STUDY ON EFFECTIVENESS OF PRE-CRASH ACTIVE SEATBELT USING REAL TIME CONTROLLED SIMULATION

Jeong Keun, Lee
Kang Wook, Lee
HYUNDAI MOBIS
Korea

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ABSTRACT

In recent years, products that make use of integrated safety that use the environmental data to optimize occupant restraints have been on the market. Pre-safe system in the integrated safety category is an adaptive and smart protection system that utilizes the occupant information and the monitoring information on the accident prediction. These pre-safe systems need the proper algorithm corresponding to the crash scenario for the crash unavoidable state. Due to the crash scenario categories for the real world accidents is quite various, the development of the algorithm and the occupant protection system to reduce the injury is quite complex and costly. For this reason, a development process for pre-safe related integrated safety systems demands new tools based on the biomechanics to help design and assessment.
The virtual development and assessment process with a viewpoint on the efficiency of the restraint development has been developed. The real time controlled restraint system is adapted for support this process. The virtual development process with real time controlled restraint system offers an optimized guide line in terms of injury reduction over various crash scenarios. With this virtual development process, definition of the proper restraint characteristics and the algorithm for the various crash scenarios can be achieved more easily and fast.
Based on the accident data analysis, there are a large number of crashes where the drivers did not put the brake. For this reason, the active safety technologies like brake assist system are being developed. Brake assist system also can make difference in occupant kinematics and injuries. The frontal impact occupant analysis model with pre-crash brake system was developed. Developed model had the braking stage that produces deceleration of 0.8g for 0.9 seconds. The significant change in the dummy posture was observed during pre-crash braking and this change led the increase of occupant injuries. In order to enhance occupant protection during pre-crash braking, pre-crash seat belt system was applied. The pre-crash seat belt system was modeled with MADYMO-SIMULINK Coupling model in order to control the webbing tension force of the pre-crash seat belt. Numerical simulations were performed with pre-crash seat belt of various tension force limits in the driver side NCAP model.
The increase of seat belt webbing tension force indicates that the occupant injury risk could be reduced due to the initial restraint effect. The chest acceleration, chest deflection and neck injury in the event of crash are basically functions of seat belt webbing tension prior to crash. The results showed the tendency of lower injury level with more retraction in certain dynamic conditions. But excessive retraction of seat belt may cause the upward trend in the chest deflection due to the initial deflection of chest generated by retraction.
Conclusion and Relevance to session submitted
The effectiveness of this process is evaluated and the obtained restraint characteristics will be used as a basis to define the appropriate integrated safety features and the performance criteria.

INTRODUCTION

The integrated safety system (the integration of active safety and passive safety systems) offers the benefit of crash avoidance and reduction of crash severity. The industry developed various ASV products for the driver assistance and safety, for example Lane Departure Warning System (LDWS), Full Range Active Cruise Control (ACC), Pre-Crash Brake Assist (PBA). The monitoring system has the important role that estimates the hazardous object kinematic characteristics like speed, direction and collision time and the object distinction. The monitoring system partitions the driving condition into two zones; collision avoidance zone and collision mitigation zone. The collision mitigation zone is composed of the “pre-crash” and “post-contact” states. Pre-crash technologies activate countermeasures prior to impact to assist in reducing the crash severity. The MSB (Motorized Seat Belt) and the active vehicle control actions (braking, steering) can be employed to enhance passive safety restraint deployments. Collision avoidance zone countermeasures can be applied during the time period (≈TCrash -3s < T < ≈ TCrash -0.5s) prior to the potential crash event. Pre-crash state countermeasures can be applied in the time period (≈TCrash -0.5s < T < TCrash) before the coming up crash event [1]. The present study focuses on the active countermeasure to reduce the crash severity in the pre-crash state.
The statistical data of accident analysis in figure 1

show that 43% ~55% drivers put the brake to avoid or mitigate the crash [2]. It can be predicted that this behavior can make difference in occupant kinematics and injuries. On the contrary, there are a large number of crashes where the drivers did not put the brake. For this reason, the active safety technologies like brake assist system are being developed. This brake assist system is a pre-crash zone countermeasure that assists in reducing the crash severity [1]. Brake assist system also can make difference in occupant kinematics and injuries.

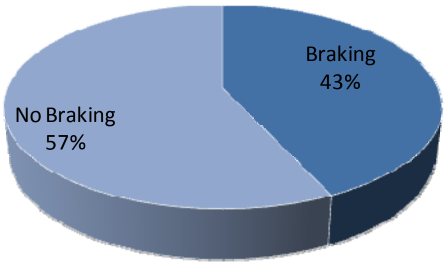

Figure1. Brake Operation in Frontal Crash (from Tobata et al. [2], Fujita et al. [4])

Figure 2 shows the operation procedure of the brake assist system. If the vehicle approaches the obstacle, pre-crash safety system activates the warning system that cautions a driver against collision. The pre-crash safety system predicts a high probability of crash, the pre-crash brake assist system is put on standby for assist driver's braking force. If the driver put the brake pedal, the pre-crash brake assist system increases the braking force in accordance with the driver's braking force. If the driver's braking response is late or the braking force is low and the monitoring system decides that a collision is unavoidable, the pre-crash seat belt system is activated.

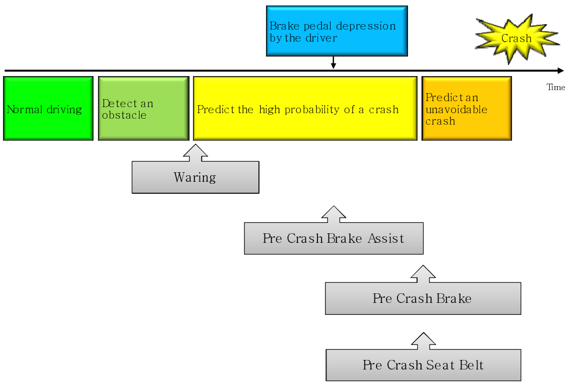

Figure2. Operation Procedure of the brake assist system (from Tsuchida et al. [3])

The pre-crash seat belt system retracts the seatbelt webbing in order to improve the effectiveness of occupant restraint just before the collision. Increase of initial restraint for occupant can help to enhance the occupant protection during the collision. If the driver does not apply the brakes as shown in figure 1, the pre-crash brake applies the brakes automatically for helping to reduce the vehicle speed and the crash severity [3].

Figure 3 shows the vehicle speed reduction due to brake operation prior to impact. The driver applied the brake 0.8seconds prior to the crash. Results of vehicle speed reduction were reported for three different braking forces and brake operation speeds of driver. Results indicate that a speed reduction effect of 10km/h or higher can be achieved when the braking force is 100N from an initial vehicle speed of 50km/h [4]. In other study, the braking system produced decelerations of 0.8g for 0.9 seconds. The 0.8g level was reached in 0.5 seconds and remaining stable at that level for the next 0.4 seconds. This deceleration reduced the vehicle velocity of 19km/h from the initial running speed of 67km/h [5]. Under these braking prior to impact, the occupant in real world or the dummy in the crash test inclined forward due to the braking deceleration. Therefore it is difficult to keep a normal position just before the collision. This change of occupant posture and the forward movement can increase the occupant injuries. In addition, the decrease of distance between occupant and airbag can lead the head or neck injury due to the direct impact of airbag (bag slap).

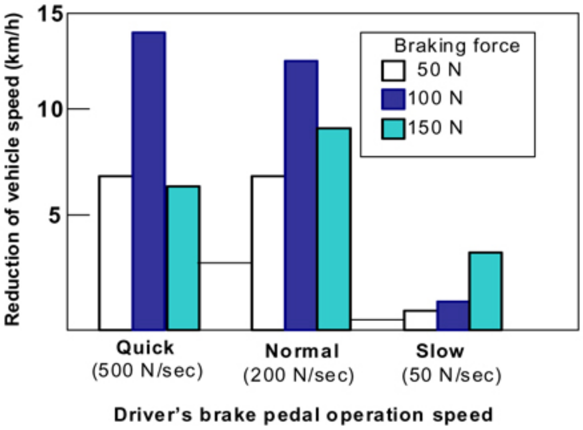

Figure3. Pre-crash braking effect (from Fujita et al. [4])

This paper introduces the numerical simulation model for the braking stage prior to collision and the posture change and forward movement are observed. The real time controlled pre-crash seat belt model is developed to control the webbing retraction with tension force. The configuration, function, and effects of the developed real time controlled pre-crash seat belt model in the occupant analysis model are investigated.

CONFIGURATION OF PRE-CRASH SEAT BELT MODEL

A pre-crash seat belt has an electric motor, reduction gear and clutch mechanism for retracting the seat belt webbing. A conventional seat belt retractor as like pretensioner and force limiter mechanism also equipped in the pre-crash seat belt. The pre-crash seat belt is operated by an electric motor, it can be used repeatedly. The seat belt is retracted by rotation of the shaft in the inlet direction. When an unavoidable crash is determined, a current is supplied to the motor. The motor rotates in the inlet direction and the rotation activates the clutch mechanism and then retracts the seat belt webbing. To release the seat belt webbing, the motor is rotated in reverse direction to disengage the clutch mechanism. Once the clutch mechanism is disengaged, the shaft becomes free and the seat belt returns to its original state. In general, the pre-crash seat belt is activated in the collision unavoidable state that is determined by the monitoring system. The seat belt returns to its original state once the crash is avoided. The pre-crash seat belt is also activated, when an emergency brake is executed by the driver [4].
Because the pre-crash seat belt is operated by an electric motor, there is a relation between the motor torque (seat belt webbing tension force) and the webbing retraction. Figure 4 shows the retraction performance of motor retractor. This linear upward monotonic increase of shoulder belt tension with the increase of retraction length clearly indicates that upper limit of the seat belt tension should be set or adjusted in accordance with the occupants' tolerance limit [2].

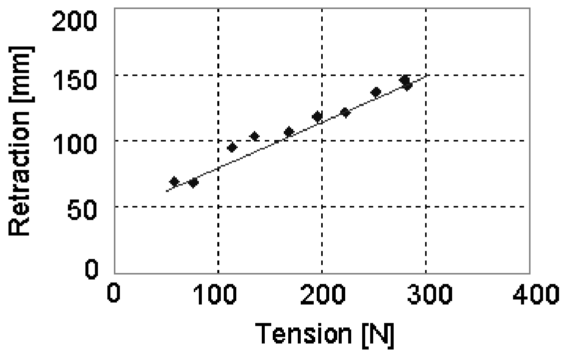

Figure4. Retraction performance of motor retractor (from Tobata et al. [2])

The retraction handling is relatively simple for the pre-crash seat belt model, but it is difficult to reflect the interaction between the tension force and the occupant, and the tension force limit of motorized seat belt. In this study, the real time controlled restraint system (MADYMO-SIMULINK Coupling) is adapted for the tension force control of the pre-crash motorized seat belt in the occupant analysis model. This simulation model can be used for getting insight of the different control aspects and setting the conceptual specifications for the seat belt actuator. Figure 5 shows a developed MADYMO-SIMULINK Coupling model for the pre-crash seat belt. The green boxes are the matlab-simulink, the red boxes are MADYMO and the yellow boxes mean the data exchange between MADYMO and the matlab-simulink. This real time controlled pre-crash seat belt model helps to prevent the unrealistic retraction exceeding the torque capability of the motorized seat belt. This means the webbing retraction length can be controlled based on the webbing tension force of pre-crash belt during braking stage. Numerical simulation was conducted to find an optimal webbing tension force level of pre-crash seat belt.

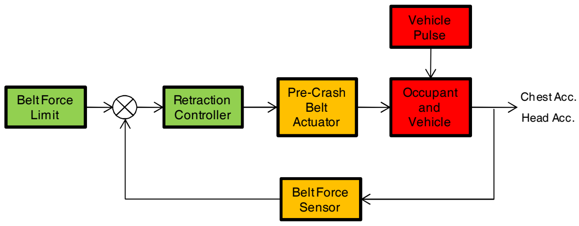

Figure5. Concept of controlled numerical model

NUMERICAL SIMULATION

Numerical simulation was conducted on the assumption that the brake was activated prior to collision. This indicates a situation of applying 0.8g brake during 0.9seconds (The 0.8g level was reached in 0.5 seconds and remaining stable at that level for the next 0.4 seconds) with an initial velocity of 75 km/h before it crashes at 56 km/h full frontal rigid barrier test conditions. Without pre-crash seat belt case, this braking deceleration leads dummy posture changes and body movement as shown in Figure 6. The dummy posture changes during the braking stage are following; the head forward displacement is 105mm, the chest forward displacement is 80mm, the pelvis forward displacement is 35mm. Numerical simulations were performed with pre-crash seat belt of various tension forces in order to investigate the effectiveness of the pre-crash seat belt and the trend of the injuries according to the belt tension force. The simulation model has an air bag in standard AM50 HYBIII-MADYMO dummy model.
Figure 7 shows the retraction performance with respect to the tension force during the pre-defined braking situation. The retraction length is linearly proportional to the shoulder belt tension.

