STUDY OF TEST PROCEDURE TO EVALUATE AIRBAG DEPLOYMENT FORCE

Koichi Kamiji
Yoshihiko Morita
Makoto Nagai
HONDA R&D Co., Ltd.
JAPAN
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ABSTRACT

Since airbags have become standard equipment on passenger cars in the U.S., a variety of organizations have reported on the effectiveness of airbags in saving occupant lives and reducing serious injuries during frontal crashes. However, there have also been numerous reports of serious injuries to occupants caused by airbag deployment. As a result, airbag deployment force is now an issue of tremendous concern. These problems primarily occur with out-of-position occupants. ISO has proposed various test methods for evaluating the effects of airbag deployment force on out-of-position occupants. This paper presents a test method for evaluating airbag deployment force at the airbag component level.

INTRODUCTION

Airbags have been installed in general mass-produced cars since the 1980's. With the enactment of FMVSS208, passenger-side airbags as well as driver-side airbags are currently standard equipment on nearly all vehicles. Airbags were considered to essentially function as restraining devices, which are supplemental to seatbelts during a frontal crash. During severe frontal crashes, they were considered to serve to prevent secondary collisions between occupants wearing seatbelts and the steering wheel or instrument panel. However, occupant usage of seatbelts through the first half of the 1990's was low. Therefore, in order to increase safety for occupants not wearing seatbelts during a crash, the U.S. government added airbags as an FMVSS208 option. In the first half of the 1990's passive seatbelts and airbags were both occupant protective devices which were compliant with FMVSS208. However, airbag installations in vehicles gradually increased, and the passive seatbelt option was eliminated for passenger cars produced on September 1, 1998 or after. This developed into the airbag installation law as a result. As the number of cars with airbags increased in the market, it gradually became clear that airbags are extremely effective at saving occupant lives. According to an NHTSA study, occupants who were saved by airbags in the U.S. number 1828 thus far. This effectiveness is especially marked in cases where airbags are used together with seatbelts. It is believed that the combination of seatbelts and airbags further reduces the number of fatalities and serious injuries.

However, in the U.S., the airbag performance requirements of FMVSS208 require capabilities to protect occupants who are not wearing seatbelts. In an increasing number of cases, satisfying this requirement necessitates relatively early deployment and strength for airbags in comparison with other countries, which have adopted performance requirements assuming seatbelt use. Since the middle of the 1990's, when an increasing number of vehicles equipped with airbags were on the market, there has been a growing concern about injuries caused by airbag deployment, as opposed to the issue of airbags' occupant protection capabilities. These conditions have led to recognition of the importance of evaluating occupant-restraining capabilities during crashes and the importance of evaluating the force of impact on occupants during airbag deployment. This paper presents the results of a study of test methods for evaluating airbag deployment injuries.

CURRENT TEST PROCEDURES

Currently a variety of test methods are being proposed as the occurrence of airbag deployment injuries gains recognition. Such deployment injuries affect out-of-position occupants. In addition, there are cases where driver seat occupants, who are fairly short, suffer injuries from airbag deployment force. This happens when an airbag deploys after such occupants, who position themselves close to the steering wheel in order to maintain their driving posture, are moved even closer to the steering wheel during a crash as a result of the deceleration force. A common type of injury involving an occupant in the front passenger seat occurs when an airbag deploys with a rear-facing child restraining system installed on the front passenger seat. Another common type of injury occurs in cases where a child sitting in the front passenger seat is not using a restraining device, and the airbag deploys after the child is displaced toward the front passenger seat airbag due to braking prior to a crash. Test methods have been studied for evaluating deployment injuries based on such out-of-position accidents.

The methods, which are most widely recognized throughout the world, are those evaluated by ISO. Common types are illustrated in Figure. 1 and 2. Currently these serve as guidelines for evaluating airbag deployment injuries.
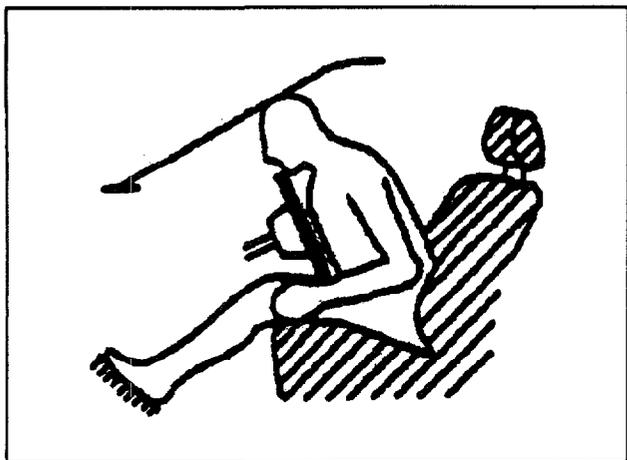
Figure 1. ISO Driver out-of-position — Chin on the rim

Figure 2. ISO Passenger out-of-position
3 years old dummy stands in front of instrument panel.

