DEVELOPMENT OF A TEST TOOL TO ANALYSE AIRBAG INDUCED INJURIES

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Paper number 11-0345

ABSTRACT

Currently, the airbag is the most important and effective restraint system available on the market. Nevertheless, its activation is related to some facial, ocular and auditory injuries. The principal objective of this project was to develop an evaluation tool capable of predicting injuries to the face.

The project was designed because previous research shows that the above-mentioned injuries occur under velocities that vary in the limits of activation/no activation set by each manufacturer ($\Delta V < 48$ km/h). The majority of these injuries occur in frontal impacts where the interaction between driver and airbag is the greatest.

Furthermore, shorter occupants (<1.60 m) tend to receive the most severe injuries due to their proximity to the airbag. The most common injuries are facial, ocular and skin abrasion. The noise produced by an activating airbag is generally over the safe limit for a person, and can cause permanent damage to the internal ear. The explosion is generated by the chemical reaction of gases that may produce intoxication or skin injury.

Therefore, the first task of this project was to evaluate the injury map related to airbag activation in frontal impact, although other configurations were considered. A revision of the state of the art and the direct relation with possible facial, ocular and auditory injuries and intoxication was also performed. The next task was to develop a set of testing procedures for the evaluation of the established injuries that airbag deployment causes to the occupants. To finalize, an assessment of the developed tools and protocols was made.

The project activities focussed on the development of a measuring system designed to predict facial and ocular injuries resulting from blunt impacts during contact with the airbag, estimating the risk of suffering facial bone fractures or severe ocular injury. This was accomplished through a special mask that measures the pressure applied at specific points of the head, such as nose tip, eyes, eyebrows, jaw, etc.

To estimate the risk of auditory injury, a specially designed dummy head made use of special microphones to measure the sound and pressure levels found in the cabin during airbag activation. This head can be used both in static and dynamic tests.

For intoxication and skin abrasion injuries, a protocol and a tool to measure the amount of toxic gases released from the explosion of the airbag was developed. In this particular case, the most relevant toxic gases were selected and the adequate instrumentation established for the development of the test.

With the three elements combined, an overall evaluation on the severity of the airbag system to be assessed can be made, allowing manufacturers and designers to create more effective yet non-injurious systems.

The results of the project are in line with the proposed objectives, and the developed tools and the protocols are good enough to provide a more stringent evaluation of restraint systems and will also help in research regarding injury mechanisms in various accident configurations.

INTRODUCTION

Airbags, in spite of being perhaps the most effective safety restraint system in combination with the seat belt, are also associated with facial and hearing injuries. They have been linked to numerous nonfatal injuries of different severities which include eye, face, upper extremities, aortic rupture, lung contusions and thoracic abdominal injuries. The most frequent are injuries to the head, including audition.

Research has shown that the injuries induced by the airbag deployment are mostly minor, although some occupants did suffer more serious injuries, according to the Abbreviated Injury Scale (AIS) (Otte, 1995). Nevertheless, the use of airbags has led to an overall reduction in AIS 2+ injuries (Kuhn, Morris and Witherspoon, 1995). Another study conducted with European and Japanese airbag deployed vehicles (Morris, 1996) examined 186 frontal crashes, and the majority of the drivers sustained AIS 1 injuries, being the head and the face the most commonly injured body region. From the analysed injuries involving airbag deployment, Kuhn, Morris and Witherspoon (1993) found that half of them were attributed to the airbag itself.

One of the reasons for sustaining airbag induced injuries is the proximity of body regions to the deploying airbag. Drivers who must sit close to the steering wheel to drive because of their height or any medical reason are more susceptible to being injured in case of accident. Sixteen of the 38 adult drivers whose deaths have been attributed to airbags were 160 cm tall or shorter, and all but one with fatal neck injuries were women.

Adams and Petri (1996) have suggested that the airbag induced injuries may be associated with specific design features, such as the amount of released energy, the speed of inflation, the volume, shape or folding pattern of the bag, etc. Also chemicals involved in inflating the bag have been implicated in injuries, so as the utilized pyrotechnic device. Some of the injuries come from the non-deployment, spontaneous deployment, airbag slap and bottom out.

We can state that airbags have a net injurious effect when activated in low severity crashes whereas they have a net protective effect in high severity accidents, meaning that the generality of the provoked injuries arise from low severity collisions or misfire situations. Also, the crash severity level at which airbags are protective is relatively higher for women than for men.