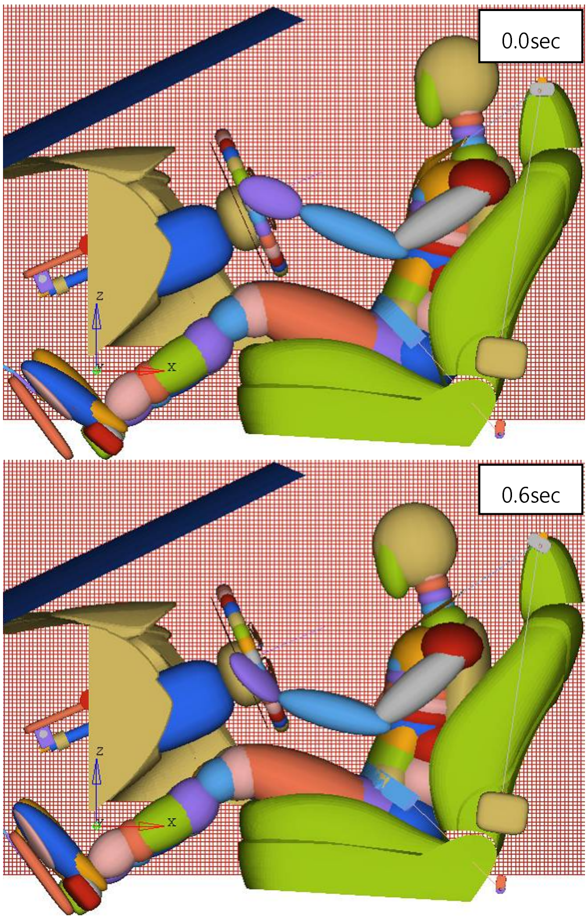

Figure6. Posture change and movement due to braking

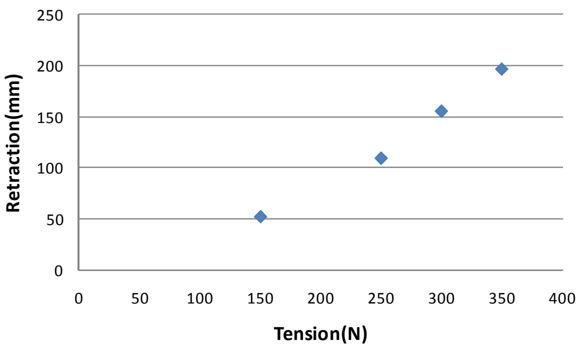

Figure7. Retraction performance in braking stage

Figure 8 shows the improvement of the chest acceleration (CG3ms) and chest deflection. The decrease in CG3ms can be observed except for the about 50mm retraction. The result shows the more belt retraction, the lower the chest acceleration over 50mm retraction. The reduction trend of the chest deflection is observed up to 109mm retraction, the chest deflection is showing an upward trend over the 109mm retraction. The upward trend in the chest deflection may caused by the initial deflection of chest generated by retraction of seat belt. The improvement of the neck injury is observed due to less neck tension force and the flexion moment. The increase of seat belt webbing retraction indicates that the occupant injury risk could be reduced due to the initial restraint effect.

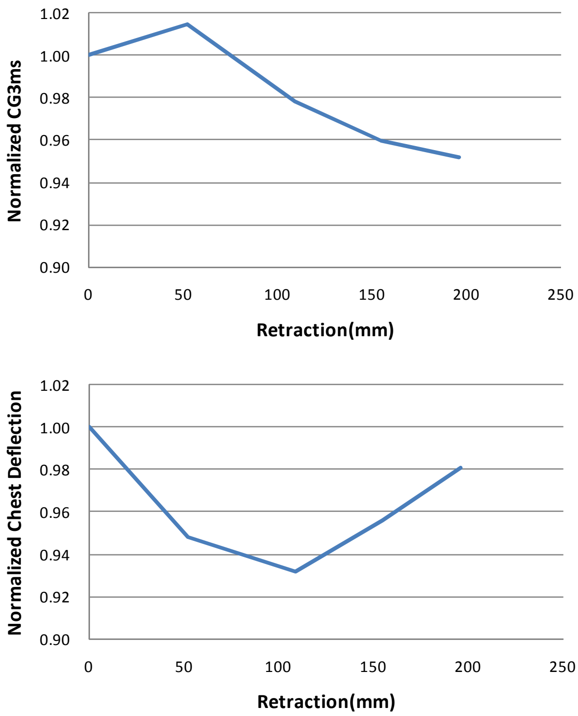

Figure8. Improved chest injuries by seat belt retraction

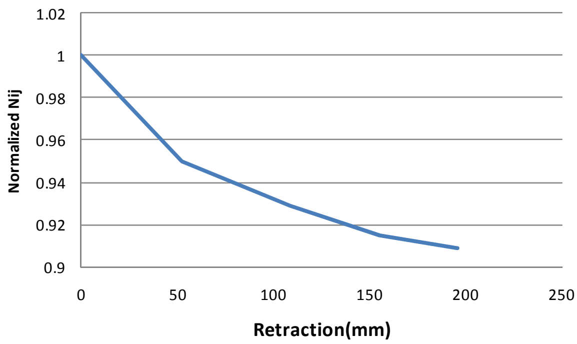

Figure9. Improved neck injury by seat belt retraction

Figure 10 shows the effectiveness of the pre-cash seat belt in the NCAP relative risk score and there is optimal retraction amount in the NCAP relative risk score. Excessive retraction length or tension force of seat belt cause the upward trend in the chest deflection due to the initial deflection of chest generated by retraction, so NCAP relative risk score is increased in spite of reduction of neck injuries. Figure 10 shows the optimal retraction length is 150mm and it corresponds to the 300N in webbing tension force in figure 7. This value can be used as an upper limit for torque control of motorized seat belt.

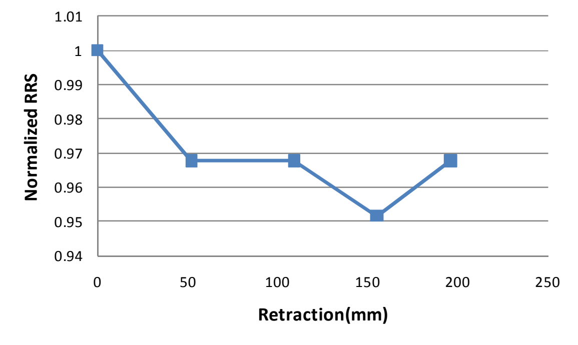

Figure10. Improved Relative Risk Score by seat belt retraction

CONCLUSIONS

Based on the accident data analysis, there are a large number of crashes where the drivers did not put the brake. For this reason, the active safety technologies like brake assist system are being developed. Brake assist system also can make difference in occupant kinematics and injuries. The frontal impact occupant analysis model with pre-crash brake system was developed. Developed model had the braking stage that produces deceleration of 0.8g for 0.9 seconds. The significant change in the dummy posture was observed during pre-crash braking and this change led the increase of occupant injuries. In order to enhance occupant protection during pre-crash braking, pre-crash seat belt system was applied. The pre-crash seat belt system was modeled with MADYMO-SIMULINK Coupling model in order to control the webbing tension force of the pre-crash seat belt, because it is difficult to model the Motorized Seat Belt having torque capacity. Numerical simulations were performed with pre-crash seat belt of various tension force limits in the driver side NCAP model. The increase of seat belt webbing tension force indicates that the occupant injury risk could be reduced due to the initial restraint effect. The chest acceleration (CG3ms), chest deflection and neck injury in the event of crash are basically functions of seat belt webbing tension prior to crash. The results showed the tendency of lower injury level with more retraction in certain dynamic conditions. But excessive retraction of seat belt may cause the upward trend in the chest deflection due to the initial deflection of chest generated by retraction. The optimal webbing tension force based on the webbing retraction length of pre-crash belt was found by using the motorized seat belt model utilizing MADYMO-SIMULINK Coupling.

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DEVELOPMENT OF DRIVER AIRBAG LRD TECHNOLOGY USING THE SINGLE STAGE INFLATOR

JUNYONG, MIN
HYUNDAI MOTOR COMPANY
REPUBLIC OF KOREA

HANIL,BAE
HYUNDAI MOTOR COMPANY
REPUBLIC OF KOREA

JINHO,BAE
HYUNDAI MOTOR COMPANY
REPUBLIC OF KOREA

ABSTRACT

North America crash regulations established regulations that require airbags mounted in 1994, and began to emphasize the need for a secondary safety device. But over time, the pressure due to the strong airbag fatalities had been occurring. So, airbag supplier and car maker had developed 30% reduction de-powered airbags compared with full-power airbag. But, An adequacy of airbag pressure in infants on the front seat and for unbelted small women had been discussed by NHTSA. Finally NHTSA released the FMVSS208 Advanced airbag regulation for out of position small female driver, unbelted small occupant and infants on the front seat.

To satisfy the Advanced airbag regulations, car makers have applied dual-stage inflator airbag, driver seat track position sensor and occupant detection and classification sensor for passenger. Especially for static deployment fatalities about out-of-positioned driver, dual stage inflator must have been applied to driver airbag.

The research and development method satisfying the FMVSS208 advanced airbag regulation with single stage inflator driver airbag will be discussed in this paper.

The various and detailed inflator performance requirement, driver airbag design method (cover tear line, cushion folding and proper initial cushion deployment shape) and layout (parts around the status of the airbag mounted on the steering wheel for the driver's seat and minimum requirement between STRG WHL and other parts) will be addressed focusing on Completed the development of the case in this paper.

This paper does not change the operating strategy applying dual stage inflator in North America and I want expect you to understand the On the other hand the improvement of performance through diverse attempts.

Introduction

The standard for abnormal seating the driver's seat defined by FMVSS208 is moving driver's seat with the middle height to the front-end of the track, and seating a 5% female dummy close to the steering wheel. There are two positions of seating the dummy close to the steering wheel.

Position #1 is chin-on-module positioning the dummy's chin right above the DAB.

FIGURE 1. POSITION1

Position #2 is chin-on-rim positioning the dummy's chin in the 12 o'clock direction of the steering wheel.

FIGURE 2. POSITION2

Injuries regulated by FMVSS208 are those on the head, neck, chest and knees. The injury on the head is expressed in the injury value of HIC. The injury on the neck is expressed in Nij and ±Fz. Nij consists of Nte (tension-extension), Ntf (tension-flexion), Nce (compression-extension) and Ncf (compression-flexion), which is an item that evaluates the vertical force and moment on the neck simultaneously. For example, Nte evaluates tension on the neck and the moment (extension) in which the neck bends back. ±Fz refers to the tension and compression applied to the neck directly. Chest injury is expressed in acceleration (Chest Acc.) and deformation (Cd). For knees injury, the load applied to the knees is measured (femur load).

Knees injury amounts to nothing in an actual OOP TEST, with a very low injury value, so it is excluded from the injury values dealt with in this study. You may want to see FMVSS208 for detailed information about injury factors.

Body

To satisfy LRD performances using a single stage inflator, the following parts should be considered:

1) Selecting inflator

2) Selecting DAB cover tear line

3) Cushion folding method

4) Position of DAB module in STRG WHL

5) Relationship between the seating position of dummy and vehicle layout

A design meeting the optimum condition for the above is necessary.

1) INFLATOR SELECTION

Inflator performances may be represented by pressure, mass flow rate, gas emission amount and gas emission duration.

1) Pressure: raw data acturally measured by tank test
2) Mass flow rate: the pattern can be estimated by the incline of the pressure curve actually measured, and the actual data is drawn out by formula
3) Gas emission amount: mass flow rate integral value
4) Gas emission duration: The time of reaching the peak of the pressure curve or the mass flow rate zero point

The number of moles and temperature among the inflator performances are relative concepts, which cannot be used as comparative data.

The number of moles is affected by the type generated by the inflator and the lighter the molecular weight of gas is emitted, the greater the number of mol may get. In other words, hybrid type that emits gas with a relatively large molecular weight shows much practical gas emissions but the fewer number of moles. Thus, the number of moles is effective only in comparison between inflators in the same series.

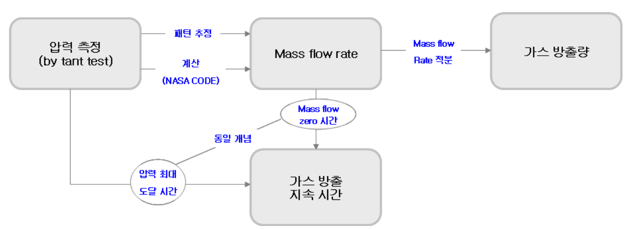

Figure3. Inflator Performance Correlation

1-1) Pressure Properties

Till now, inflator properties have been defined only by maximum pressure. In this case, it is impossible to express accurate inflator properties. In other words, overall graph pattern and maximum pressure value should be considered simultaneously.