DRIVER SIDE AIRBAG

Evaluation of Driver-Side Airbag Deployment Injuries (Chest Injuries)

This section describes method for evaluating chest injuries in occupants who have moved close to airbags. In addition to the methods specified by ISO, there are methods, which have been proposed in SAE and ISO initial drafts (Figure. 3).

Figure. 4 illustrates a comparison of these two test methods. According to the results, injury values are nearly the same for the ISO dynamic test as well as the mode illustrated in Figure. 2, in which a dummy chest is positioned on top of an airbag module. The results for the ISO static
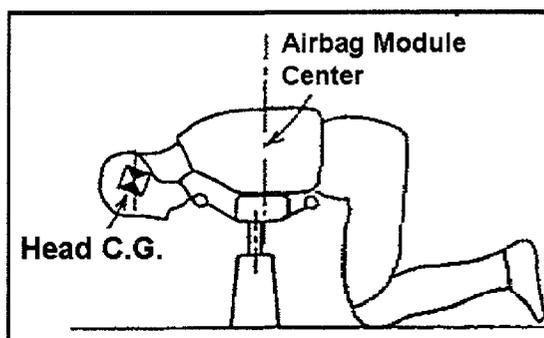

Figure 3. Driver out-of-position
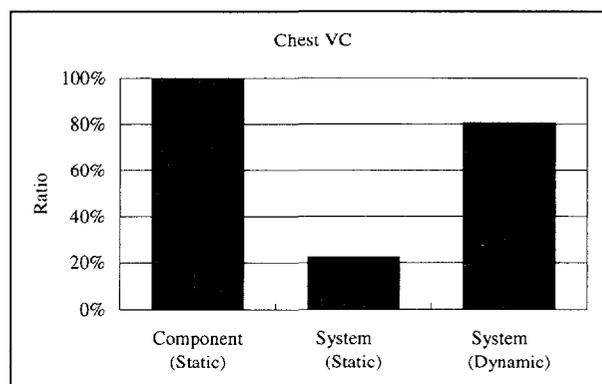Dummy's chest is placed on the driver airbag module.

Figure 4. Comparison of chest VC results

mode were extremely low. Many actual deployment injuries occur at low or medium crash speeds. Even in such cases, it is likely that the deceleration force generated during crashes are applied to the occupant.

A comparison of the ISO static and dynamic methods naturally indicates higher injury values for the dynamic method, so verifications should be made with the dynamic method when using ISO methods. However, there are a number of inconsistent factors in dynamic tests, making it necessary to use a greater number of test runs. The method in Figure. 3 is based on static verification, and is more stringent than the static ISO method because a gravity-induced load—albeit only 1 G—is applied. For this reason we decided to verify a series of tests using the mode of "chest on module".

Even with this method, however, there is still the possibility of inconsistency in test results in relation to the use of a dummy. Possible sources of inconsistency are differences, which are unique to each dummy and inconsistency in how the dummy is set in place. However, the following discussion will focus on the location of interference between the dummy and the airbag module.

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This factor is not defined in current ISO test procedures.

The parameters, which are currently used in evaluating the risk of chest injuries, are the chest (spinal column) G and the deflection of the ribs. The widely used Hybrid III dummy chest deflection scale does not measure the movement of individual ribs. Instead, it provides the rib displacement based on the angle of an arm, which is attached to a slider, attached to the sternum, which joins the six ribs together. The critical issue here is that the initial position of the arm is intermediate between the third and fourth ribs and the arm attachment point moves upward as the ribs are compressed. As a result, in chest injury measurements using a Hybrid III dummy there is a possibility that during the initial stage of deployment a true measurement may not be obtained other than for the displacement of the third and fourth ribs due to the above-mentioned structure of the dummy. One factor, which significantly affects rib bending during out-of-position tests, is the airbag deployment force against the occupant during the initial stage of airbag deployment. With the current driver out-of-position test procedures used by ISO, the chest positional reference is not determined directly, but is rather determined based on the relationship between the jaw and the steering wheel, regardless of the airbag structure. Influential factors in the acting force of the airbag during the initial stage of deployment are the pressure energy which is stored up to the time that the airbag cover tears, and the thrust of the inflator when the airbag is released through the cover opening. Of these two factors, the pressure energy, which is stored up to the time that the airbag cover tears, becomes extremely high along the tear seam of the airbag cover. For this reason the positional relationship between the deflection meter on the dummy and the tear seam on the airbag cover would be expected to be an important factor.