Vehicle speed at the time of the impact has been analyzed, showing that severe injuries such as orbital fractures, traumatic cataract and vitreous or retinal haemorrhage are found for speeds over 48 km/h. Meanwhile, below this velocity threshold, other severe injuries occur such as retinal detachment, ruptured globe, and worsened vision. In the case of hearing loss or auditory injury, the injurious mechanism is due to the elevated sound level of the explosion, the vehicle deformation and the pressure generated inside the cabin. These produce different effects inside the human ear, which can translate into temporal loss of hearing or permanent ear damage.

One important aspect to mention is that an airbag increases the amount of energy being released during an accident, which in turn increases the frequency of injuries sustained by the driver, yet they drastically reduce the probabilities of severe and fatal injuries to the body. This means that an airbag exerts distributed restraining forces over the head, face and upper chest region of the passenger, acting as a cushioning system and minimizing the most severe scenarios for serious injuries but remains as an added system that, in certain cases, can cause more damage than the damage it was intended to avoid.

In this paper, three approaches to analyse injuries caused by deploying airbags have been carried out: the injuries to the face and eyes, the injuries to the hearing system and the toxicity of the chemicals found in the cabin after airbag explosion. The objective was to develop a system that was able to measure the amount of injury suffered by the passengers in the case of an accident in the nearby threshold of 50 km/h, where the effectiveness of airbags is questioned due to the injury potential they also represent. To achieve the objective, a special force measuring mask, a microphone adapted dummy head and a toxicity analysis procedure were evaluated.

DEVELOPMENT

Facial Injury Analysis

Facial injury analysis was set to obtain the amount of force or pressure that the occupant receives when interacting with the airbag. By design, the airbag is intended to act as a cushion between the user's head and upper chest and the steering wheel, dashboard and other components. To achieve this, a very fast chemical reaction inflates the airbag in less than 50 milliseconds, time when the occupant is about to reach the contact point with the airbag and provide energy absorption of the user dynamic movement. Generally, the energy exerted by the airbag is in the same range as that of the user, eliminating some of the negative effects on the user. In some cases, especially when the crash is under 50 km/h and the airbag activates, the energy of the passenger is not enough to offset the energy from the airbag, leading to face injuries.

In order to measure the amount of damage produced to the face of an occupant, a special vinyl dummy mask was developed. This mask is equipped with a series of force sensors that are distributed throughout the face in specific locations where injury can occur. The mask comes from a Hybrid III 50^{th} percentile male dummy, which is the most widely used crash test dummy in the world for the evaluation of automotive safety restraint systems in frontal crash testing. The dummy is a regulated test device in the European ECE regulations and in the US safety standards. The skull and cap of Hybrid III 50th percentile male dummy are one piece cast aluminium parts with removable vinyl skins. The head skin of the dummy offers high bio-fidelity with its anthropomorphic structure.

To develop and improve the prototype, the required instrumentation had to comply with certain criteria, such as reliability, robustness, repeatability, ease of mounting, time response and functionality. All of these capable of being mounted over a vinyl dummy skin. The time response of the sensor was of special importance since the airbag inflates and starts deflating in about 0.2 seconds after the impact. For this task, Flexiforce sensors were selected because they can measure both static and dynamic forces of up to 4500 N and are thin enough to enable non-intrusive measurement. The sensors do not interfere with the dummy head profile and bio-fidelity. They use a resistive-based technology in which resistance is inversely proportional to applied force. Their flexibility enables them to be placed on non-planar surfaces such as a dummy face. The sensing area is a circle with a diameter of 9.53 mm, which is very adequate for positioning on critical points for precise measurement.

Figure 1. Modified dummy mask.

To validate the prototype and the latter evaluation of facial damage, three types of tests were established:

- Static tests with airbag deployment
- Dynamic tests on sled using UNECE 16 Standard pulse
- Full vehicle dynamic test (Full frontal with rigid barrier at 50 km/h)

To carry out all the tests, the same model of airbag was used. In this way a greater homogeneity and representativity of the tests and the performance is achieved. The selected airbag has the following characteristics:

- Airbag: Driver airbag.
- Vent hole diameter: 25 mm.
- Series mounted

Static tests The main objectives of the static tests were to verify that the mask and the sensors were working correctly and to obtain a basic reference value of the force exerted on the dummy face, since all the dynamic energy of the test is eliminated from the system. The system was tested and evaluated for correct functionality, with admissible levels of repeatability and reproducibility.

