DEVELOPMENT OF TEST METHODS FOR EVALUATEING CURTAIN AIRBAG DPLOYMENT FORCE

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ABSTRACT

It is well known that a CAB (Curtain Airbag) is one of the most effective restraint systems for protecting the occupant head from a side impact crash or preventing the occupant from ejection during a rollover accident. One of the most fundamental requirements for a CAB is to ensure a robust deployment. Specifically, a CAB should be deployed and positioned well in time without being trapped by any interior parts. Up to now, the deployment performance has been evaluated by measuring the fully-deployed time, which has limitation in that it is difficult to clearly discriminate performance differences resulting from design parameter changes.

The main purpose of this study is to develop a new methodology for evaluating the CAB deployment performance quantitatively and defining corresponding metrics representative of the deployment performance. For this, two test methods focusing on either the local or the global characteristics were developed in the present investigation. The first was designed to directly measure the deployment force exerted on the specific area by measuring the tension force acting on a webbing material using the load cell. The second was devised to show the overall profile of the deployment force and to measure the time history of total force by calculating the sum of inertial and elastic forces applied to a series of spring-bar impact systems. Afterward, several tests were carried out by each method in order to evaluate their repeatability and reproducibility. In addition, the tests were performed for several different CAB designs to evaluate discrimination capability of each test method. From this study, it was found out that the proposed test methods and corresponding metrics can be effectively used for evaluating the deployment performance of CAB's. It is also expected that the methodology can be applied to optimize design parameters of CAB's for the robust deployment performance.

INTRODUCTION

A CAB is the device that is generally equipped between the headliner and the side roof panel in a vehicle, and is to protect the occupant head from a side impact crash or to prevent the occupant from ejection during a rollover accident. As the importance of safety in side impact crashes and rollover accident is increasingly emphasized, NTHSA released the upgrade of FMVSS214 so as to encourage car makers to install CABs and SABs (Side Airbag) in their vehicles. Also, the cars with CABs as standard features are continuously increasing all over the world. Thus, it is most important to ensure the robust performance of a CAB.

The performance of a CAB can be generally evaluated by deployment performance and energy absorbing capability in case of an occupant head impact. The former one is a prior requirement which means the ability to be deployed and positioned well in time without being trapped by any interior parts.

Figure 1. The deployment of CAB and malfunction of a CAB hung on pillar trim.

However, in some cases the deployment time is delayed, the cushion moves unstable or it cannot fully deployed by the interference of neighboring interior parts such as pillar trims, headliner and so on. Figure 1 shows a typical problematic case where the CAB cushion is hung on the top of B-PLR Trim. The main factors to cause these abnormal behaviors are deformation of body panel from impact, low deployment force of cushion and structural inadequacy between the CAB and interior parts. Among these three factors, the deployment force can represent the characteristics of CAB itself and deployment performance.

Up to now, some researches have tried to calculate the deployment force by measuring the internal pressure or analyzed the stress distribution for checking the structural integrity of cushion using numerical simulations[1~3]. In addition, when the CAB is abnormally deployed in static deployment or barrier tests we solved these problems by just changing the structural factor of adjacent trim parts and then conducting the static deployment test for verification of the improved performance. However, this action is not sufficient to judge whether only such modification is enough or any other process should be applied like increasing the mass flow rate of the inflator for improvement. Also, it takes so long time and costs much to change the mold for interior parts by trial and error. Consequently, a method to evaluate the CAB deployment force quantitatively which may lead to a stable deployment is essentially required.

In this paper, two test methods measuring CAB deployment force focusing on either the local or the global characteristics are proposed. The first was verified by testing 20 different CAB designs and analyzing test data from the aspect of 3 design factors. Two distinctively different CAB designs are used to assess the second method finding out the deploying profile, force and energy. Finally, the merits of two methods are compared and summarized.

LOCAL EVALUATION METHOD OF CAB DEPLOYMENT FORCE

The Device and Test Method

The CAB deployment force mainly acts downward against resisting force from the headliner, the pillar trim and the body panel. The test device, shown in Figure 2, is designed to directly measure this force exerted on the webbing that a load cell is attached. It would be better to measure the deploying force in every location along a CAB. However, only the forces at the location around the B-PLR trim were measured.

