (Thermoplastic Poly Olefin) material and Jeff Jenkins, Stephen Ridella, and Suk Jae Ham (6) predicted the injury after inflatable knee bolster has been applied in offset deformable barrier crashes using MADYMO simulation. Patrick Borde(2) predicted the occupant injury with an applied pyrotechnic knee bolster using MADYMO and Trevor Ashline and Henry Bock(7) obtained good results in frontal and rear crash using an IRL Tub (aircraft) knee airbag.
The world's first knee airbag is equipped in a Kia Sportage on the driver side only and the number of dual knee airbag equipped vehicles are increasing gradually in the marketplace. Generally, the knee airbag can be categorized by IKB (Inflatable Knee Bolster) type and KAB (Knee AirBag) type. The IKB type deploys the knee airbag cushion within the IP Lower (Instrument Panel Lower) and indirectly restrains the occupant's knees using the IP lower panel. The KAB restrains the occupant's knees using the knee airbag cushion directly. In addition, the KAB module can be divided by visible and invisible type. The visible type KAB has a separate airbag door and IP lower part. The invisible type KAB, such as on the driver side, is integrated with airbag door and IP lower part, and the tear seam or outline of the KAB door can not be seen.



(1) IKB (Inflatable KneeBolster) (2) KAB (Knee AirBag)

Figure 1. Comparison between IKB and KAB

type knee airbag
For example, the IKB type is equipped in the BMW 745i and Chrysler Pacifica and the KAB type is equipped in Lexus LS430, Audi A8, MY06 Chrysler PT Cruiser and MY06 Dodge Caliber (Figure.1). The invisible KAB type for driver and passenger seating positions was chosen to be developed in this study and the knee airbag module was named DKAB.

INVISIBLE KNEE AIRBAG MODULE

Driver Knee Airbag Module

The visible knee airbag on the driver side may have some appearance issues. Visible knee airbag assembly variation may lead to gap issues between the IP lower LH (Left Hand, driver side of Left Hand drive vehicle) panel and the knee airbag module.

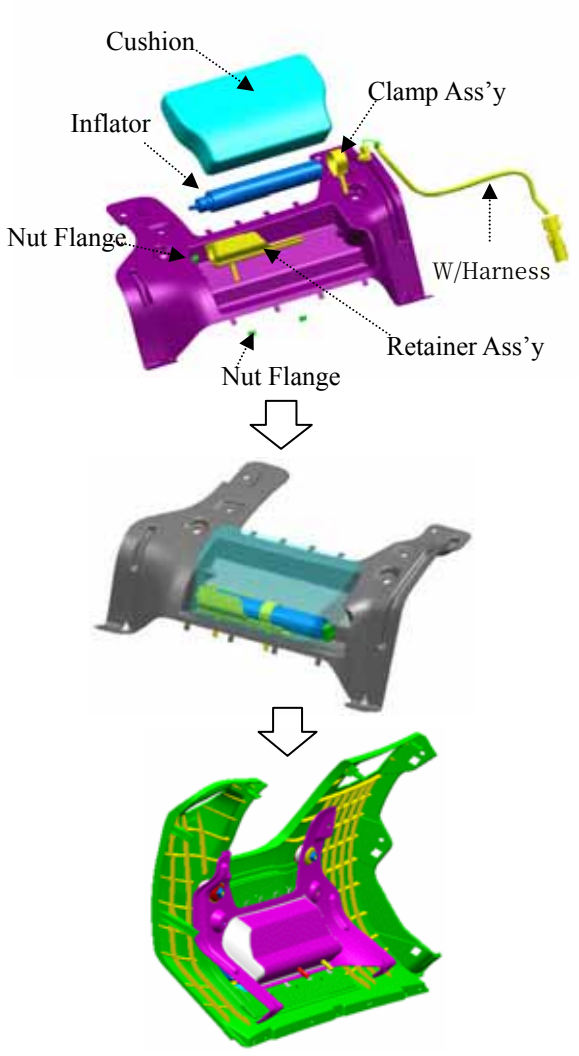


Figure 2. Assembly drawing of DKAB module

To overcome this problem and achieve wide design flexibility, an invisible type of knee airbag has been designed. Also, a knee bolster integrated housing has been designed to absorb the kinetic energy of the dummy's knees after the knee airbag cushion is compressed (Figure.3). It shares the same mounting point as the conventional knee bolster to avoid increasing number of job processes. The IP lower LH panel has been designed to be equipped in final assembly line with the same job process. Also, it is required to provide a mounting method for the IP lower LH panel (=KAB door) which is not detached during knee airbag deployment. To accomplish this, the IP lower LH panel and KAB housing have been attached by using two screw bolts in this project as shown in Figure.4.
The knee airbag door has been designed by the same methodology as for the invisible PAB (Passenger AirBag) module. Therefore, it is required to develop a laser scoring methodology according to door size to meet deployment performance.