The test was carried out with the dummy having a 20º incline to the front, achieving a close to the steering wheel position. This is required because the airbag volume is designed to fit between the dummy and the steering wheel, and without any dynamic activity, it would not contact the dummy face at all. With this inclined position, the airbag has full face contact at mid distance.

Figure 2. Dummy positioning.

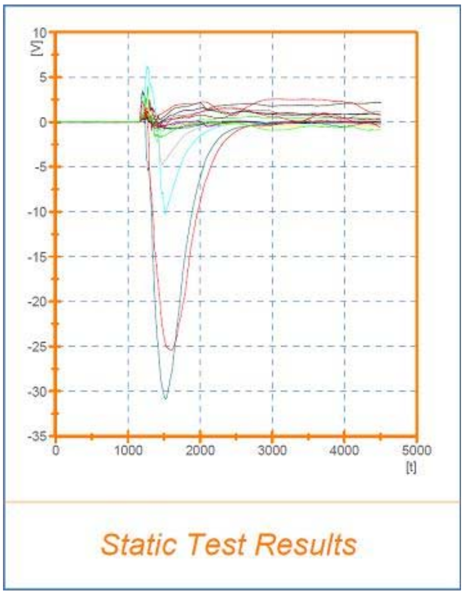

Figure 3. Static test results.

The results from these tests show the mask functionality and are a base measurement for the airbag forces. The signals shown in the graphs are the ones obtained from the mask sensors. The larger curves are the ones for the sensors located in the most critical zones, that is, the front and centre of the face. With this test, we could be able to know the damage caused exclusively by the exploding airbag.

Dynamic tests The next step was to perform dynamic tests using a sled. The main objectives were to obtain the forces received on the face with a typical accident pulse and to be able to analyse the possible injuries caused. The tests were performed according to the following criteria:

- Type of test: Frontal impact
- Velocity: 50 ± 1 km/h
- Pulse: Standard UNECE 16

The required instrumentation to carry out these tests can be classified into three groups: mask, dummy and sled.

Mask instrumentation The mask is made out of 18 load cells. When installing the mask on the dummy, these cells are located on different points where the most typical injuries occur.

Dummy instrumentation The dummy instrumentation is comprised of three accelerometers located on the head's centre of gravity, one for each direction X, Y and Z.

Sled instrumentation The sled includes two accelerometers installed in the X direction (redundancy)

Prior to carrying out the test, the dummy must be correctly positioned. For this reason, a number of requirements for seating the dummy were established. This allows having a reference initial position in all the tests.

Seat position

- The seat must be located in mid position. In case there are no position slots at the mid point, the seat should be located in the slot immediately after.
- The seat must be in the lowest position.
- The seat back may be located according to the manufacturer. If such requirement is not available, the seat back must be reclined 25º to the back with respect to the vertical line.
- The headrest will be in the highest possible position.
- The headrest angle may be set according to the manufacturer. If such measure is not available, it should be in the mid position.
- The seat's lumbar support will be set according to the manufacturer. If this is not available, then it should be fully retracted.
- The seat arms will be set to their functional position, as long as they allow for correct dummy positioning.
- The seat belt will be set according to the manufacturer.

Dummy positioning The dummy must be seated according to the EuroNCAP test protocols for frontal impact.

Figure 4. Sled test positioning.

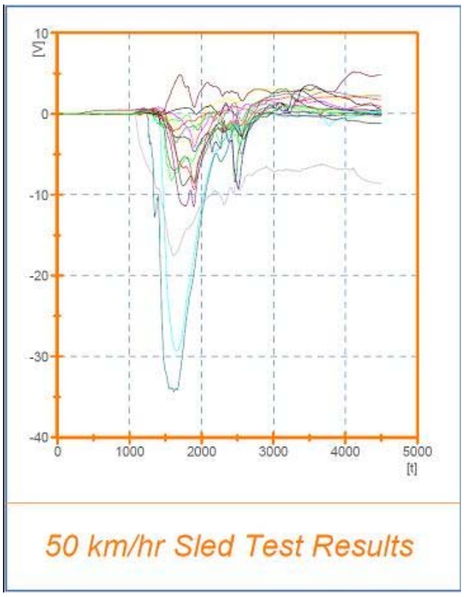

Figure 5. Sled test results.