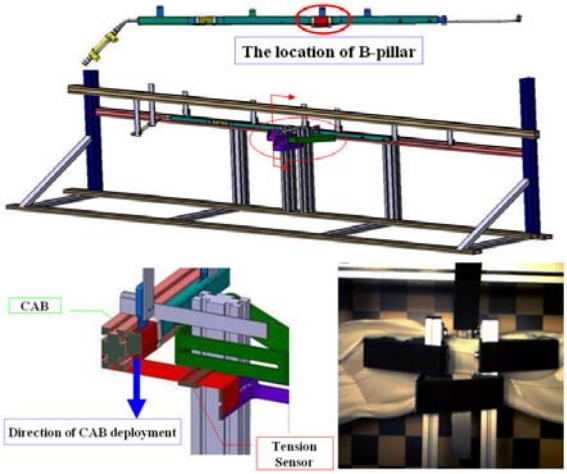


Figure 2. The schematic diagram of deployment force measuring device and the test.

The Metrics of a CAB Deployment Force

The maximum and average deployment forces, shown in Figure 3, are defined as metrics which can represent the deploying characteristics well and have good repeatability and reproducibility with the device's simplicity.

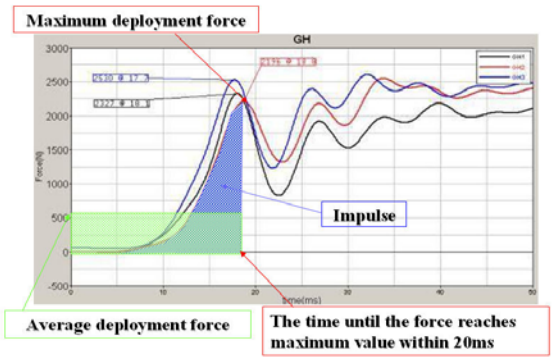


Figure 3. The standard of maximum and average deployment force.

The maximum deployment force is defined as the peak value within 20ms after a CAB is triggered, and the average deployment force is defined as the value which the impulse is divided by the corresponding time interval until the force reaches the maximum value. The definitions of maximum and average forces are expressed by the equations:

$$F_{\max} = Max\{F\} \qquad (0 \le t_{F_\max} \le 20ms) \qquad (1).$$

$$F_{avg} = \frac{1}{t_{F_\max}} \int_0^{t_{F_\max}} F dt \qquad (2).$$

where $t_{F_\max}$ is the time when F is at its peak value. Three tests were conducted for each CAB design, and the average was determined as the representative value.

Tests and the Results

The tests for measuring deployment forces for 20 kinds of CAB designs were carried out in order to evaluate their repeatability and reproducibility. The CAB modules were classified according to three factors, more specifically the location of inflator (gas injection nozzle), inflator type and vehicle segment. These factors can interact one another, but were chosen because they have major effect on CAB design concept and performance.

There are two kinds of center and rear module CABs according to the location of inflator shown in Figure 4. The former one has its gas injection nozzle in the middle of cushion and the latter one has it at the rear end. Their deployment test results are shown in Table 1, where the center module CAB is superior to rear module CAB by 64.5% in terms of average deployment forces. It is due to the close location of gas injection to the B-PLR Trim, and this shows that a center module CAB is more effective in its deploying capability by opening the headliner more quickly and forcefully.

The inflators used in CAB's are generally divided into two classes, the hybrid type using the compressed gas and pyrotechnic techniques, the stored gas type using only the compressed gas technique (usually He and/or Ar are filled).

Figure 4. Center and rear module CAB.

The latter one is also called Cold Gas Inflator because of low temperature of injected gas. It can be meaningless to compare one with the other without considering parameters such as capacity, size and geometry of nozzle, mass flow rate, and so on. Thus, two kinds of CAB's having a similar cushion volume are used for this test. In Table 2, it can be noticed that a CAB with the stored gas type inflator has a higher deployment force by 19.1% in average value, and this can be also figured out from tank test curve of inflator.

The relation between vehicle segments and their required force level for ensuring the stable deployment of CAB was investigated. Since the size of cushion and the capacity of inflator tend to be in proportion to that of vehicle's layout, CABs are classified into three groups, namely, vehicles under C segment, over D segment and SUV(including CUV). The average value of each group is shown in Table 3. The maximum and average forces of SUV

Table 4.
Comparison of deployment force according to inflator location

The location of inflator	Max. Deployment force(N)	Avg. Deployment force(N)
Center Module	2672.5(117.0%)	1251.9(164.5%)
Rear Module	2283.8(100%)	761.0(100%)

Table 5.
Comparison of deployment force according to inflator type

Inflator type	Max. Deployment force(N)	Avg. Deployment force(N)
HYBRID	2378.5 (100%)	855.7 (100%)
STORED GAS	2414.6(101.5%)	1019.4(119.1%)

Table 6.
Comparison of deployment force according to vehicle segment

Vehicle segment	Max. Deployment force(N)	Avg. Deployment force(N)
Under C	2140.5(100.0%)	776.1(101.8%)
Over D	2497.4(116.7%)	762.4(100.0%)
CUV, SUV	2561.3(119.7%)	1151.0(151.0%)

are greater than that of under C segment vehicle by 19.7% and 51.0% respectively. From these test results, it can be seen that the bigger the vehicle size is, the stronger the deployment force is required because the larger protection area of a CAB cushion needs the more powerful inflator.