Passenger Knee Airbag Module

The coverage zone study of passenger knee airbag cushion is required to avoid the contact between the PAB cushion and the PKAB cushion. The PKAB cushion was harmonized with the driver side one in this study.

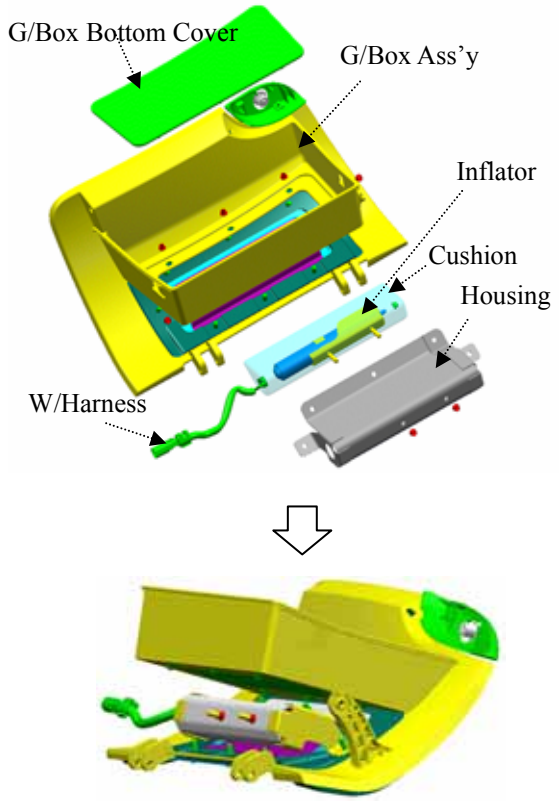


Figure 3. Assembly drawing of PKAB module

Also, the PKAB housing has been designed to be integrated into the glove box using six nuts and the glove box bottom cover has been designed to be a separate piece type in order to assemble the KAB module into the glove box easily (Figure.3) A

package study to obtain a sufficient space of glove box was not conducted in this study.
The glove box housing and PKAB door were connected by using frequency welding. The prototype sample is shown in Figure 4. The inflator, diffuser and cushion assembly were harmonized with the ones used on the driver side.

Figure 4. Proto sample of KAB module

Coverage Zone Study

A package layout study has been conducted to establish the knee airbag mounting location and the cushion coverage zones using hybrid III 5th%ile, 50th%ile and 95%ile package dummies. The knee impact zone to be restrained with a knee airbag cushion has been calculated assuming that the unbelted dummy is in free flight during frontal impacts and assuming that the cushion width is established for the dummy trajectory in a 30 degree angle barrier test (Figure 5. and 6.)

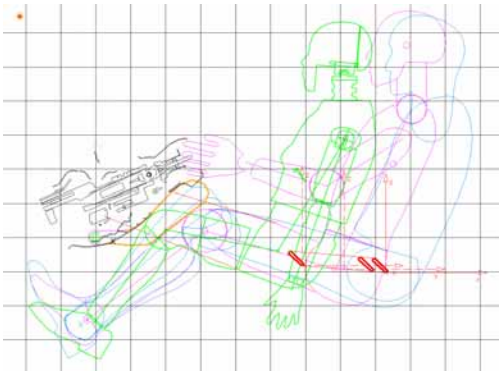


Figure 5. Coverage zone study result for the knee airbag (Side view profile)

As a result, the driver knee airbag cushion volume was found to be 17 liters and the passenger knee air bag cushion volume was found to be 19 liters.

Knee Airbag Cushion

The knee airbag cushion was made from Nylon 66, 420 Denier 49x49 weave silicon coated material. Four tethers with integral vent holes have been provided within the knee airbag cushion to control the volume as shown Figure 7. Also a diffuser to control inflator gas flow has been provided in the knee airbag cushion.