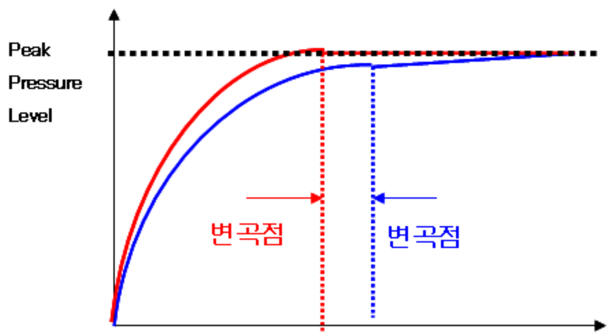

Figure4. Performances of Two Different Inflators

① The final peak pressures of the red graph and the blue graph are the same

② Compared to the red graph, in the blue graph, the time of inflection point occurrence comes after → The time of mass emission gets longer as much as the delay time of the inflection point

③ For the blue graph, the increase of additional pressure after the inflection point continues → the additional emission of mass is continuously occurring

④ The initial incline of the red graph is great → the initial mass amount is great

⇒ Showing the same peak pressure, but having different gas emission extent

⇒ In other words, pressure value cannot represent the entire properties of the inflator

1-2) MASS FLOW RATE

Mass flow rate can be estimated in the differential form of the pressure graph from the actual measurement, and mass flow rate peak time can be checked by the inflection point of the initial pressure curve while mass flow rate duration time by the time of reaching the pressure maximum.

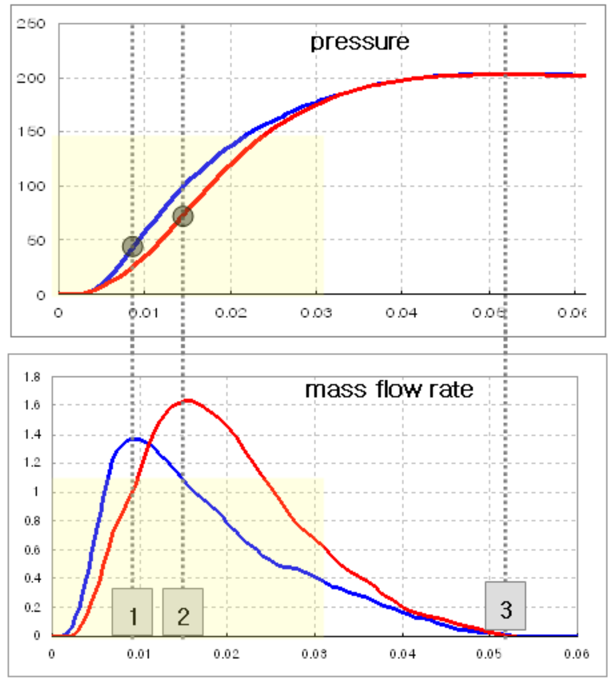

Figure5. Correlation between Pressure Curve and Mass Flow Rate

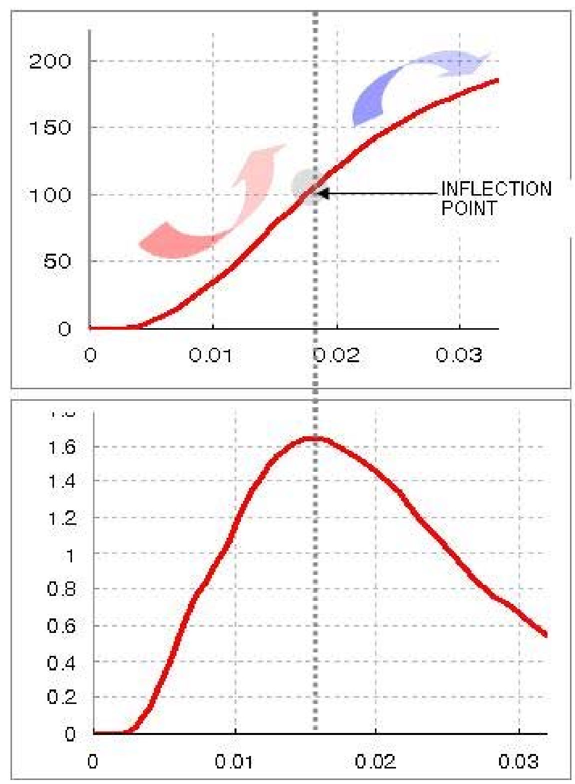

Figure6. Correlation between Pressure Curve and Mass Flow Rate

1-3) Gas Emission

Gas emission is a value of integrating mass flow rate.

$$\text{Total Mass} = \int \dot{m}\, dt$$

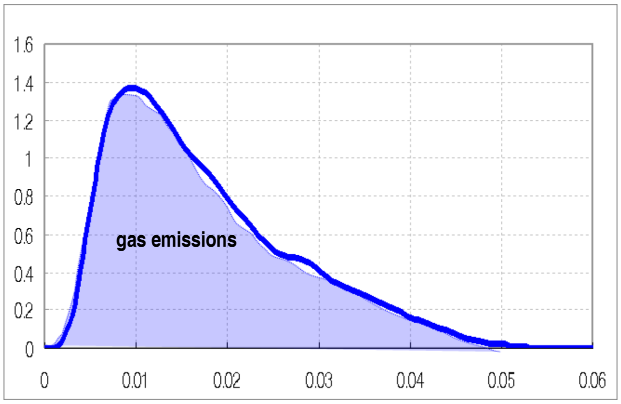

Figure7. Correlation between Gas Emission and Mass Flow Rate

1-4) Number of Moles

Mole is a kind of unit (in other words, it is not a physical phenomenon but weights and measures artificially made by chemists).

$$\text{TOTAL Mole} = \sum_{\text{GAS TYPE}} \left\{ \frac{[\text{TOTAL Gas QUANTITY}] \times [\text{PORTION Gas component}] = \text{WEIGHT CORRESPONDING GAS}}{\text{GAS MOLECULAR WEIGHT}} \right\}$$

For inflators in the same series, relative comparison is possible, but for each different series, the molecular weight of gas emitted are different, so it does not have a meaning.

GAS	CONTENT	ACTUAL EMISSION	Molecular weight
H2O	37.34%	11.2	18
N2	35.64%	10.7	28
CO2	26.88%	8.1	44

Table1. Example of Calculation of the Number of Moles by Type

1-5) Molar Fraction Curve

Applying a graph of the changes of gas generation composition ratio by time as interpretation input data can obtain a very powerful result.

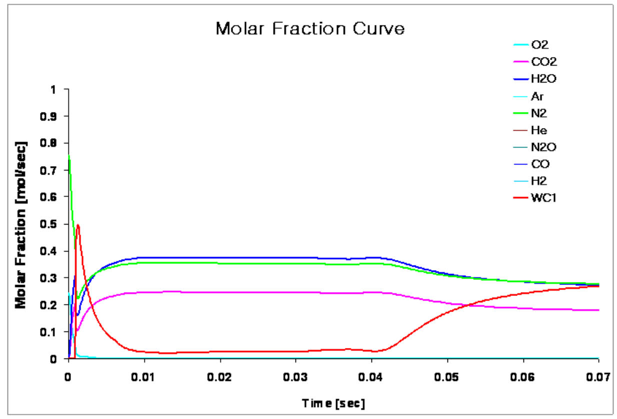

Fig.8 Molar Fraction Curve

1-6) Definition of Inflator Performance

Considering the inflator performance properties examined in Chapter 2, the inflator properties defined with existing maximum pressure only are subdivided into the below five properties.

1) Maximum pressure
2) Mass flow rate
3) Gas generation duration time
4) Maximum gas generation time
5) Gas emissions

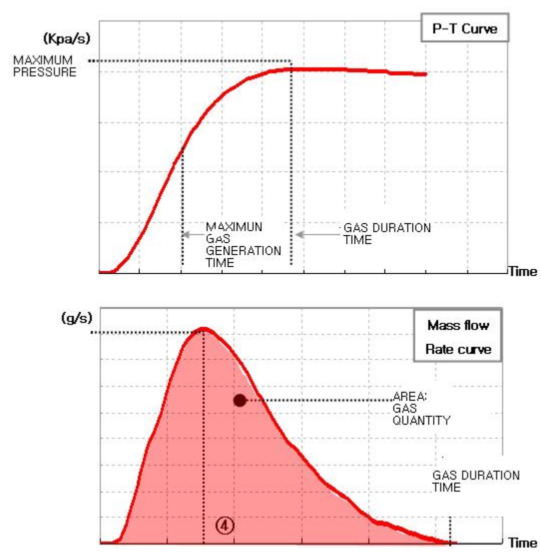

Figure9. inflator performance definition

1-7) Correlation between Inflator and Collision Performance

To analyze injuries by existing mass produced vehicles, the worst injury is Nte in neck injuries, and to examine the correlation between the worst injury and inflator performance, for mass flow peak 1g/sec↑, the neck FZ injury increases at the latter part, and accordingly, Nte occurs in 25 ~ 35ms, and some target injury performance (within 70% of the regulations) is not satisfactory.

For mass flow peak 1g/sec↓, Nte occurs around 10ms, and it all satisfies the goal.

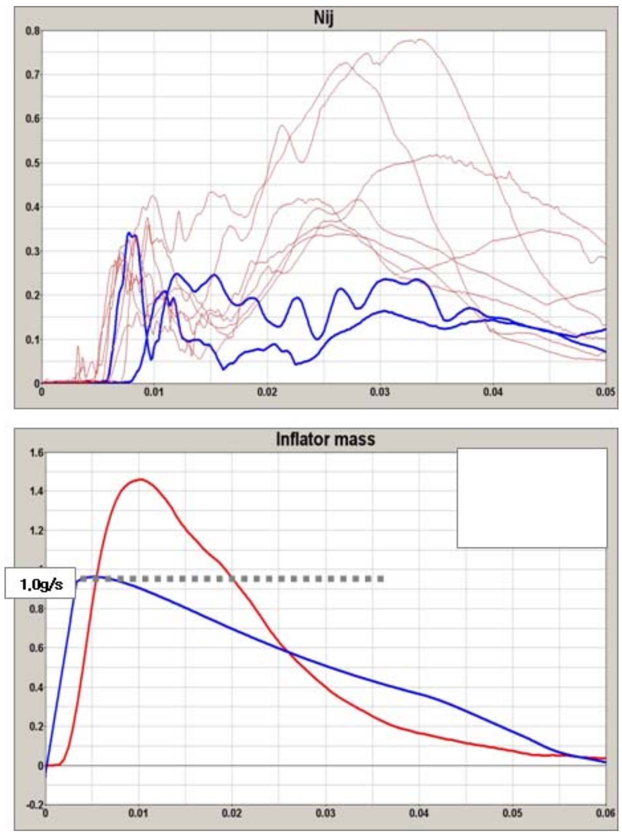

Figure10. Position 1 Nte (by inflator properties)

In other words, regardless of the final pressure, it is linked to the size of mass flow rate, and if mass flow rate peak is over 1.0, in the latter part (25 ~ 35ms), as Nte reaches the maximum with the tensil force and the resulting action of moment, some models do not satisfy the goal, and if mass flow rate peak is below 1.0, in the initial part (before 10ms), it reaches the peak of the tensile force and Nte reaches the maximum, but both show a satisfactory level.

To analyze injuries by existing mass produced vehicles, the worst injuries are CHEST d and CHEST g injuries, and to examine the correlation between the worst injury and the inflator performance, the time of mass flow rate peak and the time of chest injury peak tend to be consistent. At this time, if mass flow peak is 1g/sec↑, chest injury rapidly increases, and accordingly, the target injury performance (within 70% of regulations) is not satisfactory.

For mass flow peak 1g/sec↓, all chest injuries satisfy the goal.

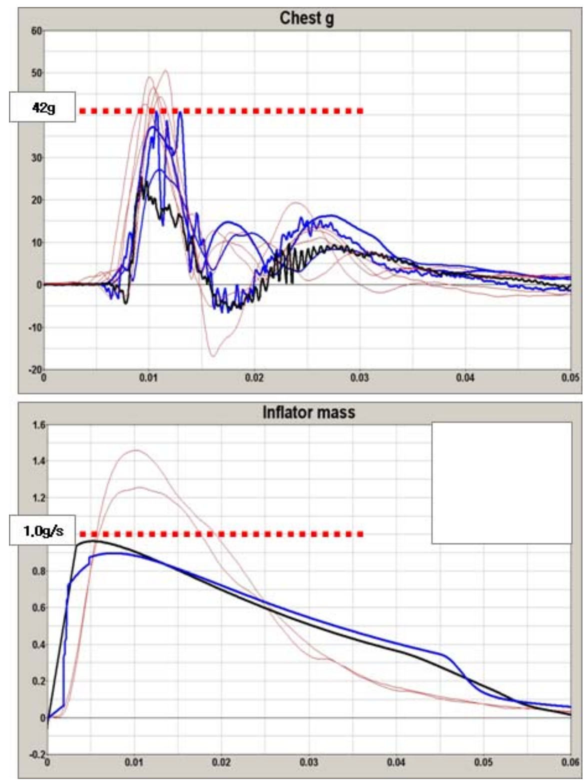

Figure11. Position 2 Chest g (by inflator properties)

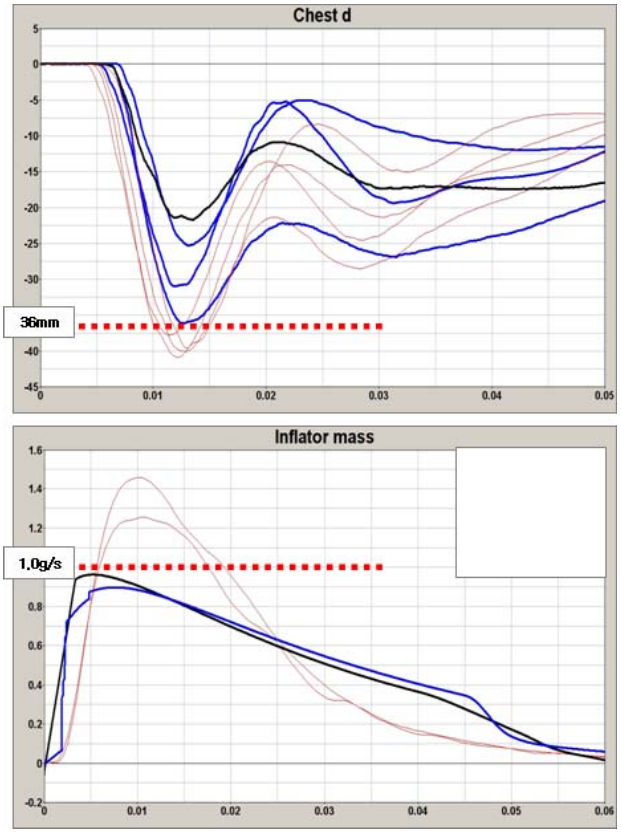

Figure12 . Position2 Chest d (by inflator properties)

In other words, regardless of the final pressure, it is linked to the time of reaching the peak of mass flow rate and its amount, and when mass flow rate peak is over 1.0 and reaches within 10ms, chest injury does not satisfy the goal, and if mass flow rate peak is below 1.0 and the time of reaching the peak is around 10~15ms, all chest injuries satisfy the goal.