GLOBAL EVALUATION METHOD OF CAB DEPLOYMENT FORCE

The Device and Test Method

It is not easy to directly measure the deployment force of a CAB during deployment because its cushion moves so fast and gets the reaction from the sensing equipment. A device that could measure the force indirectly by calculating the sum of inertia and elastic forces from the acceleration of a mass and deformation of a spring moved by the cushion was designed.

The deployment force measuring system shown in Figure 6 consists of 22 units of spring-bar impact device shown in Figure 5 along the longitudinal direction of a CAB. Each spring-bar impact device was equipped with two movable LM-GUIDEs (linear motion guides) standing vertically on the bottom plate, so that an impact bar could move up and down by the deploying force of the CAB cushion. A wire spring which passed over a pulley at the top of LM-GUIDEs was connected between the bar and the bottom plate to measure the elastic force. To calculate the acceleration of the bar from its displacement, a reference tape with the resolution of 1 inch was attached on the side of LM-GUIDE. The displacement was measured every 3ms from an analysis of film taken by using a high speed camera, and the acceleration was calculated by differentiating the displacement twice using the central difference method. Afterward, the displacement and acceleration obtained from this method were compared with those measured from a potentiometer and an accelerometer to ensure repeatability and reproducibility.

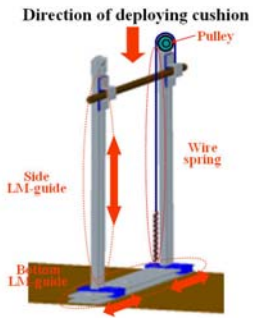


Figure 5. A unit of spring-bar impact device

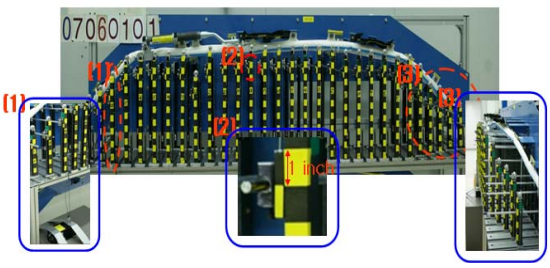


Figure 6. The global deployment force measuring system.

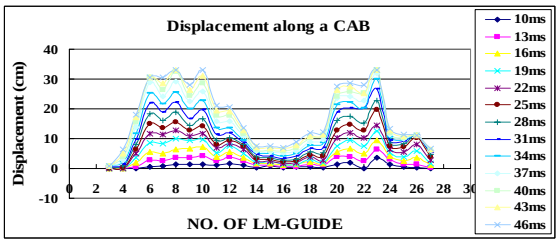
The Metrics of a CAB Deployment Force

The total deployment force of a CAB was calculated from the summation of the inertial and elastic forces applied to a series of spring-bar impact devices. This dynamic system is governed by the equation:

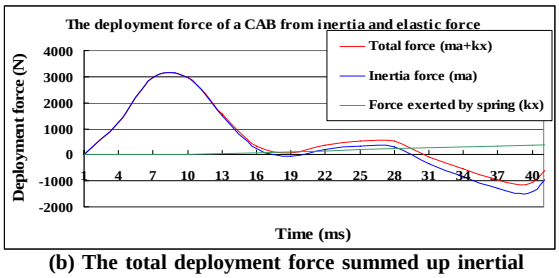
$$F = (m \times \ddot{x}) + (k \times x) \qquad (3).$$

where m : mass of moving part of a unit
k : spring constant of wire spring
x : deformation(displacement) of wire spring

The term of elastic force is the sum of spring forces of 22 spring-bar impact devices and is plotted in green color in Figure 7(b). The time history of every unit's displacement in Figure 7(a) shows the overall profile of a CAB, which can provide us with the deploying profile as well.



(a) The time history of displacement



(b) The total deployment force summed up inertial and elastic forces

Figure 7. The deploying profile and force by global evaluation method.