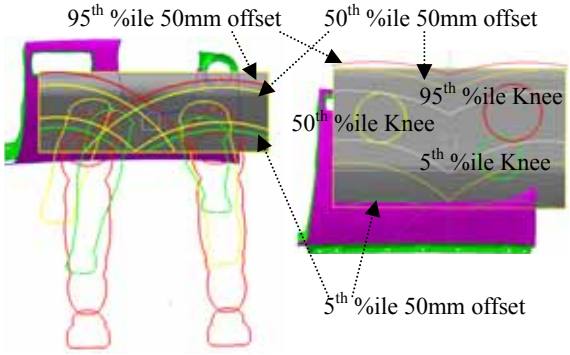


Figure 6. Coverage zone study result for knee airbag cushion (Front view profile)

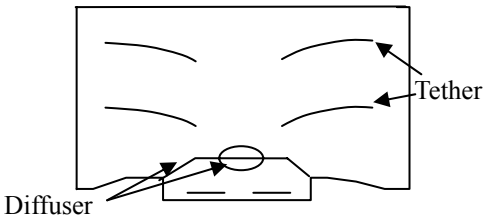
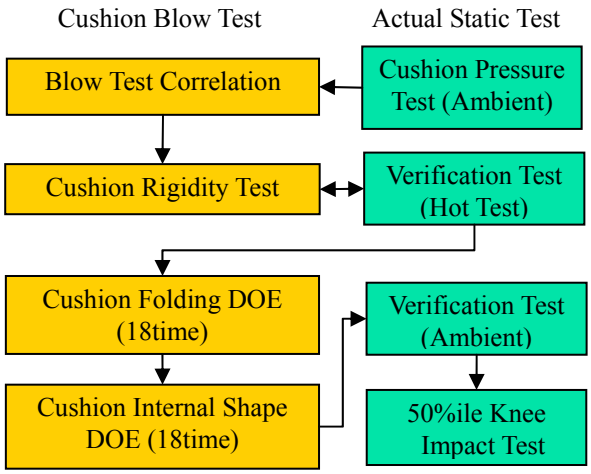


Figure 7. Knee airbag cushion drawing

INVISIBLE KAB CUSHION SHAPE DESIGN PROCESS USING DOE

As shown Table 1. , the invisible KAB cushion design process has been presented using by DOE method. The blow tests were conducted to reduce actual test number and the cushion pressure test was conducted to correlate between blow and actual test.

Table 1.
Invisible KAB shape design process using DOE



And cushion rigidity tests were conducted to evaluate cushion rigidity before the cushion DOE application. And then, cushion folding and internal shape DOE

tests were conducted using by blow test equipment. Finally, verification test and knee impact test were conducted to verify the optimized KAB cushion folding and shape using actual test.

KAB Cushion Pressure and Blow Test Correlation

A pressure tap has been attached on KAB cushion center to measure the actual and blow test cushion pressure during deployment as shown Figure 8. And the comparison result of cushion pressure has been shown at Figure 9.

	Actual Test	Blow Test
Before		
After		

Figure 8. Comparison result of actual and blow test set up condition

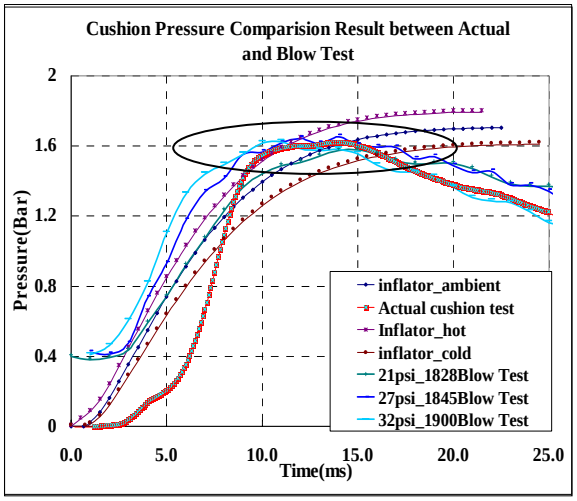


Figure 9. A cushion pressure comparison result of actual and blow test

As the comparison results, a peak cushion pressure was similar with actual one, but the initial slope has some difference. Actually, hot and cold test were reproduced using blow test, but the limitation of cushion sealing in gas exit area has been found.