Results of Verification

We conducted a verification test on the relative positions of the dummy and the airbag cover tear seam during these driver out-of-position tests.

In this series of tests, verification was performed using covers in which the tear seam position was moved 35 mm or 50 mm from the standard position as shown in Figure. 5. In other respects, the driver airbag modules had completely identical characteristics and structures.

As a result, it was learned that chest deflection and chest VC value both decline as the amount tear seam position is increasingly offset from the initial position of the chest deflection scale arm. Figure. 6 illustrates a comparison of out-of-position test results with these three airbag modules. With the original module, the location of the chest deflection scale are adjusted to the cover tear seam at the same position, the amount of the chest deflection increases continuously from the point of initial bending. In contrast, when the tear
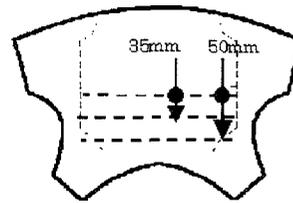

Figure 5. Tear seam location of the driver module for the varification test.
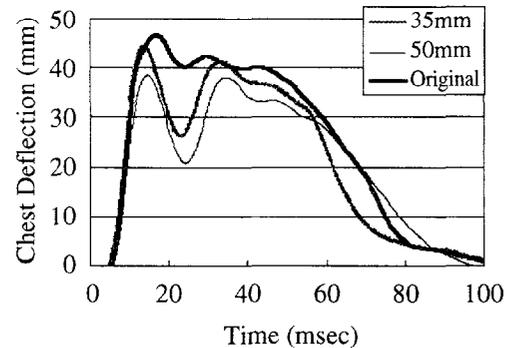

Figure 6. Comparison of driver chest deflection

seam is set at a relatively lower position, the one that is induced by the deployment force during the initial stage of airbag deployment temporarily drops. This is due to the fact that the airbag, which is released through the tear seam, concentrates its deployment force on the lower ribs in the dummy, while the displacement in the upper ribs is relatively small in comparison with the lower ribs. As a result, the chest deflection scale temporarily drops. Subsequently, the airbag presses against the entire chest, thereby increasing the amount of rib displacement. However, in cases where the tear seam has been offset from the standard position, this subsequent bending amount comes after the temporary drop in bending, so the ultimate maximum bending amount is reduced.
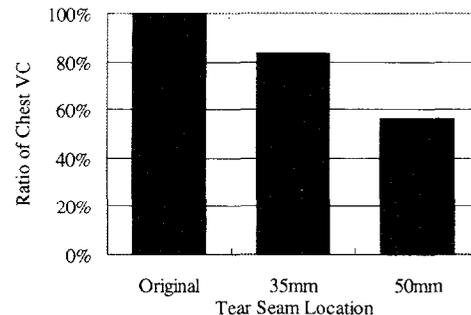

Figure 7. Comparison of chest VC among the different tear seam location

Figure. 7 illustrates a comparison of chest VC values for those cases. Offsetting the tear seam on the airbag module and the chest deflection meter reduces the chest VC value by the impact force during initial deployment. The peak value of the chest VC is also reduced as a result. During the initial stage of airbag deployment, the airbag interferes with the dummy chest along the tear seam. Therefore if the arm of the chest deflection meter and the tear seam of the airbag are at the same position, the release force of the airbag during the initial stage of airbag deployment and the subsequent deployment force will act continuously on the deflection meter (Figure. 8).
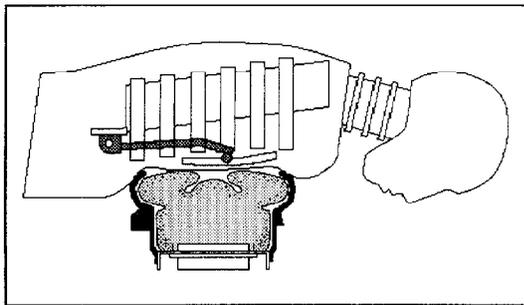
**Figure 8. Chest deflection mode at 0mm distance between the arm and the tear seam**
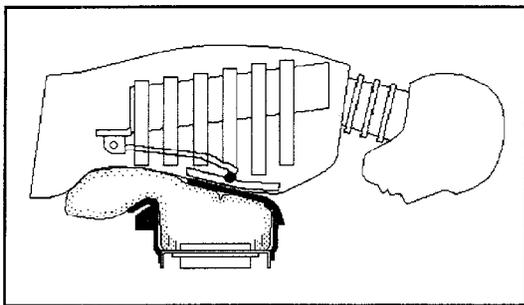
Figure 9. Chest deflection mode at 50mm distance between the arm and the tear seam