The inertial force plotted in blue in Figure 7(b) was generated by the CAB deployment. From the test result in Figure 7, it can be noticed that the inertial force was the major component of the total deployment force.

Tests and the Analysis of Results

Two kinds of CABs were used in the tests with the interior parts equipped or not equipped. One was the CAB of D segment sedan of which the gas injector was located in the rear, and the other was that of CUV of which the injector was located in the middle. The test results were investigated in the aspect of deploying configuration (displacement), force and energy. The deployment force calculated in every position of LM-GUIDE along CAB was divided into 4 or 5 sections (Front, B-Pillar, Middle1-2 and Rear) shown in Figure 8, and each section was evaluated separately and compared with one another.

The Deploying Configuration of Center and Rear Module CABs – The displacement of each measuring point along the CAB was interpolated every 3ms in Figure 9. Figure 9(a) and 9(b) represent the results of the rear module CAB and center module CAB, respectively. Figure 9(a) shows that there was comparatively slow deployment in the region of (c) due to an inactive chamber of cushion behind the B-PLR Trim. The cushion of rear part (d) deployed faster than the other parts. This characteristic was related to the location of the gas injector and cushion shape, and could be discriminated clearly by comparing this with that of center module CAB in Figure 9(b). The fastest deployment velocity occurred in the region of (d) which was just in rear of the gas injector and had an active cushion chamber. The results also denote that the region (a) and (d) of the center module CAB where the occupant head's impact on uniformly reached their full displacement at 30ms, while that of the rear module CAB had the disparity of about 10~50%. This phenomenon could be also seen in a high speed film of deploying CAB just in empty space, but it did not show a distinct difference along a CAB.

The Regional Deployment Force along CAB – The deployment force in each region of CAB was analyzed. The result in Figure 10 clearly distinguishes the characteristic of two different CAB designs. The regional force deviation of the rear module CAB was much bigger than that of the center module. Especially the difference of maximum force between the region of (a)Front and (b)Rear in the rear module CAB is about 200N. There was also a time delay of 7ms in Front part (a) than in rear part (d) in terms of the time when the deployment force reached its peak value. But the center module CAB had comparatively similar maximum deployment force and peak force in every region.

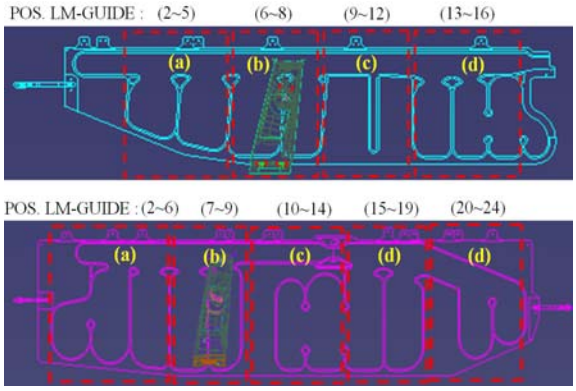
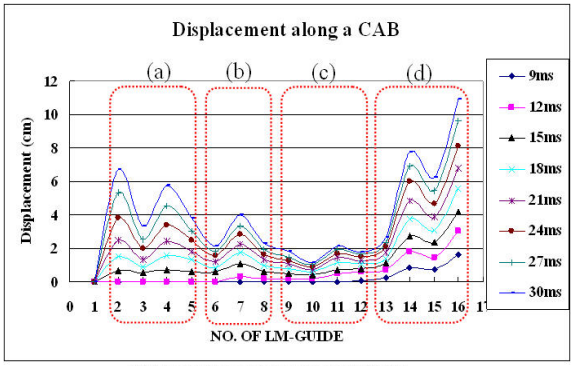
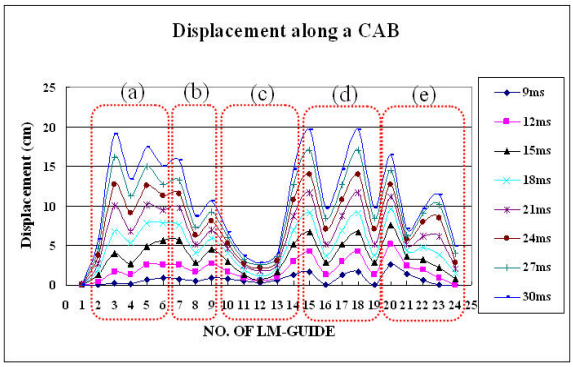


Figure 8. The regional classification of the rear and center module CAB and the location of LM-GUIDEs.