Blow Test Set-Up

A Hybrid III 50th%ile dummy has been set up at the middle of lowest seating position with seat, instrument panel and KAB module. A SureFire inflation system (250V, 50Hz) of Microsys technologies which has been installed at Kolon Inc. was used for the cushion blow test to tune the cushion shape and develop the folding methodologies as shown in Figure 10.

Figure 10. A cushion rigidity test set up condition

The initial tank pressure of SureFire inflation system was 2.3 psi [=15.8KN/m^2] and internal cushion pressure of knee airbag was 1.6bar [=160KN/m^2].

Cushion Rigidity Test and Results

Originally, some cushions which has been sewn tether, diffuser, vent hole and side panel were conducted using blow test, but all cushions were torn at sewn areas. Therefore, cushion rigidity test was conducted regarding to with and w/o tether and diffuser shapes as shown at Table 2. And the test result has been shown at Figure 11.

Table 2.
Cushion rigidity test matrix and result

Test No	Tether	Diffuser	Test result
1	Yes	Yes	OK
2	Yes	No	Non-OK
3	No	Yes	Non-OK
4	No	No	Non-OK

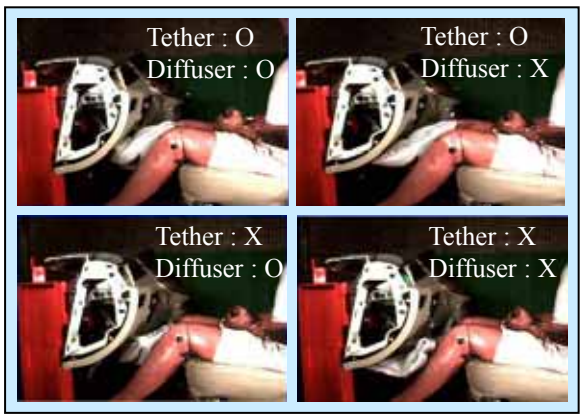


Figure 11. Cushion rigidity test results

As the results, DOE has been conducted using four tether and diffuser cushion, test number 1.

Shape and Folding Optimization Concept and Object Function

The knee airbag shape can be divided to airbag folding method and inner cushion shape. At first, KAB folding DOE has been conducted and then,

inner cushion shape DOE was performed.
The TEMA software has been used to measure KAB side view contour at each 5ms or 10ms of static deployment test and blow test. And the center points of measured KAB contour area were obtained at each time and then, the trajectory has been obtained through the center point's connection. And KAB deployment slopes were obtained from regression analysis as shown at Figure 12. And it was used for the object function (=magnitude of KAB deployment slope) of KAB shape optimization. The example of real blow test has been shown at Figure 13.

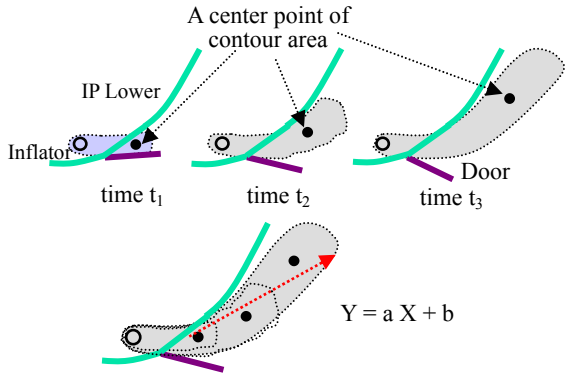


Figure 12. Shape and Folding optimization concept and object function

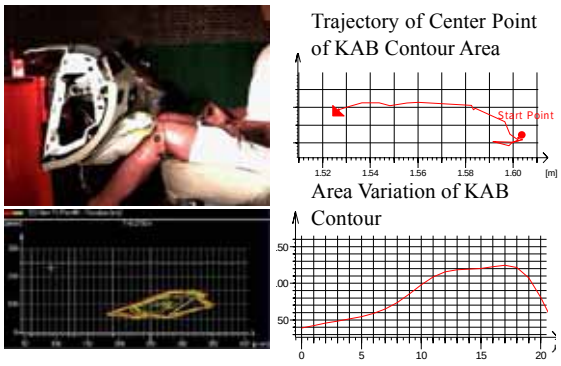


Figure 13. Example which was induced the object function from motion analysis.