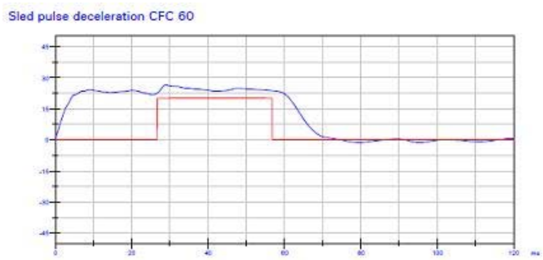

Figure 6. Sled pulse.

The results from the dynamic tests clearly show an increase in the overall pressure exerted over the mask sensors, accompanied by higher head acceleration provoked by the higher energy of the tests. It is important to say that the readings from the sensors become more precise when the energy of the test increases. In this scenario, the force received by the central part of the face is much more than in the static tests.

Full vehicle test To complete the validation of the system, a full scale vehicle test was performed. This test helped us to verify that the mask can be used in more aggressive environments. Also, this test allows a comparison amongst the sled test values and the crash scenario test. The latter data shows the existing relation between the laboratory results and the ones observed and defined during the accidentology study phase. With these tests we have closed the Laboratory – full vehicle – real life scenario circle, defining a simplified methodology for the validation of the protocol (using the sled with the UNECE 16 standard) and comparing the results obtained with a full scale vehicle crash.

General test parameters:

- Type of test: Full frontal impact.
- Impact velocity: 50 ± 1 km/h
- Barrier: rigid

The required instrumentation to carry out these tests can be classified into three groups: mask, dummy and vehicle.

Mask instrumentation The mask is made out of 18 load cells. When installing the mask on the dummy, these cells are located on different points where the most typical injuries occur.

Dummy instrumentation The dummy instrumentation is comprised of three accelerometers located on the head's centre of gravity, one for each direction X, Y and Z.

Vehicle instrumentation The vehicle includes two accelerometers installed in the X direction (redundancy). They must be located in the tunnel, at halfway in the longitudinal direction.

Prior to carrying out the test, the dummy must be correctly positioned. For this reason, a number of requirements for seating the dummy were established. This allows having a reference initial position.

Seat position

- The seat must be located in mid position. In case there are no position slots at the mid point, the seat should be located in the slot immediately after.
- The seat base must be inclined according to the manufacturer's data up to the mid position as maximum.
- The seat must be in the lowest position.
- The seat back may be located according to the manufacturer. If such requirement is not available, the seat back must be reclined 25º to the back with respect to the vertical line.
- The headrest will be in the highest possible position.
- The headrest angle may be set according to the manufacturer. If such measure is not available, it should be in the mid position.
- The seat's lumbar support will be set according to the manufacturer. If this is not available, then it should be fully retracted.
- The seat arms will be set to their functional position, as long as they allow for correct dummy positioning.
- The seat belt will be set according to the manufacturer. If the data is unavailable, it should be set to the middle position or the slot right above the middle.
- The steering wheel must be located in the mid position, horizontally and vertically.
- All vehicle windows must be in the lowest position.
- The gear change lever must be in neutral position.
- The pedals must be at resting position.
- Vehicle doors must be closed and unlocked.
- Rear-view mirrors should be in normal use position.

Dummy positioning The dummy must be seated according to the EuroNCAP test protocols for frontal impact.

Figure 7. Vehicle test setup.

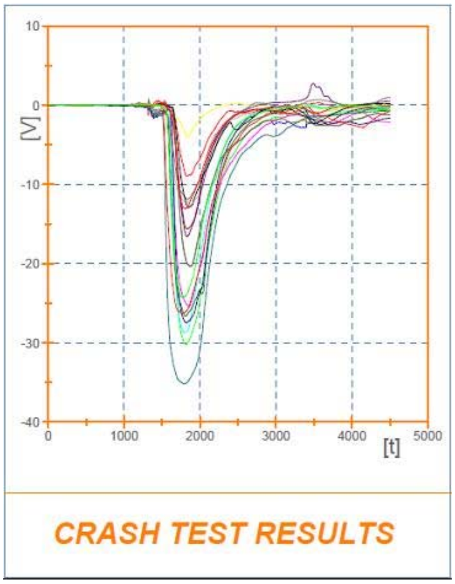

Figure 8. Crash test results.