When the positional relationships are offset, the release force of the airbag deforms the shape of other ribs without pressing directly on the sternum and the deflection meter arm attachment point. This deformation indirectly displaces the deflection meter arm via the sternum (Figure. 9). In addition, during the period when the airbag is deploying, and while it is pushing the dummy aside, if the tear seam is offset downward as described above, the airbag cover will remain obstructed by the dummy's chest. As a result, the airbag to deploy downward and the sternum will rotate instead of moving parallel, and making it more difficult for the deflection meter arm to be pressed on. This explains the large difference in results among tests with identical

deployment forces but different positional relationships between the dummy and the cover tear seam.

Example Evaluation of Deployment Injury for Driver-Side Airbag

Chest injury results in driver out-of-position test will be effected by the structure of the dummy's chest. A component test method without dummy was tried to evaluate the deployment force of the driver airbag. A sensing mass with a guide rod is placed in the face of the driver module.(Figure 10) The mass is moved by the deployment force of the airbag. The purpose of this test is to measure the energy of the airbag deployment as a momentum of the sensing mass instead of the deflection of dummy's chest. Figure 11 shows the relationship of the maximum velocity of the sensing mass and the maximum chest VC in the same airbag module configuration. There is good correlation in those two measures.
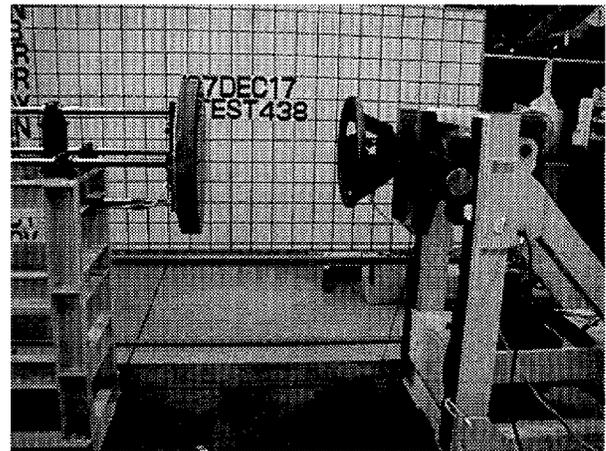
Figure 10. The whole view of the linear reactor for the driver out-of-position test
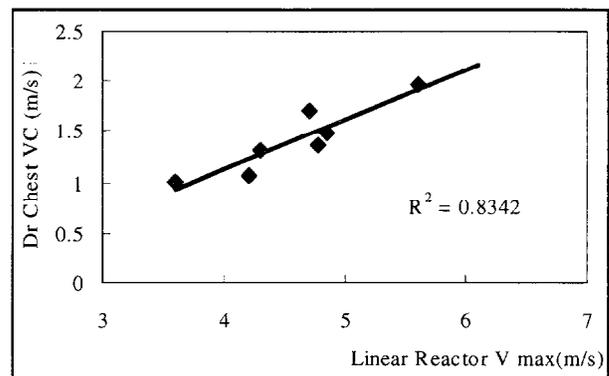
**Figure 11. Linear reactor test result
Correlation between Dr. chest VC and the reactor V max.**

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Proposal for Dummy Placement with Respect to Driver-Side Airbag

The above results indicate that with driver-side airbag out-of-position test methods involving the use of a Hybrid III dummy based on the current ISO procedure, satisfactory dummy placement conditions are not always established. This is due to the fact that the airbag module structure includes no definition for the tear seam, which is an influential factor in deployment injuries. One way of solving this problem is to use dummies in which the deflection of the individual ribs can be measured, as in the case of ATD dummies, which continue to be evaluated at present, otherwise some suitable component test may be utilized as mentioned above. Another approach is to focus on the dummy placement position. The appropriate position should align the tear seam with the initial position of the chest deflection meter arm on a Hybrid III dummy.