DOE Application of KAB Cushion Folding

Basically, airbag folding can be divided to folding method and process. The airbag folding method could be divided by flattening, half, tuck, roll and accordion (=zigzag) folding. And KAB folding process has been categorized three phases in this study as shown Figure 14.

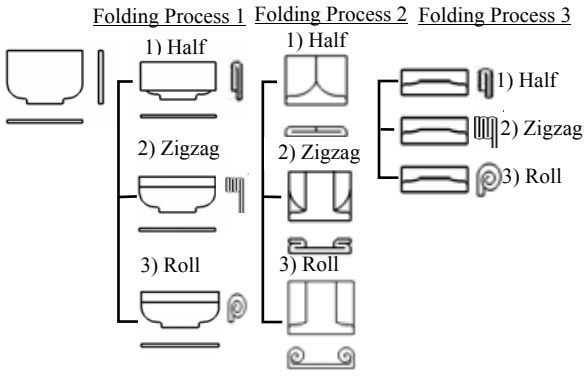


Figure 14. DOE range of KAB folding method

L_9 matrix of Taguchi method has been used and folding types were applied for DOE factor. And folding processes were applied for DOE level as shown at Table 3.

Table 3.
Folding DOE Matrix, Factor and Level

Level: Folding Process →

Factor: Folding Type ↓	Process 1	Process 2	Process 3
Half			
Roll			
Zigzag			

Taguchi Matrix: L_9

Otherwise, the distance between IP lower and knee surface was applied for the noise factor. Because KAB folding types are effect to KAB deployment shapes according to that distance. (55mm, 75mm)

DOE Results of KAB Cushion Folding

Eighteen blow tests were conducted at 75mm and 50mm gap (=distance between IP lower and knee surface) using KAB cushion which has chosen at rigidity test. The eighteen test results of trajectory of center point of KAB contour area had been shown at Figure 15.

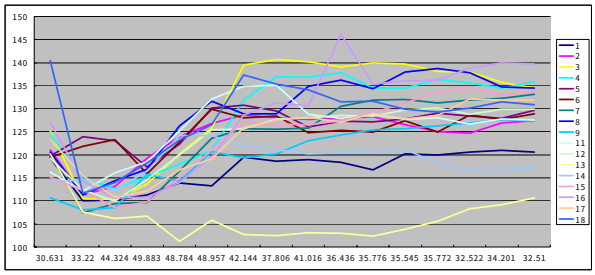


Figure 15. Trajectory results of center point of KAB contour area during deployment

The values of object function (=Deployment Slope)

Table 4.
KAB Folding DOE Result of Blow Test (Slope)

Level: Folding Process →

Factor: Folding Type ←	P 1	P 2	P 3	N1=75mm	N2=55mm
1	Half	Half	Half	0.6038	0.7033
2	Half	Roll	Roll	1.7592	1.5722
3	Half	Zigzag	Zigzag	0.5499	0.5196
4	Roll	Half	Roll	1.6476	1.6047
5	Roll	Roll	Zigzag	1.3558	Data Loss
6	Roll	Zigzag	Half	0.8068	1.215
7	Zigzag	Half	Zigzag	-0.155	0.1389
8	Zigzag	Roll	Half	1.7698	1.9863
9	Zigzag	Zigzag	Roll	1.2546	0.653

N1, N2: distance between IP lower and knee surface
P1, 2, 3: Folding Process 1, 2, 3

are obtained from regression analysis of trajectory results as shown at Figure 15.and applied the weighting factor to consider KAB top view shapes, Good→+1, OK →0, Bad→-1 and the values of object function are summarized at table 4., 5.and Figure 16. The Data loss was assumed to 1.3 as shown at Table 4. The compensated slope has been summarized at Table 6.

Table 5.
KAB Folding DOE Result _Top View Shape

Level: Folding Process →

Factor: Folding Type ←	P 1	P 2	P 3	N1=75mm	N1=55mm
1	Half	Half	Half	OK	OK
2	Half	Roll	Roll	Good	Good
3	Half	Zigzag	Zigzag	OK	Good
4	Roll	Half	Roll	Bad	Bad
5	Roll	Roll	Zigzag	Good	Bad
6	Roll	Zigzag	Half	Good	OK
7	Zigzag	Half	Zigzag	OK	Bad
8	Zigzag	Roll	Half	Bad	Bad
9	Zigzag	Zigzag	Roll	Bad	Good

N1, 2: distance between IP lower and knee surface
P1, 2, 3: Folding Process 1, 2, 3