Results from this impact show that the mask is still receiving the sensor data correctly, maintaining an adequate repeatability level. The forces found in this test are similar to those obtained from the sled test. A few slight differences are found regarding the head acceleration, mainly due to the fact that the pulse in the vehicle impact is different, and which will vary from case to case. Nevertheless, the vehicle has a greater energy absorption capacity, which makes the sled test more representative since the pulses can be repeated in an easier way and sets a worse case scenario for the dummy in terms of energy absorption.

Auditory system injuries

Another important step was the generation and validation of a tool to measure the sound level and pressure generated inside the vehicle's cabin during airbag activation. This is with the aim of evaluating the risk of suffering injuries, either temporal or permanent, to the hearing system. Generally, these injuries occur due to the high level of the sound generated by the airbag explosion and the accident noise itself and also because of the sudden increase in cabin pressure that occurs when the airbag inflates and displaces an extra amount of air equal to the volume of the airbag.

As mentioned earlier, the system designed to measure the sound level and pressure is also based on Hybrid III 50th percentile dummy heads. In this case, the heads have been modified to receive a couple of special microphones to measure the right and left side sound and pressure of the occupants. Two versions of the head exist: one in which the microphones are set in place through a special attachment harness and another one where the microphones were built in. The position of the microphones was established considering that they must be the same place as the average human ear.


Figure 9. Microphones in dummy heads.

The microphones are protected in such a way that during the tests, these do not receive any damage and maintain their listening capability. To validate the protective device, a couple of tests were carried out. The system proved effective in protecting the device and maintaining its functionality.


Figure 10. Protected microphone.

The following equipment was used

- Microphones Bruel & Kjaer 4938 modified according to WB 1418
- Microphone preamplifiers Bruel & Kjaer 2670 modified according to WB 1419
- Microphone conditioners Bruel & Kjaer 2690-OS4
- Multichannel acquisition system LMS Pimento
- TMON software from the LMS CADA-X Package
- Workstation Hewlett Packard C360

Apart from the microphones installed in the dummy heads, an additional microphone is installed in the rear part of the vehicle, in the central position. This microphone allows measuring the sound and pressure levels from a further position and compares the data from the front (closer to the users) and the rear, where a passenger may also receive some of the effects.


Figure 11. Rear seat microphone.

The data obtained from the microphones of the heads and rear seat are used to calculate the amount of noise generated in the cabin. Two times are selected to make the calculation of acoustic pressure and sound level: 1 ms and 0,2 ms.

Calculation of the moving average of the squared acoustic pressure, with the following expression (Equation 1):

$$p_{AV}^2(t) = \frac{1}{T}\int_{t-T}^{t} p^2(t)dt \quad (1).$$

Where $p_{AV}^2(t)$ is the moving average of the squared acoustic pressure in squared pascals,
T is the time window (1 ms or 0,2 ms were used),
$p(t)$ is the acoustic pressure in pascals.

Calculation of the sound pressure level of the moving average with the following expression (Equation 2):

$$SPL(t) = 10\log\frac{p_{AV}^2(t)}{p_0^2} \quad (2).$$

Where $SPL(t)$ is the sound pressure level in dB, $p_{AV}^2(t)$ is the moving average of the squared acoustic pressure in squared pascals, p_0 is the reference pressure equal to $20 \cdot 10^{-6}$ pascals.

With the idea of quantifying the noise and pressure values inside the cabin during an accident and airbag deployment, static and dynamic tests are performed. This is done in order to compare the difference in the level of sound and pressure with the airbags only and then with the added noise coming from the vehicle while crashing (deformation, breaking parts, other systems).

The system allows measuring the sound and pressure levels from the lateral and head airbags too. As the microphones act as the human ear, and are in the same location, the amount of noise perceived by them is the same in all accident configurations. All these tests can be carried out with the windows up or down, and that will also make a difference in the pressure levels. It is important to mention that front and lateral airbag tests must be carried out separately, since these systems never activate at the same time in a real accident. The last test should be the dynamic test, since in this case, the test is destructive.

Shown next are the main configurations for tests to measure sound and pressure levels inside a car:

Static

- Driver and/or passenger airbag, windows up.
- Driver and/or passenger airbag, windows down.
- Lateral airbags, windows up.
- Lateral airbags, windows down.