PASSENGER SIDE AIRBAG

Evaluation of Passenger Side Airbag Deployment Injuries

Out-of-position evaluations of passenger-side airbags are primarily made using a child dummy, which is caused to approach the vehicle instrument panel when the airbag is deployed. The dummy is placed so that the chest position or dummy jaw is aligned with the instrument panel. Unfortunately, there is a wide range of passenger-side airbag layouts, and the line of movement of the airbag during deployment is affected by an extremely large number of parameters, including airbag folding, the angle at which the module is attached, and the distance to the windshield. Therefore, if a single dummy placement position is used with respect to the instrument panel, the injury value on the dummy could be significantly affected by non-airbag factors. This is due to the fact that different vehicles have different airbag module specifications and layouts.

Effects of Attachment Layout

We compared the layouts in two vehicles using top dash mounted airbags. Figure. 12 illustrates the differences between the two layouts. Figure. 13 is a comparison of the C3Y dummy neck moment at the ISO Z4 Position in the two vehicles. In Vehicle A, the impact force causes neck flexion during the initial stages of airbag deployment, after which the airbag continues to surround the dummy, increasing the flexion moment. In contrast, in Vehicle B there is initially an extension moment followed by a flexion moment. This is simply due to the fact that the two models have different airbag and dummy interference modes. Interference between the airbag and the occupant can be
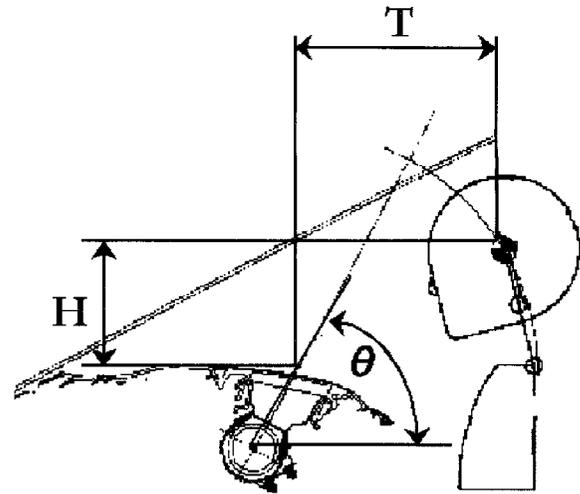

Figure 12. Dimensional parameter of passenger airbag in vehicle A and B

	Vehicle A	Vehicle B
T (mm)	240	280
H (mm)	120	110
(θ °)	62	75

Table 1 Comparison of the dimension of passenger airbag between Vehicle A and B

divided into two forces according to the elapsed time. One force is an impact force, or punch-out force (Figure 14), which is caused by the collision with the occupant immediately after the airbag punches out of the module cover during the initial stage of airbag deployment. The other force is a membrane force, representing the action of the
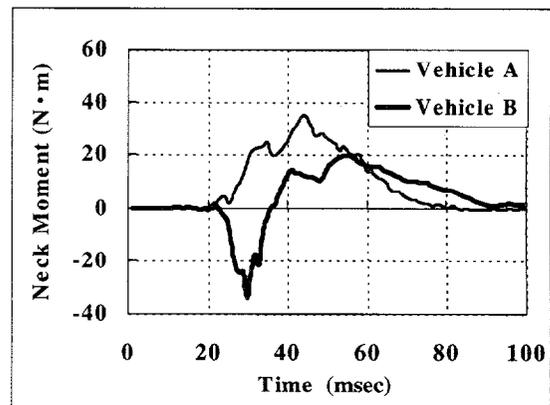

Figure 13. The comparison of neck injury results between Vehicle A and B

**Figure 14. Punch out phase for passenger out-of-position occupant**

Figure 15. Membrain phase for passenger out-of-position occupant

membrane force (Figure 15), which is generated when the airbag surrounds the occupant, taking on the shape of the occupant's body. In Vehicle A, the punch-out force acts below the head's center of gravity, generating a flexion moment, whereas in Vehicle B it acts above the head's center of gravity, generating an extension moment. Because the airbag widened to a certain extent in both Vehicle A and Vehicle B, the membrane force generated a flexion moment in both vehicles. The difference in airbag and dummy interference modes in the punch-out force seems to be strongly influenced by the positional relationship between the airbag module and the dummy.