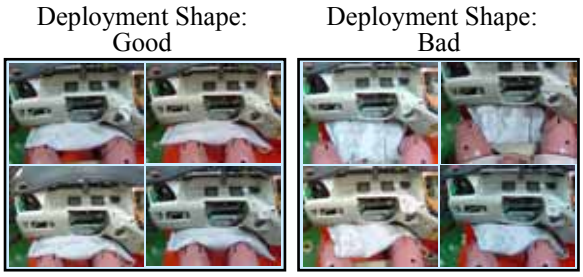


Figure 16. KAB Blow Test Results of Deployment Shape _Top View

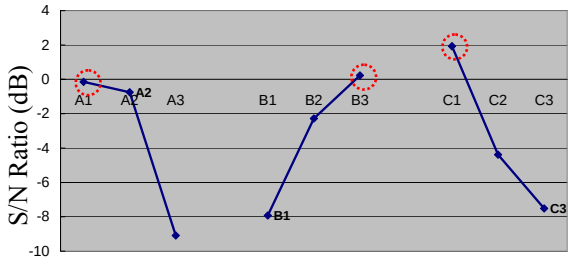
Table 6.
KAB Folding DOE Result _Compensated

Level: Folding Process →

Factor: Folding Type ←	P 1	P 2	P 3	N1=75mm	N2=55mm
1	Half	Half	Half	0.6038	1.733
2	Half	Roll	Roll	1.7592	0.5722
3	Half	Zigzag	Zigzag	1.5499	1.5196
4	Roll	Half	Roll	1.6476	0.6047
5	Roll	Roll	Zigzag	0.3558	1.3
6	Roll	Zigzag	Half	1.8068	2.215
7	Zigzag	Half	Zigzag	0.1	0.1
8	Zigzag	Roll	Half	1.7698	0.9863
9	Zigzag	Zigzag	Roll	0.2546	1.653

N1, N2: distance between IP lower and knee surface
P1, 2, 3: Folding Process 1, 2, 3

S/N ratio of KAB folding DOE had been calculated and the main effect plot has been shown at Figure 16. As the result, it was found that the third folding process was largely effect on KAB deployment shape. And it was found that the best level of KAB folding process compose of P1→ half, P2→zigzag (=accordion), P3→half folding. The best level has been indicated to a red dot line at Figure 17.



A,B,C: Folding Process, A→P1, B→P2, C→P3
1,2,3 : Folding Type, 1 : Half, 2 : Roll, 3 : Zigzag

Figure 17. Main Effect Analysis of KAB Folding

VERIFICATION

The static deployment tests of DKAB and PKAB module were conducted to verify the best level of DOE result. It was found to be a good deployment without any jamming between knees as shown at Figure 18. But it was found to be torn the tether at cushion inner. Otherwise, the gain between actual and blow test has not been calculated, because the actual test could not be set up with the same camera viewing and zooming of blow test.

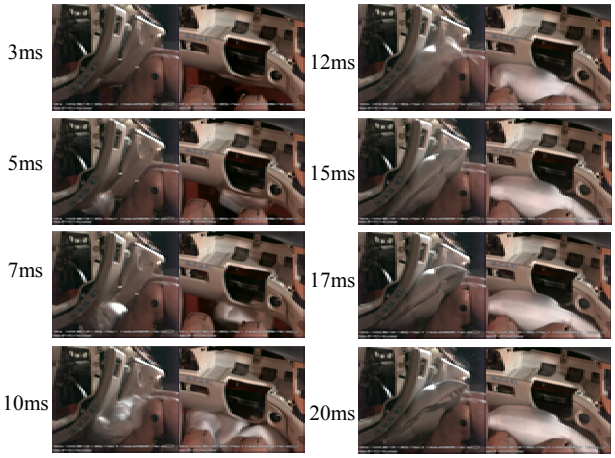


Figure 18. Verification test of DKAB module

In previous study [13], KAB folding process has been developed using trial and error method as shown at Figure 19. And DOE result of KAB folding process has been compared with the one.