That is, the inflator properties requested through analysis on LRD performance are as follows:

구 분	Primary
최대 Mass flow rate	1.0g/s ↓
Mass peak 시간	10 ~15ms

Table2. Requirements for inflator

DAB Tear Line Selection

DAB cover pattern can be designed in various specifications, but for LRD performance, it is most advantageous to decide the specifications in which the additional reaction applied to the cushion after unfolding is minimized.

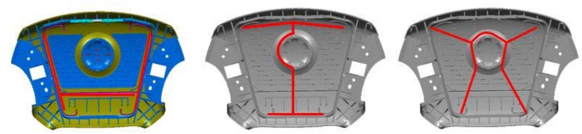

Figure13 . tear line pattern

Cushion Folding Method

The difference of the cushion shape in unfolding because of the cushion folding is very clear. To optimize LRD performance, it is advantageous to unfold it in a radial unfolding method by which the punch-out force applied to the dummy in unfolding decreases.

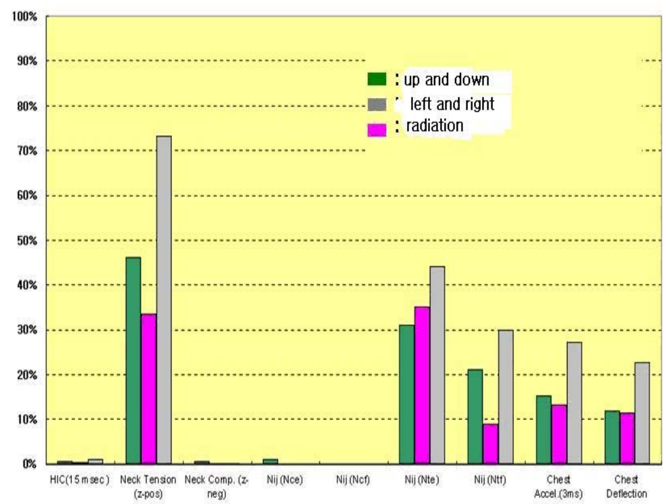

Figure14 . test result according to folding pattern

Mounting Location of DAB Module

The degree of position of DAB module on STRG WHL, also, may greatly affect LRD performance. When DAB unfolds, to make DAB cover pass over the visible space at the top of STRG WHL, it is good to be positioned downward if possible, and in terms of chest injury value, it is good for DAB module to be positioned below the plane of STRG WHL REFERENCR.

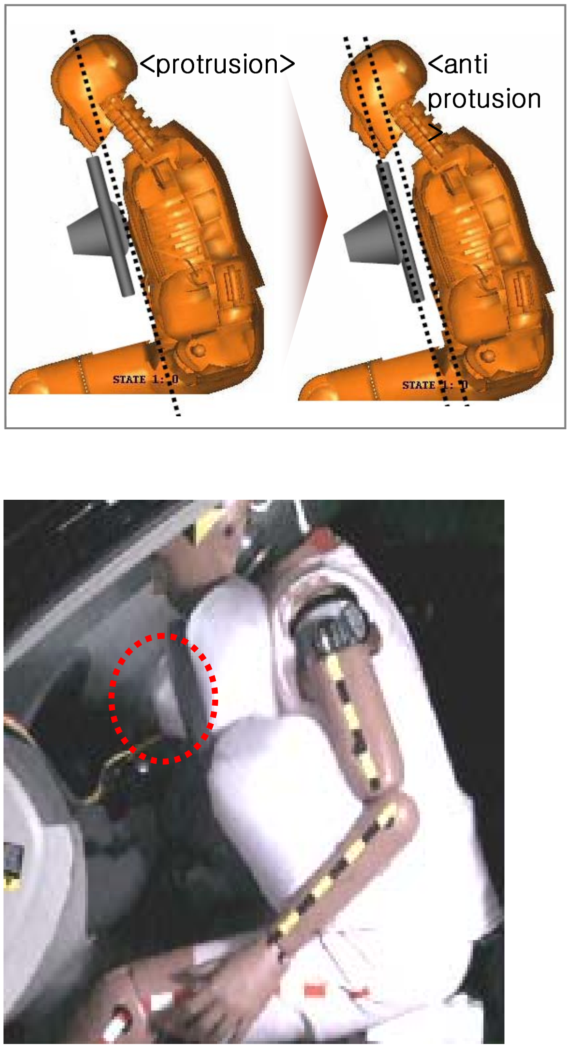

Figure15 . test result LRD accoring to STRG layout

Distance between the bottom of the Sun Visor and the center of STRG WHL

In LRD unfolding, the dummy flies to the sheet because of the reaction of DAB cushion, and at this time, if the space from the sun visor is narrow, the back of the head directly contacts the sun visor, which may adversely affect the head injury, sufficient space should be secured.

Figure16 . test result LRD accoring to vehicle layout

Conclusions

1) DAB applying a Single Stage Inflator that meets North American LRD performance may be overcome only by the detailed analysis on the element design technology of each component part and sufficient understanding about the vehicle layout.

2) Our company is working on the mass production of two models based on the details mentioned in the body.

3) We ask you for understanding about the parts about which we may not present guide figures of each item except inflator since they are our company's know-how.

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Seat belt wearing characteristics of drivers aged 75 years and older

Julie Brown
Neuroscience Research Australia and School of Medical Science UNSW
Australia
Kristy Coxon
The George Institute for Global Health, University of Sydney
Australia
Cameron Fong
Neuroscience Research Australia and School of Medical Science UNSW
Australia
Elizabeth Clarke
University of Sydney
Australia
Lisa Keay
The George Institute for Global Health, University of Sydney
Australia
Paper Number 13-0389

ABSTRACT

Elderly motor vehicle occupants are over represented among serious occupant casualty numbers, and the most common region of the elderly occupant's body injured in crashes is the chest. Chest injuries carry a significantly higher risk of death among elderly than younger occupants. While three point seat belts are effective in reducing the risk of death and injury in Crashes in the general population, the seat belt is often cited as a source of chest injury among elderly occupants. Little is known about the seat belt wearing characteristics of older drivers. This study aims to describe seat belt wearing patterns among drivers aged 75 years and older by examining quality of seat belt use in terms of correctness and fit.

Driver's aged 75 years and older were interviewed and observed in their vehicles. Demographic, vehicle, and seat belt wearing data were collected during interview. Seat belt information included self-reported frequency of use and response to questions about positioning of seat belts, ease of use and comfort. Seat belt fit was assessed visually. Sash belt fit was judged 'good' if it passed over the mid portion of the shoulder. 'Poor' sash belt fit included belts positioned off the shoulder, across the tip of the shoulder or in contact with the neck. Lap belt fit was judged 'good' if the belt passed low over the abdomen with at least the bottom edge of the webbing in contact with the upper thigh. Participant height, weight and seated height were also recorded. A sample of 380 participants is being sought.

To date, data has been collected for 115 participants and data collection continues. Preliminary data indicates high rates of self –reported seat belt use, with only one participant reporting occasional non-use. However 22% indicate that they regularly re-position the sash portion of the seat belt. This is despite 92% reporting that wearing a seat belt is comfortable. In our sample, 44% reported having vehicles that allowed sash height adjustment, 30 were unsure if their vehicle had this feature, and only 70. % who had this feature, had ever used it. Visual observation of belt fit revealed good sash and lap belt fit in 30% of participants. Sash belt fit was good in 69% of participants, with 28% positioned off or across the tip of the shoulder, and 5% in contact with the neck. The lap belt was too high in 43% of occupants. Poor lap belt positioning was significantly associated with greater body mass index (BMI), but there was no association between sash belt fit and BMI or stature.

INTRODUCTION

Fatalities among older drivers are predicted to increase by more than 280% between 1995 and 2025[1] due to the ageing population and expected increases in mobility. Currently drivers over the age of 70 account for over 14% of driver fatalities[2] Hospitilization rates for drivers aged over 75 years are approximately 60 per 100,000 population – a rate only exceeded by young drivers aged 15-25 years.[3]

Elderly drivers have a high rate of crashes per kilometre driven[4,5] but tend to drive less than younger drivers, resulting in a lower crash involvement than any other age group.[6,7] Yet the elderly sustain more injury, and the injuries sustained by the are more severe than those in younger age groups.[6,-9] It is estimated that injury risk is 9 times higher per mile driven in drivers 85 years and older compared to 25-69 year olds.[10-12] Many older drivers die from crashes that would be survived by younger drivers.[13]

Chest injuries, including rib fractures, are the most common injuries seen in elderly drivers and occupants, and rib fractures carry a much higher rate of morbidity and mortality in older people than younger people[13-16]. While seat belts are acknowledged to be a highly successful countermeasure for reducing risk of death and injury, seat belts are the primary source of the chest injury seen among elderly occupants. [7,8,17]

There is no doubt that physiological changes associated with aging play a role in the increased overall susceptibility to injury, and the specific increased susceptibility to chest injury. Tolerance to seat belt loading is reduced with age[18,19]. This change in tolerance is associated with thoracic structural differences, such as variation in thoracic geometry[19], and spinal geometry associated with aging.[20] Furthermore, overall body shape changes with age[21].

It has been established that body shape variations, like that which occur with obesity can negatively influence seat belt fit [22] and it is possible body shape variations with aging may also negatively influence seat belt fit.

Poor seat belt fit may negatively impact on chest injury risk in two ways. Firstly it might alter the distribution of loads applied to the chest during a crash, and secondly it might affect user comfort leading to users inappropriately positioning the seat belt for comfort.

This paper reports preliminary observations from study investigating belt wearing patterns among drivers aged 75 years and older by examining quality of seat belt use in terms of correctness and fit.

Method

Driver's aged 75 years and older were recruited as part of a randomised control trial (RCT) of a program aimed at enabling older, at risk drivers to self-limit driving but maintain mobility[23] The study aims to recruit 380 drivers aged >75 years over from the outer suburbs and semi-rural areas of Sydney using advertising in local media, seniors groups and through a mail-out to members of a motoring organisation in New South Wales.

As driving is to be measured objectively in the RCT, all participants are the primary driver of their own car.

During baseline assessment for the RCT a home visit by an occupational therapist was conducted. During this visit a short questionnaire to collect demographic information and details about seat belt use was completed. Questions asked include how often the participant travels unrestrained and if so to explain why they sometimes don't use a restraint; if they find the seatbelt comfortable; if they ever reposition the seatbelt and if so, how they reposition the belt; and to report on specific issues they have had with belt fit e.g. does the belt cut into their neck, does the belt slip of their shoulder. Participants were also asked to report if the seat belt sash height is adjustable in their vehicle and if it is, have they adjusted it to improve belt fit or comfort.

Weight, standing height and seated height were also measured during the baseline visit. Standing height and weight were used to calculate the participants Body Mass Index (BMI).The participant was then asked to sit in their vehicle and engage their seat belt. A series of photographs were taken to record seat belt fit.

Seat belt fit was then assessed visually from the photographs taken during the baseline visit. Sash belt fit was judged 'good' if it passes over the mid portion of the shoulder. 'Poor' sash belt fit includes belts positioned off the shoulder, across the tip of the shoulder or in contact with the neck. Lap belt fit was judged 'good' if the belt passes low over the abdomen with at least the bottom edge of the webbing in contact with the upper thigh. Good overall seat belt fit required good sash belt fit and good lap belt fit.