Effects of Bag Configuration

We verified injury values under different dummy positions in vehicles with standard top dash mounted airbags using two different airbag configurations. The airbag configurations are shown in Figure 16 and 17. The inflator characteristics are the same in these configurations. However,

Configuration 1 uses an orthodox bag shape with Accordion & Roll-style folding (Figure 16), whereas *Configuration 2* consists of two panels (known as a two-piece bag) similar to a driver-side airbag and uses a simple accordion-style folding. (Figure. 17) The dummy position was altered with respect to the ISO Z4 Position by changing the distance 100 mm or 200 mm, parallel to the windshield. The results are compared in Figure.18. This comparison shows that Configurations 1 and 2 have different positions for the maximum neck injury value depending on the injury value parameter. In general, Configuration 1 showed maximum values at relatively close positions, while Configuration 2 showed maximum values at a somewhat greater distance (200 mm). In addition, these two configurations had different airbag deployment paths. This seems to account for the difference in interference intensity between the airbag and dummy and the difference in interference direction.
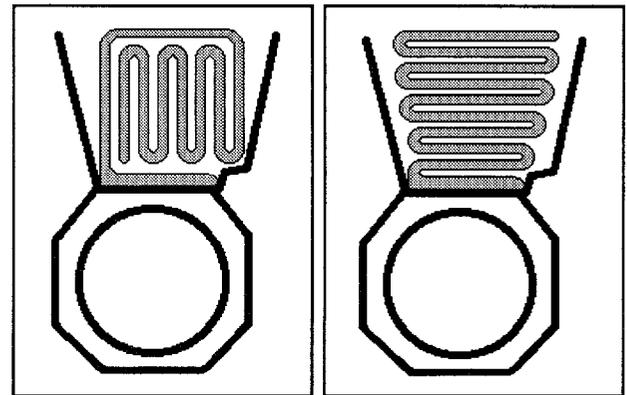
Figure 16. Accordion and Figure 17. Accordion-style roll-style folding folding

Example Evaluation of Deployment Injury for Passenger-Side Airbag

In some cases, high injury values occur away from the dummy position specified under the ISO position in passenger-side airbags with various test procedures and layout variations under the current instrument panel positional references. With current technology, it is extremely difficult to provide estimates for these based on the layout. In light of this situation, we conducted an impact experiment during deployment using a simple mass with Configuration. This involved suspending the head of a three-year-old dummy by itself in the passenger-side airbag deployment area. (Figure 19) The airbag was then deployed and the impact on the head was measured. The impact forces for various head positions were then compared in an attempt to identify the position where the airbag applied the strongest impact force against the occupant. Figure 20 and 21 illustrate those test results in comparison of the mass head and the maximum velocity.
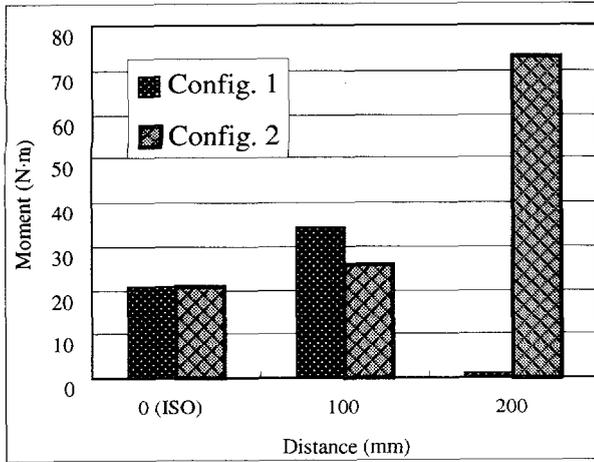
Figure 18. Comparison of the neck flexion moment in two bag configurations
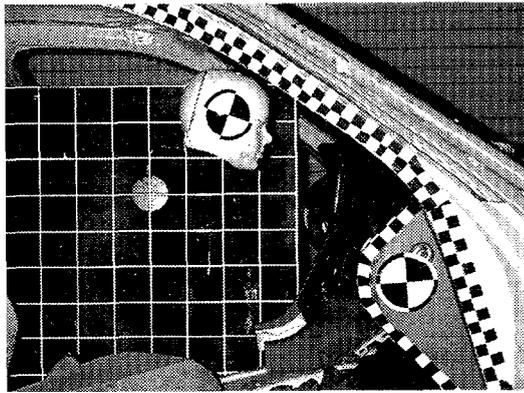