Dynamic

- Frontal impact with driver and/or passenger airbag activation, windows up.
- Frontal impact with driver and/or passenger airbag activation, windows down.
- Lateral and curtain airbag activation, windows up.
- Lateral and curtain airbag activation, windows down.
- Pole impact with lateral and curtain airbag activation, windows up.
- Pole impact with lateral and curtain airbag activation, windows down.

Reference values The reference values that are considered for the evaluation correspond to the intensity which the human ear is able to withstand for a certain period of time. If the intensity is low, the human ear can tolerate the sound for a longer period of time. If the intensity is high, then a short period of exposure could result in temporal or permanent injuries, especially to the inner ear.

A sound that exceeds 125 dB is considered to be above the human pain threshold and has a large probability of permanently damaging the ear, even in short time exposures. It is not recommended to be exposed to sounds that exceed 140 dB, even if the threshold time is in the range of 50 ms. Since the airbag explosion takes place in less than 1 ms, a person could theoretically withstand a sound in the range between 157 dB and 160 dB.

Figure 12. IDIADA's FTIR machine.

Table 1.

Sound level time exposures

Continuous dB	seconds
85	28800,000000
100	900,000000
115	28,125000
124	3,515625
130	0,878906
142	0,054932
145	0,027466
151	0,006866
157	0,001717
160	0,000858
166	0,000215
172	0,000054
184	0,000003

For the tests, the pressure and sound levels were recorded in the following positions:

- Driver left ear
- Driver right ear
- Passenger right ear
- Rear central area

Finally, ten tests were considered, which included eight with airbag deployment only, the ninth is an impact test with airbag deployment and the tenth is an impact with no airbag deployment.

Table 2.
Test setup

Kind of crash	Vehicle	Description of the test
Static front	1	Deployment of steering wheel and dashboard airbags and seat belt Pyrotechnic. Windows closed
Static front	1	Deployment of steering wheel and dashboard airbags and seat belt Pyrotechnic. Windows closed. Dashboard not changed
Static front	1	Deployment of steering wheel and dashboard airbags and seat belt Pyrotechnic. Windows open. Dashboard not changed
Static side	1	Deployment of curtain and side airbags. Windows closed
Static side	1	Deployment of curtain and side airbags. Windows closed. Side airbag cover and roof not changed
Static side	1	Deployment of curtain and side airbags. Windows open. Side airbag cover and roof not changed.
Static front + side	2	Deployment of all the airbags. Windows closed.
Static front + side	2	Deployment of all the airbags. Windows open. Dashboard, side airbag cover and roof not changed
Dynamic front	1	Deployment of steering wheel and dashboard airbags and seat belt Pyrotechnic. Windows closed.
Dynamic front	2	NO airbag deployment. Windows closed.

Table 3.
Test results

* open windows	Test Number									
	1	2	3*	4	5	6*	7	8*	9	10
Driver left ear (dB)	163,7	163,6	157,7	160,6	161,8	160,1	164,6	161,8	166,2	149,1
Driver right ear (dB)	165,2	164,2	159,3	156,8	157,2	155,3	164,7	157,9	168,5	149,6
Passenger left ear (dB)	167,2	165,2	156,0	157,6	157,8	153,8	164,5	156,9	165,9	150,0
Center rear (dB)	163,0	162,7	153,4	155,6	157,7	155,7	163,0	156,2	162,8	150,7

The results show that the most critical configuration is test number 9, which is the dynamic test with frontal airbags deployment, pyrotechnic seatbelt retractor and windows closed.

This test passed the threshold of the 168 dB. According to the risk exposition timetable, this sound is enough to cause permanent damage to the human ear, even with very low exposure time. Comparatively, the three tests made with the windows open reveal lower sound and pressure levels; nevertheless, the difference is not much and the sound level is still over the 140 dB maximum recommended limit.

Toxicity analysis

The airbags while deploying expel gases that result from the detonation used to inflate. This explosion needs to be controlled and extremely quick. Some manufacturers measure the resultant gases expelled through the vent holes and the effects they have on persons.