Data from the questionnaires were coded and recorded in a custom designed database. BMI was categorised into underweight (BMI < 18.5), normal (BMI 18.5-25) and overweight (BMI >25). Standing height was used to group participants into height categories of 'tall' (174cm and greater) and 'short' (less than 174 cm tall). This breakpoint was chosen as it represents the 50th percentile height of males aged 70 to 79 years[24] As no anthropometric profiles for seated height of people in this age range (or for adults per se) were available, seated height was used as a continuous variable only.

All analysis was conducted using SPSS (IBM Corp. Released 2012. IBM SPSS Statistics for Windows, Version 21.0. Armonk, NY: IBM Corp). Descriptive

techniques were used to calculate frequencies and cross tabulations. Chi square was used to assess significance in the cross tabulations. Logistic regression was used to examine the association between seat belt fit and BMI and height.
This study has been approved by the University of Sydney Human Research Ethics Committee.

Results

A total of 115 participants have been recruited to date. There is incomplete data for 8 participants and these have been excluded from analysis, leaving a sample of 107.

Participants range in age from 75 to 92 (mean 80 years), and currently there are 39 females and 68 males. Almost all participants (97%) report always using a seat belt, and most (92%) described the seat belt as comfortable. However 23% report sometimes repositioning the belt to improve comfort. Table 1 presents responses to a number of situations where participants were asked if they specifically encountered comfort problems. The most commonly reported were 22% reporting experiencing the belt cutting into their neck and 14% reporting the belt touching their neck when they turned. Participants were asked if they ever put the sash under their arm or behind their back and 6% reported doing this.

Situation	% (n)
Belts cuts into neck	22 (24)
Belt tightens over time	8 (8)
Belt slips off shoulder	0 (0)
Belt feels loose	4 (4)
Belt touches neck when turning	14 (15)
Belt interferes with side view	3 (3)
Belt feels tight	4 (4)
None of the above	63 (67)

Table1.
Situations reported in response to question "Do you experience any of the following when having your seat belt on?" NB could choose more than one answer, response add up to >100%

Almost one third (30%) of participants reported not knowing if their vehicle allowed adjustment of the sash belt height, 44% reported that their vehicle did allow this adjustment and 26% had vehicles with no height adjustment feature. Of those with potential height adjustment, 70% (?/107) had adjusted the height for better fit or comfort.

Photographs for seat belt analysis were currently available for 58 participants (26 females and 32 males). Figure 1 illustrates the observed seat belt fit. While 69% of participants demonstrated good sash belt fit, and 60% demonstrated good lap belt fit, only 36% demonstrated good overall belt fit. Poor sash belt fit and poor lap belt fit was observed in 10% of participants.

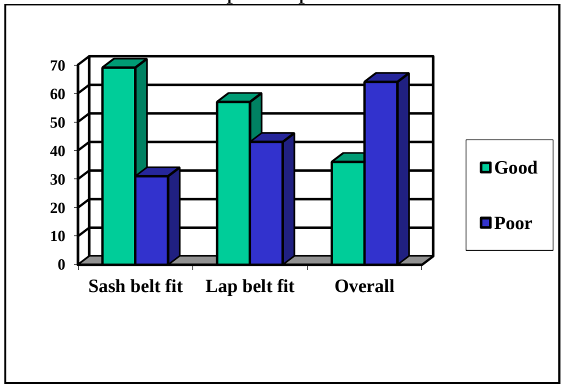

***Figure1*. The proportion of participants with good sash belt fit, good lap belt fit and good overall belt fit.**

In this preliminary sample there was no association between whether or not participants reported that they sometimes reposition the belt for comfort and observed belt fit. Nor were there any associations between the situations experienced (see Table 1) and observed belt fit.

There was a significant association between observed belt fit and BMI. Participants in the overweight group were 4.2 times (95% CI 1.2-15.1) more likely than those in normal range to have poor lap belt fit (no participants fell within the underweight range). While there was a trend towards 'tall' participants having good lap belt fit (OR 3.8, 95% CI 0.9-15.5), and good overall belt fit (OR 1.7, 95% CI 0.5-5.6), this did not reach significance. There was no association between standing height and sash belt fit. When adjustment of sash belt height was controlled, the odds of having good sash belt fit was 1.1 times greater for 'tall' participants compared to short participants but this did not reach significance (95% CI 0.2-8.8).

There was no association between seated height and seat belt fit but seated height was only tested as a continuous variable (OR 1.02, 95% CI 0.95-1.1).

DISCUSSION & CONCLUSIONS

The key findings of this preliminary analysis is that despite high self reported restraint use, there appears to be high rates of seat belt fit problems among elderly (≥70 years) drivers. Furthermore this does not appear to be associated with discomfort, although almost one quarter of participants in this study report sometimes repositioning the belt to improve comfort.

A strength of this study is that observations about seat belt fit were made in the elderly drivers' own vehicles, but caution should be exercised in reviewing these results as this community sample may not be representative of all drivers in this age range. The fact that drivers were also asked to fit their seat belts while being observed is also a potential source of bias as participants may have altered they way they naturally wear their belts. Importantly the results presented here represent a preliminary analysis only and may vary somewhat when the final full sample is included.

Tthese preliminary survey responses suggest that almost all older drivers in this setting regularly use seat belts. While 22% report sometimes repositioning the belt only 6% describe positioning the sash part of the belt behind their back or under their arm.

Despite the good seat belt wearing behavior observed in this study, the high rate of poor seat belt fit warrants further investigation. It is possible poor seat belt fit might contribute to the increased risk of injury, and increased severity of injury observed in older occupants. Interestingly, two-thirds of our sample were 'overweight' according to their BMI using a breakpoint for overweight of BMI of 25. Obesity has been reported as increasing the severity of injury in crashes[26] and also modifies kinematic response and loading patterns.[27] There appears to have been no study of the interaction between obesity and the vulnerability to crash injury associated with aging but our observations suggest this might be a useful area of further study.

We observed significantly more poor lap belt positioning among the elderly drivers in the overweight category and this supports the findings by Reed et al.[23] Reed reported that obesity adversely affected seat belt positioning by effectively introducing slack into the seat belt system and routing the belt further away from the skeleton. They found with obesity, the lap belt is positioned further forward, and higher, relative to the anterior iliac spines than in normal weight people, a finding similar to what we observed here. However Reed also noted differences in sash position, with obesity associated with a more-inboard sash belt routing. We did not find any association between BMI and sash belt fit but this difference may be attributed to the scoring system we used. We did not measure or assess sash belt angle, but scored seat belt fit on the gross position of the belt relative the tip of the shoulder and the neck.

Similarly we did not find any association between standing height or seated height with sash belt fit. We were unable to categorised this variable due to the absence of good normative anthropometric data, and therefore the lack of an appropriate breakpoint for categorising this variable.This will be further explored in the final analysis when data for the full sample of 380 elderly drivers is available.

Another important issue for future consideration is the reported poor relationship between BMI and body shape in the elderly[22] In a large UK sizing study using 3D body scanning Wells *et al.* found BMI to be insensitive to age-associated changes in the distribution of body weight. Their observations suggest thatthere is a shift in fat toward the upper body with age and, within the upper body, to a preferential distribution around the waist rather than the arm and bust, may have significant impact on seat belt fit with increasing age of the occupant. It might be sensible to include measures of occupant shape, such as chest and waist girth, in addition to BMI in future studies examining the effect of obesity and/or age and seat belt fit.

Besides the convenience-based community sample, self report and observation of fit limitations described earlier, another limitation in this study was in the measurement of comfort. Here we simply asked participants 'Overall, with the seat belt on do you feel comfortable?'. This may have been too general, and did not provide the opportunity to quantify discomfort. The use of a validated tool like the ASDQ[28] is recommended for future similar studies.

In conclusion, this preliminary analysis has demonstrated that elderly drivers aged 75 years and older may be experiencing significant seat belt fit problems, and this issue is worthy of further study.

ACKNOWLEDGEMENTS

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Optimization of an Automobile Curtain Airbag using Design of Experiments

Yong-Won Yun
Korea Automobile Testing and Research Institute

Jung-Sun Choi
Ph.D. Student, Mechanical Engineering, College of Engineering, Hanyang University

Gyung-Jin Park
Corresponding author, Professor, Mechanical Engineering,
College of Engineering Sciences, Hanyang University

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ABSTRACT

A side collision of an automobile poses a higher risk of injury compared to those of a frontal collision. Therefore governments and insurance companies establish and implement new safety standards in order to ensure the safety of the occupants throughout the world. Most of the suggested standards aim to reduce the Head Injury Criterion (HIC). Widely used side airbag systems, including the curtain airbag, are known to be the most effective means to reduce HIC, but designing a curtain airbag is a very difficult task due to the non-linear characteristics of HIC and the airbag deployment mechanism. These difficulties cause an airbag engineer to choose design variables more cautiously and seek more effective design methods. This paper introduces the curtain airbag design procedure which uses current optimization methods in order to reduce the HIC risks of the occupants. First of all, it defines various elements of the curtain airbag as design variables, performs a computer-based analysis based on the Analysis of Variance (ANOVA) technique, and then selects and defines design variables important to the head injury criterion. These defined variables and the Orthogonal Array (OA) test to reduce the head injury criterion were used. The Response Surface Method (RSM) was used as an approximation method. The results were reviewed and compared in order to find a design solution to minimize the head injury criterion. These test results will give effective design methods for curtain airbag engineers.

INTRODUCTION

A side collision of an automobile imposes a higher death rate compared to a frontal collision because an automobile does not have enough space to absorb the impact energy. Throughout the world, government agencies and private sectors are using various automobile safety standards, such as the New Car Assessment Programs (NCAP) to protect occupants from a side collision. The common objective of those safety standards and NCAP standards is to reduce the occupants' injuries, especially a head injury. In the case of a frontal collision, the structure of a car is designed to be deformed enough to absorb the collision impact energy, and it consequently provides protection to the occupants. However, in the case of a side collision, due to the structural limitation, it is impossible to install such a protective mechanism. Therefore curtain airbags are widely adopted as a protective means for the occupants.

The noticeable benefits of a curtain airbag system include the easiness of installing/activating in a narrow space and the very short deflation time. However, designing a curtain airbag system is a difficult task because of the many non-linear characteristics of related variables, including the head injury criterion and the variety of possible collision situations. In the past, researchers accomplished various studies for the curtain airbag system. Zhang and his colleagues designed an airbag system and also the kind of inflator needed to improve the curtain airbag inflation speed and in order to reduce the head injury criterion.(1) Foneseka and his colleagues performed sensitivity analysis on design parameters such as the thorax/pelvis airbag systems and the thickness of car door structures, in order to reduce the occupants injuries in a side collision.(2) Jeon and his team researched the injury patterns of dummies and their dependence on airbag design parameters.(3) Marklund and his colleagues used elements that have an influence on airbag inflation as the design parameters and applied them in order to achieve an optimum airbag design to minimize occupants' injuries.(4-6) There is a research suggesting that in the case of a side impact, generally chest and abdomen related injury parameters, such as chest compression are the most important factors to body injuries.

In existing assessment methods, the performance of an airbag is regarded satisfactory if the head injury criterion does not exceed a certain level. However, some research suggested that more attention should be given to the head injury criterion in the airbag design stage because of the newly amended United States New Car Assessment Program (U.S. NCAP) regards the level of the head injury criterion as an important factor of assessment.(9) It means that head injuries are the most influential factors on the injury distribution chart in case of death during an accident. Whereas chest and back injuries are the influential factors on the injury distribution chart in case of serious injuries during an accident.

Previous studies have identified important elements that pose an important influence on the performance of an airbag. These are Mass Flow Rate (MFR), Time to Fire (TTF), Vent Hole Area (VHA), Material Density (MD), Tether Length (TL).(10-13) Especially one study performed sensitivity analysis on these design parameters and identified MFR, TTF, and VHA as the most important design parameters.(13)

One benefit of using the Orthogonal Array (OA) table is that engineers can obtain non-continuous design values instead of continuous design values which is difficult to use in a real manufacturing stage just like an optimum design.(15-16) Moreover using orthogonal arrays in a discrete space helps engineers to obtain design results with a limited number of analysis trials because they can use fractional replication for the combination of design parameters.(12)

One of the simplest test plan strategy is known as the One-Way Table. This test table can be used when only one factor is used while multiple levels are used.(14) This table is most widely used when the rest of the influential factors, that influence the characteristics values are examined. Only one influential factor remains to be examined for its influence under a given condition. The one-way table is most commonly used if the number of levels are between 3 to 5, and the number of repetition is between 3 to 10.(17) Setting the number of levels to 3 and ±20% is done because the level of design parameters can be selected appropriately according to a given condition. Also normal design changes are limited and the design parameter values are choosen from several values.

In statistics, the response surface methodology (RSM) explores the relationships between several explanatory variables and one or more response variables. The method was introduced by Box and Wilson in 1951, and it has been studied by many other researchers recently.(17) This method is mainly used to optimize the approximation function.

In the case of analysis of occupants injuries, the response surface methodology can be a great tool to estimate HIC, an objective function, more effectively and easily.(12) In this research, PIAnO(Process Integration Automation and Optimization),(18) a commercially-sold statistical application, for optimization was used.