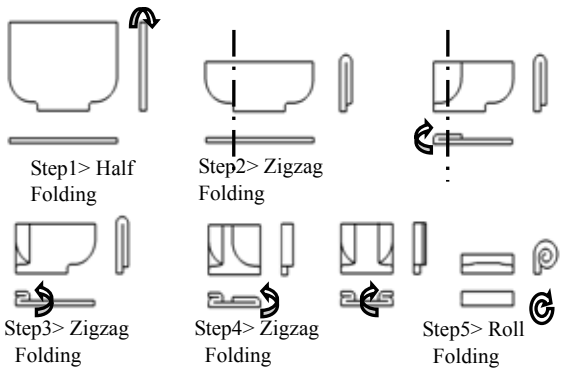


Figure 19. Folding process of KAB cushion

As the results, it was found to be same process with the one except folding process 3 and the result was summarized at Figure 20.

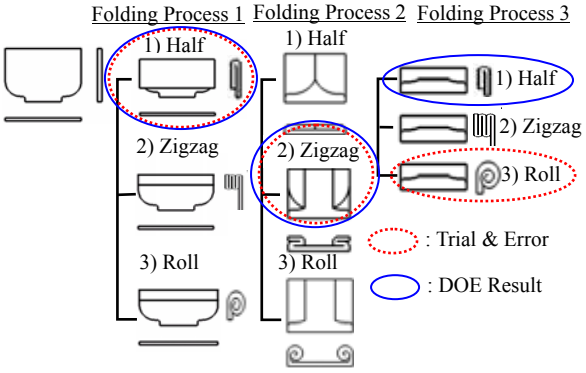


Figure 20. Comparison result between DOE result and previous study

CONCLUSION

The invisible knee airbag module has been developed independently and evaluated through design, simulation and test. Generally, airbag folding process has been developed using by trail & error method in the past. But, the knee airbag folding methodology has been developed using by DOE technique in this paper and conclusion remarks are as follows:

1. It was found the DOE application result for knee airbag folding process was same with the ones in previous approach (trial & error method) except third folding process. And it was found the final folding process (third folding process) was a main effect.

2. It could be used widely the DOE technique on shape study and folding process development of other airbag (DAB, PAB, SAB, etc) using proposed optimization concept in this paper.

3. It will be conducted the further study for knee airbag inner shape design using DOE technique continuously.

REFERENCE

[1] “Sled Test Procedure for assessing Knee Impact Area”, European New Car Assessment Program Version 1.0a, 2004
[2] Patrick Borde, “Pyrotechnic Kneebolster Development and Its Contribution to Car Drivers Safety”, SAE2001-01-1049.
[3] Lisa Shoaf Ore and C. Brian Tanner et al, “Accident Investigation and Impairment Study of Lower Extremity Injury”, SAE930096.
[4] Mark R.Sochor, Daniel D Faust and Stewart C. Wang et al, “Knee, Thigh and Hip Injury Patterns for Drivers and Right Front Passengers in Frontal Impacts”, SAE2003-01-0164.
[5] Raj S. Roychoudhury, James K. Conlee et al, “Blow-Molded Plastic Active Knee Bolster”, SAE2004-01-0844.
[6] Jeff Jenkins, Stephen Ridella and Suk Jae Ham, “Development of an Inflatable Kneebolster by using MADYMO and DOE”, 9th International MADYMO Users Conference, 2002.
[7] Trevor Ashline and Henry Bock, “Investigating the Effects of Anchor Pretensioners, Kneebolster Airbag and Seat Belt Changes In an IRL Tub”, SAE 2004-01-3563.
[8] James K. Conlee, “Passenger Side Airbag System for Open Interior Architecture”, SAE970721.
[9] Donald F. Huelke, “Anatomy of the Lower Extremity-An Overview”, SAE861921.
[10] Posz & Bethards, “Knee Protection Airbag Device”, Patent No : 20040164527a1.
[11] MADYMO User’s Manual ver.6.1, TNO, 2003.
[12] S.G.Hong et al, “Design Considerations of Invisible Knee Airbag Module Development”, 6th Korea MADYMO Users Conference, 2005
[13]S.G.Hong et al, “Invisible Knee Airbag Module Development”, SAE2007-01-0347

DEFINITIONS, ACRONYMS, ABBREVIATIONS

Euro NCAP : Europe New Car Assessment Program
IIHS : Insurance Institute for Highway Safety
MADYMO : MAthmatical DYnamic MOdelling
DAB : Driver AirBag
PAB : Passenger AirBag
DKAB : Driver Knee AirBag
PKAB : Passenger Knee AirBag
SAB : Side AirBag