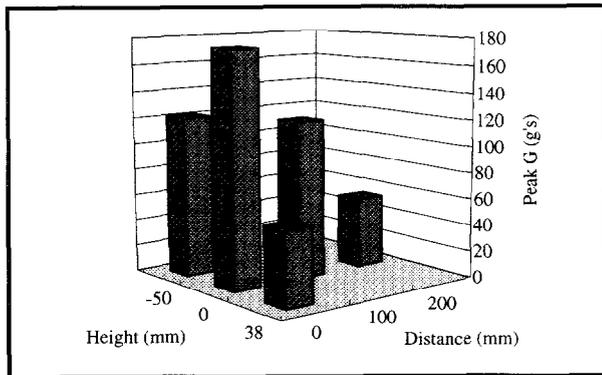**Figure 19. The whole view of the mass head test for an evaluation of the deployment force of Passenger airbag**
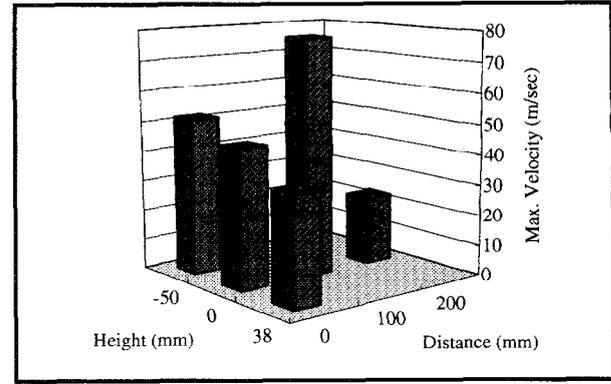

Figure 20. Maximum peak G of the mass head

Figure 21. Maximum velocity of the mass head

Head Peak G Comparison

Figure 22 and 23 illustrate the results obtained using a mass head and C3Y dummy, with three different distances and three different heights for the head position.

The G-force occurring on the mass head and the maximum velocity which was treated as the energy moving the mass head were compared with the dummy's head peak G and the resultant of the head peak G. The HIC results were inconsistent when the head position was lowered 50 mm. On other hand the head peak G could be approximated with the peak G of the mass head test results. The inconsistency of the HIC value when the head position was lowered 50 mm seems to be due to the fact that the positional relationship between the airbag movement line and head center of gravity was different than in other cases, resulting in a different impact force vector against the head.
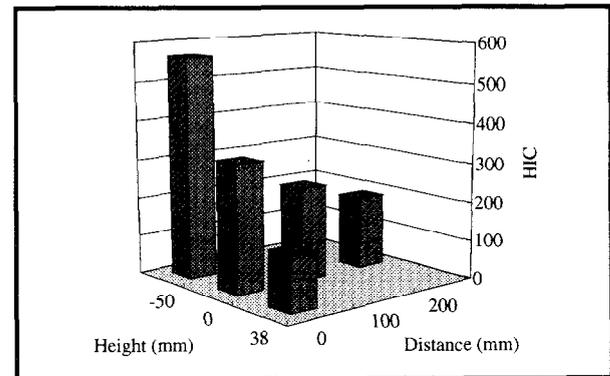

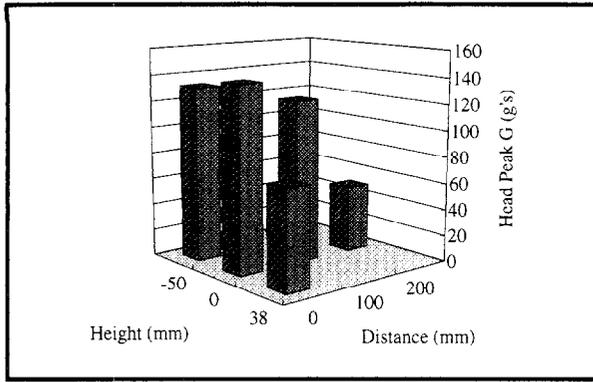**Figure 22. Comparison of HIC results of 3 years old child dummy**

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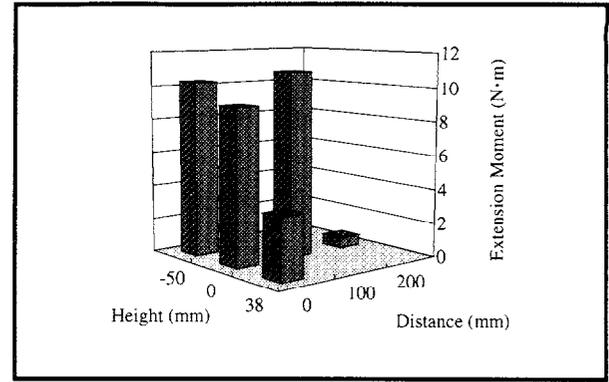**Figure 23. Comparison of the head peak G of 3 years old child dummy**