In this research, 4 new design parameters (gas temperature, cushion thickness, elasticity constant, and fabric leakage) and 4 already-studied design parameters (MFR, TTF, VHA, MD)were used. They were combined to perform variance analysis to analyze their influences, find/choose the most influential design parameters, and use them to design a curtain airbag that minimized the head injury criterion. In this analysis, the impact speed is set to 55 km following the side collision speed used in the Korea New Car Assessment Program (KNCAP). And this test is conducted to simulate a vehicle crash in a SLED condition. In order to construct an optimal design methodology, the orthogonal array, the one-way table and the response surface method were applied in order. Moreover, the results of each test were checked through a verification test and the optimal curtain airbag design methods to reduce head injury were introduced. The results of this research is expected to be a meaningful tool in designing the curtain airbag to protect occupants during a side crash.

Safety Standards for Side Impact

<u>Safety Standards and Safety Level Assessment</u>

There are two major safety standards concerning occupants' safety in a vehicle crash: automobile safety standards and new car assessment programs. Side crash safety standards include the Vehicle Safety Standard Act (article 104, Korea), FMVSS (214, U.S.), UN Regulation (95, European Union).(19) Generally, the test conditions are not severe or extreme, but if a test automobile does not satisfy the regulations, legal actions, such as a forced recall is done.

Generally new car assessment programs impose more severe test conditions compared to normal automobile safety standards, but they do not have legal binding power. Most of the automobile safety agencies have adopted a star rating system to provide safety information to the customers. There are many new car assessment programs concerning a side collisions which include KNCAP (Korea), US NCAP (U.S.), Euro NCAP (Europe), JNCAP (Japan), etc.

Side Crash Safety Test Methods

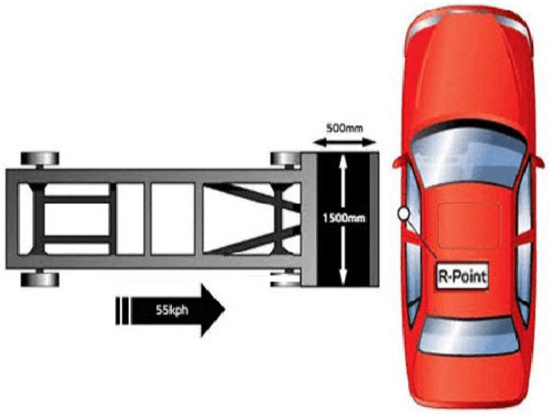

Figure 1. Side Crash Test Methods

Figure 1 shows the side crash assessment method of KNCAP. In this assessment test, a side crash mobile wall crashes into a test vehicle driver's side at 55±1 km/h perpendicular to the direction of the vehicle. Injury values such as head injury, chest injury, abdomen injury, and pelvis injury are measured. More specifically, injury values are categorized into the head injury criterion (HIC), chest compression, viscous criterion, total abdominal force and pubic symphysis force. In terms of HIC, a vehicle should have 1,000 points or lower to pass the test, and to achieve the most credit, it should have 650 points or lower.

Head Injury Criterion (HIC)

Body injury criterion is adopted in order to assess the occupant protection performance of a vehicle. The injury criterion is a physical measurement (acceleration/deceleration, impact load, changes in shape) of the human body which occurred due to the collision. HIC is the most widely used parameter in body injury assessment, and it can be calculated using the acceleration history values as shown below:

$$\text{HIC} = \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a\,dt\right]^{2.5} (t_2 - t_1) \quad (1)$$

Curtain Airbag System

Components and Activation Principles

Generally an airbag system consists of airbag modules, impact sensors, and a control unit. The airbag module includes an inflator (an inflation device for operation gas), an airbag cover, and a cushion. Impact sensors measure acceleration/deceleration of the vehicle, and they are installed in both sides of the vehicle, or in both door sides of the vehicle in the case of curtain airbags. They detect the deceleration of the vehicle when a side impact occurs and send a signal to the inflator to activate the curtain airbag.

Before inflation After inflation

Figure 2. Curtain Airbag

Finite Element Model Used for Simulation

The European side impact dummy, EUROSID II (Euro Side Impact Dummy), was used for the body analysis. This dummy model was developed to be used in side impact tests by TNO, a Dutch company, to compete with FTSS's existing modeling dummies. Side crashes were simulated following SLED test conditions to simulate the side impact of a vehicle, and collision speed was set to 55 km/h. This Finite Element Model for side impact consists of the SLED test and the dummy, specially designed for side impact. The dummy was seated wearing a seat belt on the driver's seat. In this simulation, LS-DYNA was used for finite element modeling.

Figure 3. Finite Element Module (Initial)

Figure 4. Finite Element Module (90ms)

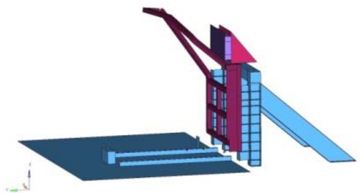

Figure 5. Finite Element Module (SLED)

Curtain Airbag Design Optimization

Design Formulation

This research defined new design parameters of the already widely identified major design parameters from previous researches for optimum design of the curtain airbag. The newly defined design parameters include fabric leakage, cushion thickness, gas temperature, and fabric elasticity constant. These 4 design parameters are used upon on 4 other previously known design parameters. These 8 parameters assumed to have ±20% of variation in reference to the reference value (100%).

Table 1. Design Parameters and Levels

	80%	100%	120%
MFR	0.0008	0.001	0.0012
TTF	6.4	8	9.6
VHA	141.28	176.6	211.92
MD	7.20E-07	9.00E-07	1.08E-06
Leakage	0.8	1	1.2
Thickness	0.248	0.31	0.372
Gas Temp	0.8	1	1.2
Elasticity Constant	0.2548	0.3186	0.3832

The objective function in this research is a minimization of HIC occurance, and the optimum design is fomulated as below:

Minimize HIC(b_1,b_2, b_3, b_4, b_5, b_6, b_7, b_8) (2)

$0.0008 \leq b_1 \leq 0.0012$ (2.a)

$6.4 \leq b_2 \leq 9.6$ (2.b)

$141.28 \leq b_3 \leq 211.92$ (2.c)

$7.20E\text{-}07 \leq b_4 \leq 1.08E\text{-}06$ (2.d)

$0.8 \leq b_5 \leq 1.2$ (2.e)

$0.248 \leq b_6 \leq 0.372$ (2.f)

$0.8 \leq b_7 \leq 1.2$ (2.g)

$0.2548 \leq b_8 \leq 0.3832$ (2.h)

Optimum Design Method and Procedure

Using the full fractorial experment technique with 8 design parameters in level 3 requires a total of 6,561 tests. However, with the help of an orthogonal array, one can find a valid solution with only 36 tests (L_{36}). An orthogonal array table is formed for the defined design parameters, and Analysis of Variance is performed to find influential design parameters. The orthogonal array table, the one-way table and the response surface method are all applied in order.

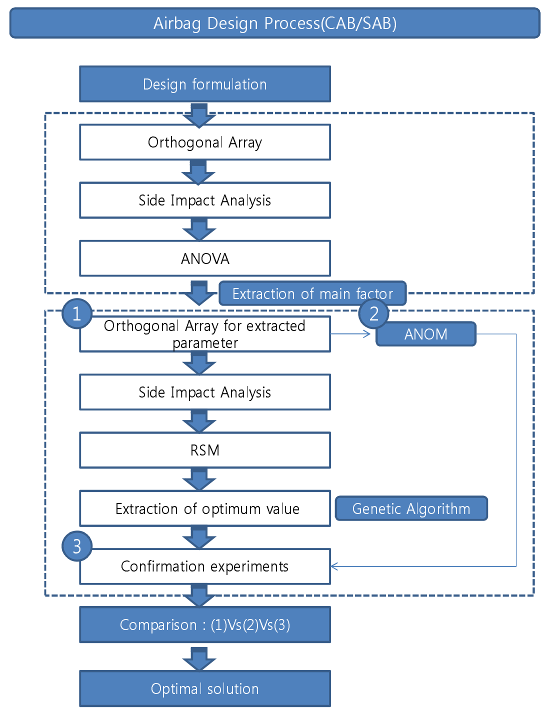

Figure 6. Optimum Design Method and Procedure

Results of Optimal Design

A design solution was found using the level 2 orthogonal array table for the 8 selected design parameters. Orthogonal array table, $L_{36}(3^8)$, was chosen and used, and the results are shown in Table 2. In the $L_{36}(3^8)$ orthogonal array table, the optimal result was found in the 30[th] test and HIC was 78. For the reader's reference, HIC was 255 in the validation test result while using the basic model.

Table 2. Orthogonal Array Table(L_{36})

Based on Table 2, the influence of 8 design parameters on HIC was analysed using ANOVA. As

	x1	x2	x3	x4	x5	x6	x7	x8	HIC
1	7.20E-07	0.8	0.248	0.0008	0.0064	141.28	0.8	0.25488	122
2	7.20E-07	0.8	0.248	0.0008	0.008	176.6	1	0.3186	88
3	7.20E-07	0.8	0.31	0.0012	0.0064	176.6	1.2	0.38232	201
4	7.20E-07	0.8	0.372	0.001	0.0064	211.92	1	0.38232	105
5	7.20E-07	1	0.31	0.0012	0.0096	141.28	1	0.25488	143
6	7.20E-07	1	0.372	0.001	0.0064	141.28	1.2	0.3186	148
7	7.20E-07	1	0.372	0.0008	0.0096	176.6	0.8	0.38232	108
8	7.20E-07	1	0.248	0.0012	0.0096	211.92	0.8	0.3186	111
9	7.20E-07	1.2	0.248	0.001	0.0096	176.6	1.2	0.25488	129
10	7.20E-07	1.2	0.31	0.001	0.008	141.28	0.8	0.38232	89
11	7.20E-07	1.2	0.372	0.0012	0.008	211.92	1	0.3186	157
12	7.20E-07	1.2	0.31	0.0008	0.008	211.92	1.2	0.25488	107
13	9.00E-07	0.8	0.372	0.001	0.0096	141.28	0.8	0.3186	88
14	9.00E-07	0.8	0.372	0.0012	0.0096	176.6	1	0.25488	149
15	9.00E-07	0.8	0.248	0.0008	0.0096	141.28	1.2	0.38232	112
16	9.00E-07	0.8	0.31	0.0012	0.0064	211.92	0.8	0.3186	86
17	9.00E-07	1	0.372	0.0008	0.008	211.92	0.8	0.25488	121
18	9.00E-07	1	0.31	0.001	0.008	176.6	1	0.3186	115
19	9.00E-07	1	0.31	0.001	0.0096	211.92	1.2	0.38232	142
20	9.00E-07	1	0.248	0.0012	0.008	141.28	1.2	0.25488	168
21	9.00E-07	1.2	0.248	0.0012	0.008	176.6	0.8	0.38232	113
22	9.00E-07	1.2	0.248	0.001	0.0064	211.92	1	0.25488	91
23	9.00E-07	1.2	0.372	0.0008	0.0064	176.6	1.2	0.3186	108
24	9.00E-07	1.2	0.31	0.0008	0.0064	141.28	1	0.38232	93
25	1.08E-06	0.8	0.248	0.001	0.008	211.92	0.8	0.38232	85
26	1.08E-06	0.8	0.372	0.001	0.008	176.6	1.2	0.25488	145
27	1.08E-06	0.8	0.31	0.0008	0.0096	211.92	1	0.25488	89
28	1.08E-06	0.8	0.31	0.0012	0.008	141.28	1.2	0.3186	202
29	1.08E-06	1	0.372	0.0008	0.008	141.28	1	0.38232	87
30	1.08E-06	1	0.31	0.001	0.0064	176.6	0.8	0.25488	78
31	1.08E-06	1	0.248	0.0008	0.0064	211.92	1.2	0.3186	99
32	1.08E-06	1	0.248	0.0012	0.0064	176.6	1	0.38232	128
33	1.08E-06	1.2	0.372	0.0012	0.0096	211.92	1.2	0.38232	179
34	1.08E-06	1.2	0.372	0.0012	0.0064	141.28	0.8	0.25488	103
35	1.08E-06	1.2	0.248	0.001	0.0096	141.28	1	0.3186	111
36	1.08E-06	1.2	0.31	0.0008	0.0096	176.6	0.8	0.3186	112

a result of the analysis, the magnitude of the influence of the design parameters were estimated: gas temperature (27 %), MFR (25%), cursion thickness (6%) and TTF (5%).

Table 3. Variance Analysis Results

Design variables	Effect
b1	5.21%
b2	4.73%
b3	6.56%
b4	25.79%
b5	5.23%
b6	4.43%
b7	27.44%
b8	0.21%
interaction	20.39%
TOTAL	100.00%

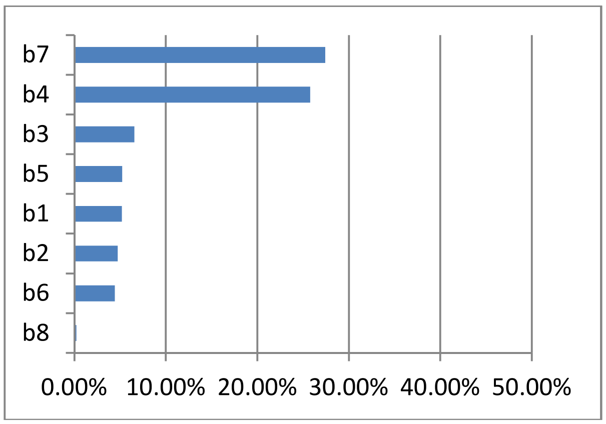

Figure 7. Variance Analysis Results

After completing ANOVA analysis, the 4 most influential design parameters were found, and a design solution was found using the $L_{18}(3^4)$ level 3 orthogonal array table. This is shown in Table 4.