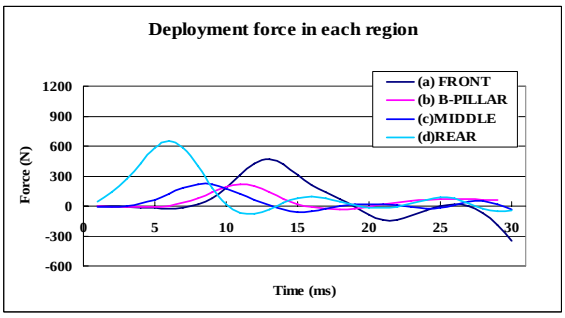


(a) The profile of rear module CAB

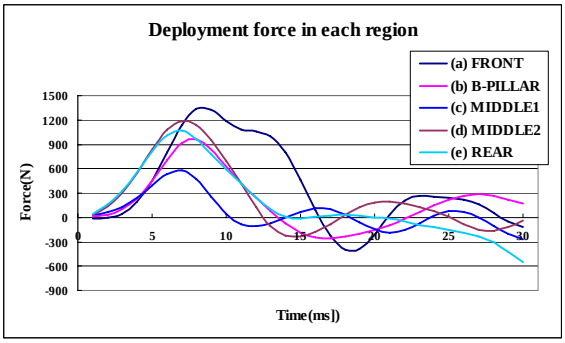


(b) The profile of center module CAB

Figure 9. The comparison of deploying profile according to the location of gas injector.



(a) The regional deployment force of rear module CAB



(b) The regional deployment force of center module CAB

Figure 10. The comparison of regional deployment force.

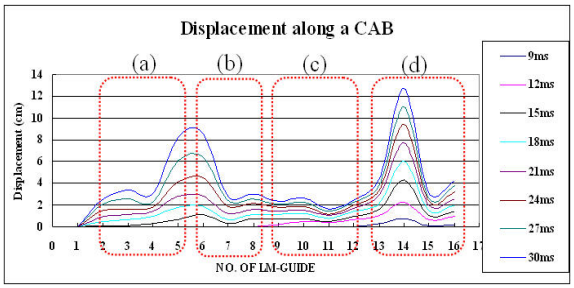
The Deploying Energy in Each Region of CAB

–The deployment test of the rear module CAB was carried out in a vehicle with interior parts equipped, and their results are shown in Figure 11. The deploying configuration in Figure 12(a) apparently shows two superior speeds near the region of (a) and (d) in comparison to Figure 9(a) although they were the test results of the same kind of CAB module. It seems that the interior parts had a deteriorating effect on the deployment of CAB, especially in front position of (a), rear position of (b) and (d) where the trim parts and headliner were coupled. The deploying energy of region (d) shown in Figure 12(b) rose fast, but finally that of region (a) reached twice the peak value of (d) within 30ms when the CAB was fully deployed. The energy level of each part along a CAB could easily estimated from this analysis.

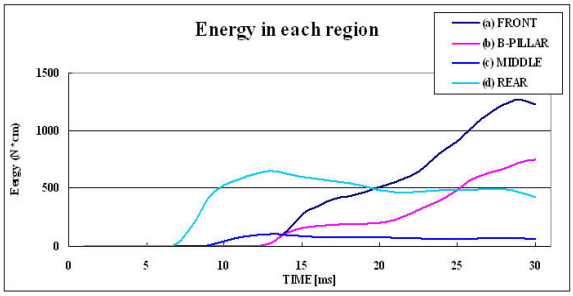
CONCLUSION

In the present investigation, two different test methods were developed in order to evaluate the CAB deployment performance quantitatively. The first was designed to directly measure the deployment force on the specific area by measuring the tension force on a webbing material. From the

Figure 11. The deployment test in vehicle equipped with interior parts.



(a) The profile of rear module CAB



(b) The deploying energy in each region

Figure 12. The deploying energy in each region in vehicle with the interior parts equipped.

test results of 20 different CAB designs, it could be noticed that this test method showed good repeatability and reproducibility with appropriate discrimination capability for the CAB design factors. Also, a specification for CAB deployment force could be established by using this testing method for ensuring a robust deployment performance.

The second was designed to show the deploying profile along a CAB and to calculate overall deployment force and energy indirectly from the cushion's displacement. Also, this method helped compare the partial distribution of deployment force and energy along a CAB.

From the test results of two different CAB designs, it was found that the method could be effectively used to discriminate the deployment performance of CABs. In particular, it was shown that the deploying performance of a center module CAB was more stable than that of a rear module CAB.

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