Neck Injury Comparison

Figure. 24,25 and 26 illustrate a comparison of neck injuries (Flexion, Extension and Tension) under conditions, which are the same as for HIC. It was learned that the correlation with the maximum velocity of the mass head is stronger for neck injuries. This is because the neck moment and neck shear force are generated by the phase difference between the head motion and the torso when the head is moved with respect to the torso, and are thus not related to simple impact forces which are induced by the airbag. Rather, they seem to be related to the magnitude of energy moving the head. However, neck tension and compression are caused by the force in the direction in which the head is pressed against the neck and the force whereby the airbag attempts to spread on the neck. Therefore they cannot be described by the resultant G and the maximum velocity obtained with the mass head. Instead it will be necessary to study data relating to the direction of action of the deployment force, especially data relating to the correlation between the direction and position of the occupant over time.
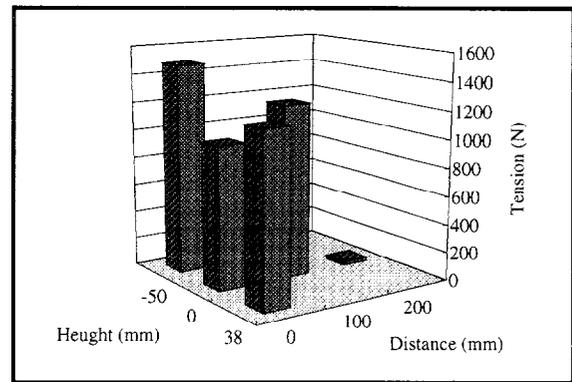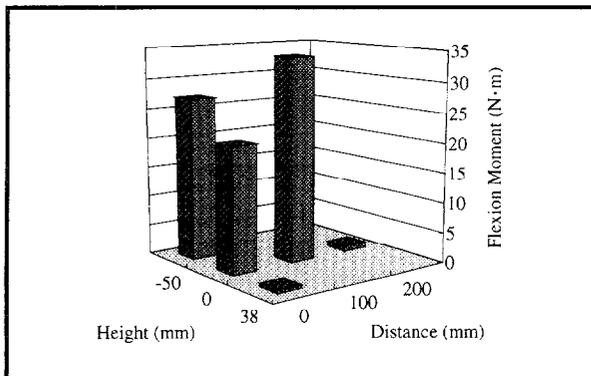

Figure 24. Comparison of the neck lexion moment

Figure 25. Comparison of the neck extension moment

Figure 26. Comparison of the neck tension force

CONCLUSION

The results of a series of parameter studies have shown that somewhat more-detailed factors need to be established in order to enable objective evaluations through dummy set procedures in the out-of-position tests with current test procedures. The problem with these procedures is that dummy placement procedures are based on the dummy's position in relation to the internal components surrounding the airbag, instead of its position with respect to the airbag. Because occupant behavior during a crash cannot be predicted, an out-of-position evaluation at a certain position may end up being a relativistic evaluation reflecting the influence of the inflator output in a given configuration. Nevertheless, it is necessary to study the mechanisms whereby occupant deployment injuries occur, as well as the deployment characteristics and deployment modes of airbags in relation to objective injury risk evaluations for out-of-position accidents. The deployment modes of passenger-side airbags in particular are extremely complex and the front passenger seat occupant may be sitting in a variety of positions. It is therefore difficult to select a layout based on drawings. It is also unrealistic to conduct verifications of

all possible modes using dummies. Therefore, methods using pretests such as the experiments described in this paper may be one means of analyzing the mechanisms whereby deployment injuries occur.

Future Issues

There is relatively little leeway for interference between an airbag and an occupant in driver chest injury evaluations. However, in verifying neck injury evaluations, which we were unable to cover in this paper, it is necessary to be very careful since there are more factors, which influence the injury value due to interference between the airbag and the dummy. In contrast, passenger-side airbags are attached in an extremely wide range of positions as mentioned above. In addition, the airbag deployment process is extremely complex in top dash mounted passenger-side airbags. Furthermore, there is a wide range of freedom in the possible position of the occupant who is affected by the airbag deployment. It would thus seem to be extremely difficult to develop a method, which would permit the dummy placement position to be established easily and objectively while taking these various parameters into account. Even in the mass head pretests with the method tried in this paper, an extremely large number of tests was required to improve the suitable dummy positioning precision. If the pretest verification position is established on a more-detailed level in order to improve positioning precision, there is a possibility that inconsistency in the airbag deployment modes would make the problem of precision in the measurements more apparent. This type of test method requires a high level of reproducibility, so it is hoped that measurement methods involving highly precise dummies, computer simulations and the like will be developed to solve this problem.

ACKNOWLEDGMENTS

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