Table 4. Orthogonal Array Table (L_{18})

	TTF	MFR	Temp.	Thick.	HIC
1	0.0064	0.0008	0.8	0.248	121
2	0.0064	0.0008	1	0.372	83
3	0.0064	0.001	0.8	0.372	87
4	0.0064	0.001	1.2	0.31	146
5	0.0064	0.0012	1.2	0.248	177
6	0.0064	0.0012	1	0.31	145
7	0.008	0.001	1.2	0.248	142
8	0.008	0.001	1	0.31	110
9	0.008	0.0012	1	0.248	140
10	0.008	0.0012	0.8	0.372	108
11	0.008	0.0008	0.8	0.31	118
12	0.008	0.0008	1.2	0.372	105
13	0.0096	0.0008	1	0.248	91
14	0.0096	0.0008	1.2	0.31	108
15	0.0096	0.0012	1.2	0.372	194
16	0.0096	0.0012	0.8	0.31	108
17	0.0096	0.001	1	0.372	112
18	0.0096	0.001	0.8	0.248	89

The optimal result was found in the second test condition of the $L_{18}(3^4)$ OA table, and it was HIC of 82. Optimal results were extracted from Table 4, added to a one-way table, and the design parameter solution was calculated and shown in Table 5. The optimal design parameter levels were level 3(TTF), level 1(MFR), level 1(gas temperature) and level 3(cushion thickness). More specifically, parameter values were 0.0096(TTF), 0.0008(MFR), 0.8(gas temperature) and 0.372 (cushion thickness). HIC was found to be 108 in the validation test. The results produced in the one-way table were worse than the results produced from the orthogonal array table because the interaction between the design parameters were not taken into consideration when the orthogonal array table method was used.

Table 5. One-way Table

	TTF	MFR	Temp.	Thick.
Level 1	126	104	105	126
Level 2	120	114	113	122
Level 3	117	145	145	114

After completing the above mentioned procedues, the reponse surface method was applied to calculate HIC using the 3rd order formula (cubic). The results of the calcuation are shown in Table 6. Candidate points were selected from Table 2 (results of the orthogonal array table) to produce the reponse surface method. After applying the response surface method for HIC calculation, optimal design parameters were found to be 0.0064(TTF), 0.0008(MFR), 1(gas temperature) and 0.372(cushion thickness) while HIC was 84. Validation tests were performed by combining the above mentioned design parameters, and HIC was found to be 213.

Table 6. Response Surface Method

	Lower	Initial	Optimal	Upper

TTF	6.40E-03	8.00E-03	6.40E-03	9.60E-03
MFR	8.00E-04	1.00E-03	8.00E-04	1.20E-03
Temp.	8.00E-01	1.00E+00	1.00E+00	1.2E+00
Thick.	2.48E-01	3.10E-01	3.72E-01	3.72E-01
HIC			84	

HIC values, calculated from $L_{36}(3^8)$ and $L_{18}(3^4)$ orthogonal array tables, one-way table, and response surface method, were tested through the validation test, and the final results were found as shown in Table 7.

Table 7 Final Results

	TTF	MFR	Temp.	Thick.	HIC
O.A.(L_{36})	0.0064	0.001	0.8	0.31	78
O.A.(L_{18})	0.0064	0.0008	1	0.372	83
O.W.T.	0.0096	0.0008	0.8	0.372	108
R.S.M.	0.0064	0.0008	1	0.372	84

As a result, optimal HIC(78) was obtained from the orthogonal array table while the design parameters were 0.0064(TTF), 0.001 (MFR), 0.8 (gas temperature) and 0.31 (cushion thickness). It means that HIC is reduced by more than 69.4 % compared to the initial reference HIC, which is 255. The optimal solution found from the reponse surface method was HIC(84), but after examining it through a validation test using design parameters, it produced the worst HIC(213).

Conclusions

In this research, the optimal design of the curtain airbag to provide safety to the occupants in a vehicle was conducted. Generally, due to the nonlinear characteristics of the airbag, head injury criterion and a variety of crash conditions, designing a curtain airbag is a difficult task. Therefore, a literary search of previous researches have been carried out to define important design parameters.

In this research, newly found design parameters were adopted upon already identified important design parameters, used in the curtain airbag design. A design solution was produced by the use of 8 design parameters, 4 of them were newly adopted, and an orthogonal array with 3 levels. Furthermore, ANOVA analysis was carried out along with orthogonal array table method to find the most important design parameters concerning HIC. The orthogonal array table, the one-way table, the response surface method were all applied in order, and the results produced from each method were tested and validated through impact simulation.

As a result, optimal HIC(78) was obtained from the orthogonal array table $L_{36}(3^8)$ while design parameters were 0.0064(TTF), 0.001(MFR), 0.8(gas temperature) and 0.31(cushion thickness). It means that HIC was reduced by more than 69.4 % compared to the initial reference HIC, which was 255. Generally the results obtained from the response surface method is supposed to be better. However, the optimal solution found from the response surface method was HIC(84), but after examining it through a validation test using design the parameters, it turned out to produce the worst HIC of 213. This unmatch was caused by the difference between continuity condition of the response surface method and the nonlinear characteristcs of the real values produced from the validation test.

Acknowledgements

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The Protections of the Elderly Vehicle Occupants: Need lower belt loading

Younghan Youn
Korea University of Technology and Education, Korea, Republic of
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ABSTRACT

With continuously efforts of improving vehicle safety adopting the emerging new technologies, reduction of traffic fatality has been dramatically improved. Also the rule making bodies in globally have been contributed significantly to protect vehicle occupants and pedestrians with global harmonization activities more enhanced safety regulations and requirements.
However, until recent a few years, the protections of vulnerable vehicle occupants, such as elderly drivers or passengers were not focused in the main stream of vehicle safety issues.

In globally, most of developed countries are either aged or aging societies. The fatality of elderly occupants (65 years old or more) rapidly increased in Korea. In 2010, while the fatality rate (per 1,000 accidents) for all age group was 24.3 deaths, but elderly vehicle occupant fatality ratio was 43.3. The major sources of elderly occupant fatality were come from the thoracic injuries.

In this paper, the average size of Korean elderly morphemic figure was investigated and developed the Koran elderly anthropometric models to assess kinematics of occupants and injury mechanism. Based on the existing injury risk curves, the injury risk curves of Korean elderly occupant and Korean elderly version of Hybrid III were developed. With scale methods, their injury risks were converted to the standard Hybrid III injury measurements.

With the developed injury risk curves, the probability of AIS 3+ injury of 50%, 20%, and 5% for 45 years old adult male (50th percentile) case, the rib deflections are 91.6mm, 73.28mm and 50.38 mm, respectively. For the Korean elderly case, the rib deflections are 77mm, 59.4mm and 37.4 mm, respectively. As the results, the current Hybrid III structure especially thoracic body is not good enough to assess the elderly thoracic injury.

The other additional requirements, such as limiting seat belt forces were recommended. The main sources of fatality or sever injury for elderly in vehicle occupants are from thoracic injuries due to aging effects of rib cage structures. Since the current Hybrid III's thoracic structure are stiffer than a human body, the more stringent rib deflection injury criteria may result the higher belt loading to the elderly rib cage.

INTRODUCTION

Already in 2000, Korea was in the stage of aging society with the 7.2% of elderly population. As rapidly increasing older age group, 65 years old group reached 11.4% in 2011 and it will be estimated entering aged society in 2017 with 14.0%. In 2026, elderly group will be reached up to 20.8% as the super aged society. The driver license for older age group was only 0.5% of the total driver license holding age group in 2001. But, the annual increase ratio of elderly driver is 14.9% compared 3.2% increasing ratio of total driver licenses.

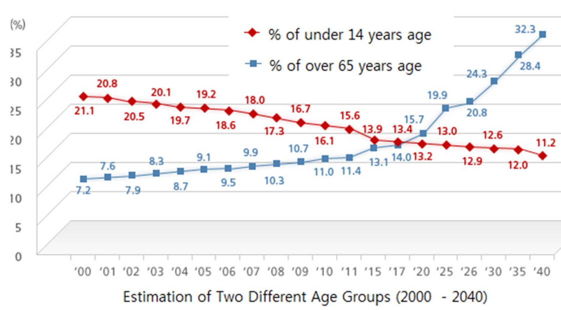

Figure 1. Trends of two different age groups

As other countries, in general, the overall traffic accidents are continuously decreased. In 2011, the total number of accident in Korea was reduced 14.9 % compared with 2001. The numbers of elderly driver involved accidents were only 3,768 in 2001, but with continuously increased the numbers of elderly driver accidents it was reached 13,596 in 2011. During the 10 years period, the elderly driver involved numbers of accidents were increased more than 360%. As shown in figure 2, in same period of time, the fatality ratio of elderly driver was increased 260%. The injury ratio was increased 380%.

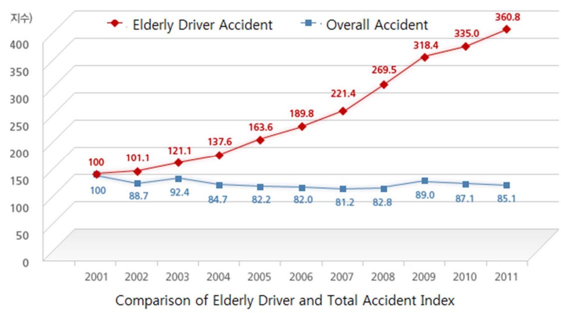

Figure 2. The annual trends of elderly driver involved traffic accidents

The percentage of elderly driver involved accidents was only 1.4% in 2001. In 2005, it was reached 2.9%. With continuously increased, in 2011, the percentage of elderly driver involved accidents was 6.1% of the total number of accidents. During 2001 to 2011 time period, the average fatalities per 100 accidents were 2.8 persons but, the fatalities per 100 accidents for the elderly driver was 2 times higher than the average fatality ration. It was 6 persons per 100 accidents as shown in figure 3.

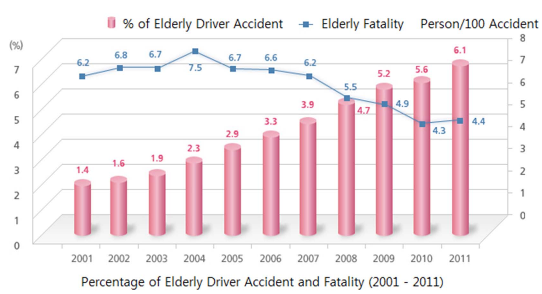

Figure 3. The Fatality ratios of elderly drivers

KOREAN ELDERLY OCCUPANT INJURY CHARACTERISTICS

The accident database of an insurance company was statistically evaluated to examine the elderly occupant's accident patterns and injury types. The total 64,424 car-to-car type frontal accidents was scanned but injury involved 32,195 accidents (injured person: 61,645) was collected as 1st data set. After eliminate the improper data not provide sufficient information, the final data set was targeted 26,057 injured accidents.

The data was categorized 4 different age group, such as less than 25 year old, 25 year to 54 year, 55 year to 64 year and 65 year and older. The injury characteristics were classified by 9 AIS injured body segment classes. The 3 highly injured body parts compared with other age groups were carefully investigated to find any statistical significant.

From results, the elderly occupants exposed higher risk in thorax, head and abdomen. The thoracic injury risk is 2.6 time higher than other ages. The head injury is 1.3 time higher and abdomen injury is 1.9 time higher. The male elderly's abdomen injury is 26.2% higher than that of female elderly occupant. But, female elderly has higher potential risk in head and lower extremity 57 % and 11.6 % respectively more than those of male elderly. In seating position, driver side is 2.9 times more suffered thorax injury compared with 25 - 54 year old age group. The elderly occupant seated in front passenger seat or rear seats reveals 1.4 - 1.8 times higher injuries in abdomen and lower extremity as well as thorax injury.

Regardless the type of vehicles, the thorax injury of the elderly occupant is more than 1.7 - 2.1 times more frequently occurred. The elderly seated in SUV and RV vehicles are more injured than sedan type vehicle during the car-to-car frontal collisions. The seat belted elderly is more suffered thorax, abdomen and upper extremity injuries than other age groups. However, compared with no-belted occupants, there are no differences in terms of injury between different age groups. Even the airbag equipped vehicle, still elderly occupants exposed 12.9% more sever thorax injury compared with other age group

Table 1 Injury Patterns with Different Age Group in Car-to-Car Frontal Accidents

	MAIS 3↑				MAIS 2↓			
Age	~ 24	25~ 54	55~ 64	65 ~	~ 24	25 ~ 54	55 ~ 64	65 ~
Head	28	194	34	20	736	4,316	505	220
Neck	52	420	84	37	2,078	11,719	1,265	473
Lumber	19	219	47	27	179	1,142	136	55
Thorax	25	325	55	41	14	1,91	36	24
Abdomen	37	192	31	21	59	212	29	21
Arm	53	402	54	40	316	1,613	156	87
Leg	41	244	33	21	177	810	83	38
Whole Body	21	86	18	14	45	275	30	13
Total	227	1,408	246	153	3,508	19,314	2,248	987

LITERATURE REVIEW - INJURY OF THE ELDERLY OCCUPANTS

The risk curve, based on serious casualty data, exaggerates older drivers' crash involvement because of the 'frailty bias'. Because older people are more readily injured by a given physical impact, proportionally more of their total crashes have serious casualty outcomes. Many of research suggest that around one-half of the heightened fatality risk of drivers aged 75 years and more might be due to frailty rather than to unsafe driving practices. The same correction can be made to older drivers' involvement in non-fatal serious injury crashes.

Aging is a complex process which yields numerous mental and physical changes. In the present study, only physical changes were considered (e.g., geometrical, material, and structural). A number of studies have shown that, with increasing age, the energy-absorbing capacity of body structures generally declines. Burstein, Reilly, and Martens concluded that there was a 5% decrease in the fracture strain per decade in the femur and a 7% decrease for the tibia. Zhou, Rouhana, and Melvin reviewed a number of aging functions of the femur bone and showed that the maximum bone strength occurs at approximately 35 years of age. The bone strength then begins to decline, with the rate of decline increasing significantly after 60 years of age. Zhou et al. also determined that the human soft tissues follow a similar trend.

Although older drivers are involved in relatively few collisions due to limited exposure, once involved in a crash they are more likely to sustain severe injuries or death (Cunninghan *et al.*). Several studies have confirmed that as people age, they are more likely to sustain serious or fatal injuries from the same severity crash (Evans, Evans, Bedard *et al.*, Mercier *et al.*, University of Michigan, Wang, Peek-Asa *et al.*, Li *et al.*).

Elderly drivers and occupants are especially at risk of thoracic region injuries due to increased bone fragility (University of Michigan, Wang *et al.*, Wang, Augenstein *et al.*, Foret-Bruno, Schiller, Sjogren *et al.*, Bulger *et al.*). Results from S.C Wang, the head injury is the most frequent in younger age group, while the older age group is suffered from mostly thoracic injury as shown in Figure 10. From the NASS (1993-1996) data, the more old age group, the more numbers of rib fracture is occurred in the frontal collision.

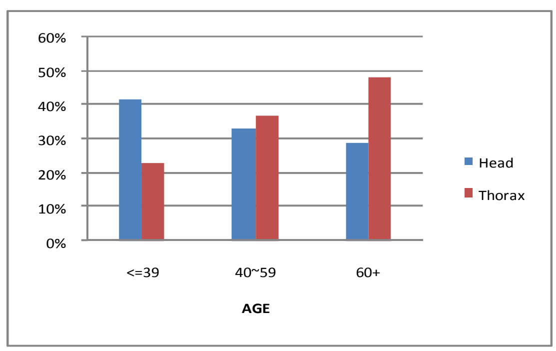

Figure 4. Incidence of Thoracic and Head Injury by Age Group. (S. C. Wang).

Results from Trosseille researches, the chest injury risk of AIS+3 for 40 year old occupants reveal less than 10% up to 6kN of shoulder belt force. However, the risk is dramatically increased. For the same level of shoulder belt force, 50 year old can be exposed 35% of risk and for 70 year old occupant, it can be reached up to 95% of AIS+3 thoracic injury.

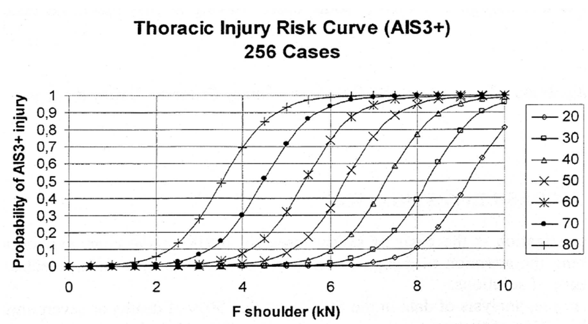

Figure 5. Probability of severe thoracic injuries (AIS3+) depending on the shoulder belt force and the occupant age (Trosseille)

SLED TEST WITH THE VARIOUS IMPACT SPEEDS.

A series of sled test was conducted to check the belt loading forces in the Hybrid III 50%tile male dummies with the various impact speeds as shown in Figure 6 and Table 1.

Figure 6. The sled test set-up with the various impact speeds in different types of load limiters.

The impact speeds were selected 56kph as KNCAP test speed, 48 kph for regulation test. Since the most frequent accident speeds for the elderly drivers was less than 40kph, the test speed was selected 40 kph. In this test, 5 different types of belt load limiters were used to measure the dummy belt forces.

Table 2. The sled test conditions

Test No.	Vehicle	Dummy	Impact Speed	Seat belt spec.
T1	A Type-1	Hybrid 50%tile	56km/h	(2.5kN) Single
T2	〃	〃	48km/h	〃
T3	〃	〃	40km/h	〃
T4	A Type-2	〃	56km/h	2.0 kN Single
T5	〃	〃	48km/h	〃
T6	〃	〃	40km/h	〃
T7	A Type-3	〃	56km/h	2.0 kN Single
T8	〃	〃	48km/h	〃
T9	〃	〃	40km/h	〃
T10	B Type-1	〃	56km/h	4.0 kN Single
T11	〃	〃	48km/h	〃
T12	〃	〃	40km/h	〃
T13	B Type-2	〃	56km/h	4.0 kN Single
T14	〃	〃	48km/h	〃
T15	〃	〃	40km/h	〃
T16	C Type-1	〃	56km/h	1.5kN Single
T17	〃	〃	48km/h	〃
T18	〃	〃	40km/h	〃
T19	C Type-2	〃	56km/h	(2+2kN) DLL
T20	〃	〃	48km/h	〃
T21	〃	〃	40km/h	〃

As shown in Figure 7, while the higher impact speed shows some indication of increasing thorax force levels, but in general, the shoulder belt forces were not strongly influenced by the different impact speeds.

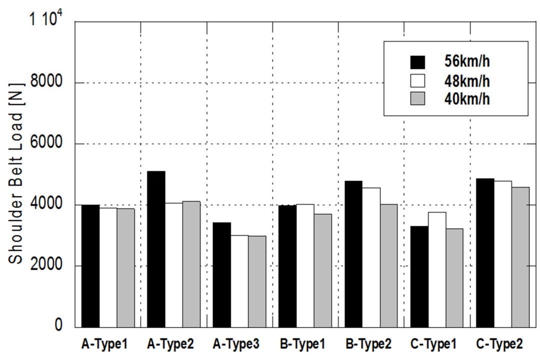

Figure 7. The shoulder belt forces in different impact speeds

However, the lap belt forces were directly increased when the impact speed were higher as shown in Figure 8.

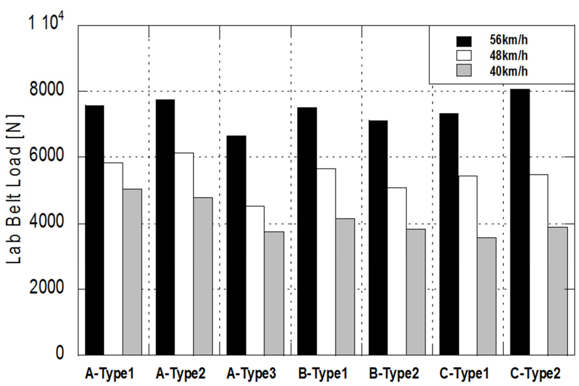

Figure 8. The lap belt forces in different speeds

Although should belt forces were not proportionally increased by the higher impact speeds, the rib deflections were strongly influenced by the impact speeds. Since the shoulder belt force was measured from near the D-ring location, the actual thorax compression force was not uniformly distributed well. Also, this may cause by the coupling effects of the shoulder and lap belt forces.

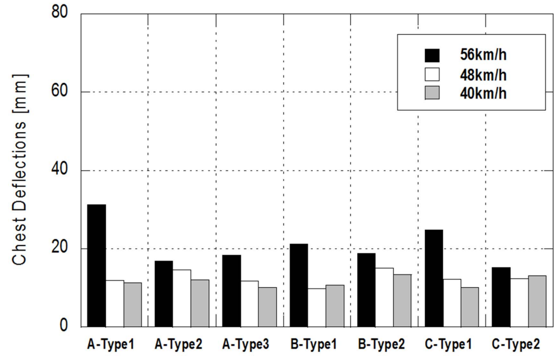

Figure 9. Chest deflections in different speeds

The chest deflections can be reduced when using the lower load limiter. Compared with 2.5kN load limiter and 1.5kN load limiter, the chest deflection can be reduced 24% of rib deflection as shown in Figure 10.

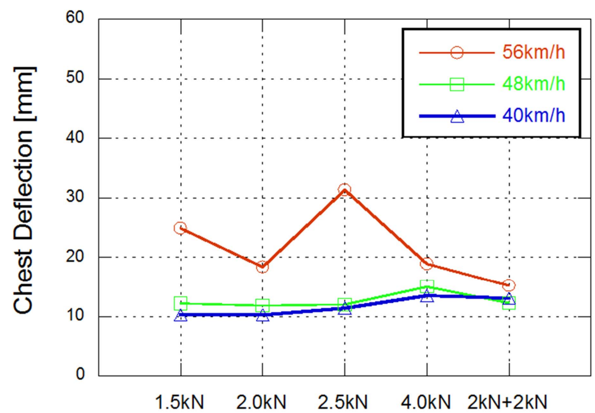

Figure 10. Chest deflections with different types of load limiters

ENHANCEMENT OF THE ELDERLY THORAX INJURY PROTECTIONS

Since 2009, the most of the KNCAP tested vehicles earned 5 star ratings in the full wrap 56 kph fontal impact test. Compared with previous year's (1999-2008) results as shown in Figure 11, the safety performances were dramatically improved. In 2009, the average of combined sever injury probability for the driver was 10.1% and 8.9% for the passenger.

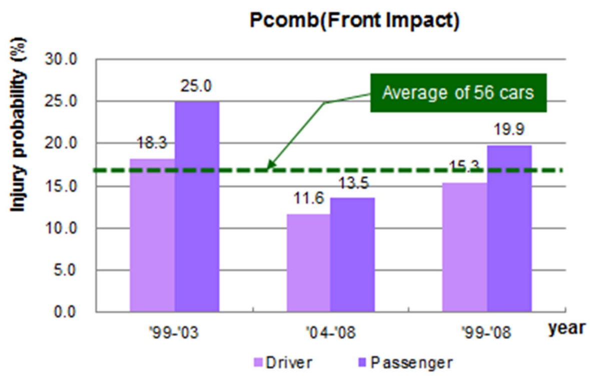

Figure 11. Improvement of vehicle safety in KNCAP Test

Currently, the most of vehicles earned the highest score from NCAP program around world except a few countries. But, elderly drivers and passengers have a disproportionately higher crash involvement rate and commonly sustain more severe injuries than the general population. As the population ages, there is a growing awareness of the need for vehicle safety to suit older occupants. It takes less energy to produce tissue damage in older adults, making this group more vulnerable to injury in a crash. Their skeletal structures are more easily damaged and the consequences of any assault are likely to be exaggerated by pre-existing health conditions.

Therefore, there is a need to improve the crashworthiness of vehicles to provide better protection for older occupants in the event of a crash. The level of personal mobility and independence afforded by the motorcar is fundamentally important for older people. The next generations of older drivers will bring a new set of challenges for road safety. The baby-boomer generation has grown up with the car, have higher licensing rates and travel longer distances by car than persons of their parents'' generation. As a consequence of the increased number of older drivers and passengers in the community and their greater reliance on cars for mobility, older occupant safety is likely to become a bigger issue in the years ahead.
The chest is clearly vulnerable as the major load bearing area for restraint systems as well as a major point of contact with the vehicle structure during a crash.

Currently, no motor vehicle safety standards in the world are designed to specifically address the needs of elderly persons. Currently, the Hybrid III 50%tile male dummy is only one dummy regulatory body accepted in the world except USA. To protect elderly occupants from the thoracic injury during the frontal crash events, the simply improvement of the chest deflection criteria only is not sufficient enough without the controlling the stiffer seat belt force level.

The load limiter in the 3-point belt is intended to limit the forces exerted by the belt and thus the values for the thoracic load. Already in the early 1970 load limiters were applied in serial production, at that time, of course, without airbag. Their benefit has been demonstrated by accident analyses. Today load limiters are mostly applied in combination with an airbag to achieve an optimum alignment of the restraint system.

From our researches and other previous researches, to protect elderly occupant from the thoracic injury, the load limiter should be in the range of 1.5 kN – 2.0 kN. In short term, if applying the modifier in the NCAP scoring system, this may lead the lowering seat belt force loadings as well as stimulating development of an adoptive restraint system as a universal design both beneficial for the standard size male occupant and the vulnerable occupants like elderly occupants and small size female occupants.

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