The following list of gases, which may represent a risk to the health of people, are taken from the Standard AK-ZV 01 "Pyrotechnic Retention Systems in Vehicles" used by: Volkswagen AG, Audi AG, Bayerische Motoren Werke AG (BMW), Daimler AG (Mercedes-Benz) and Porsche AG. This standard is applicable to different types of airbag available on the market and establishes the tests and limits of gas concentration that can be present after airbag deployment.

The list of gases and the limits are shown next:

Table 4.
Dangerous gases list

Cl_2	5 ppm
CO	500 ppm
CO_2	20.000 ppm
$COCl_2$	1 ppm
NO	50 ppm
NO_2	10 ppm
NH_3	150 ppm
HCl	25 ppm
SO_2	50 ppm
H_2S	50 ppm
HCN	25 ppm
$HCHO$	10 ppm

The established values are considerably under the IDLH (Immediate Danger for Live and Health)

These limits are considered as the TLV (Threshold Limit Value) – TWA (Time Weighted Average) for a person within an 8 hour exposure time. According to the substance, the TLV – STEL (Threshold Limit Value Short Term Exposure Limit) or the TLV – C (Threshold Limit Value Ceiling) is used. The TLV –STEL is the total amount of gas to which a person can be exposed during a maximum period of 15 minutes, and up to 4 times in one day. The TLV –C is the maximum value that should never be exceeded.

On international material safety data sheets, the value can be given in any of these three categories. These limits have been established by the ACGIH (American Conference of Governmental Industrial Hygienists). Parallel to the ACGIH, the MAK from the Federal Republic of Germany considers some different values for each gas.

To determine the quantity and concentration of the gases present in the cabin of a car after airbag deployment, a test in a sealed chamber must be carried out. To correctly obtain the data, measurements should be taken for the following 30 minutes after explosion. All the installed modules in the vehicle must comply with the requirements established in the AK-ZV 01 "Pyrotechnic Retention Systems in Vehicles".

The chamber must have an approximate volume of 2,5 m^3 with a cubic form. The modules must be detonated in a controlled manner. There are two different configurations to measure the released gases:

Measuring setup 1 For Cl_2 (Chlorine) y HCl (Hydrogen Chloride) Dräger tubes must be used.

To measure NO (Nitrogen Oxide) and NO_2 (Nitrogen Dioxide), CLD (Chemical Luminescence Detection) or an infrared system can be used. An infrared system must be used to determine the other toxic gases in the list.

All the measurements shall be taken in parallel in a 30 minute range.

Measuring setup 2 A mass spectrometer, which is able to measure all gases simultaneously.

Measuring lines

For measuring setup 1: fluoropolymers (e.g. Viton, Teflon etc.)
For measuring setup 2: heated stainless steel pipe of TTL quality
Inside diameter: max. 5 mm
Length: max. 5 m

Dust filter CLD does not involve a filter, all other devices require a filter with 5 mm pore width. The NO and NO2 measurements shall be performed without a filter.

Test point Test point: Centre of the sidewall in the unfolding direction

Test conditions Test temperatures: Room temperature

Test procedure

Preparation To prepare for measurement, the measuring setup is stabilized by means of room air measurements 5 minutes before module detonation; the module does not need to be in the chamber at this point. The airbag module is mounted on a fixture in as-installed position or optionally rigidly mounted with vertical airbag unfolding (Figure 1) in a 2.5 m^3 chamber. Ambient air is present in the 2.5 m^3 chamber. The module is detonated in the pressure-tight chamber using a suitable power source.

Samples for further analyses, if necessary, shall be taken from this chamber. The interior chamber temperature and the ambient temperature around the chamber shall equal room temperature immediately prior to detonation.

Gas analysis The tests must occur (60 ± 5) sec. after detonation of the module in the 2.5 m^3 chamber, whereby the airbag must not be pressed out after module detonation and the gases that occur during or after detonation must not be agitated (as with a ventilator, for example). The measurements must be taken over a period of 30 minutes. The average must then be calculated.

Measuring setup 1 When measuring using Dräger Tubes, measurements are carried out in 5 minute intervals, whereby the cross sensitivities must be taken into consideration. The sample is removed directly from the chamber using a bypass, for example. When using CLD, the volume removal is in the order of □1.2 l/min.; when using FTIR, a flow rate of 0.5 to 2.5 l/min must be selected.

Measuring setup 2 When using a mass spectrometer, a flow rate of approximately 10 l/min shall be selected.

For all the installed modules in the vehicle (front, lateral, pyrotechnic) the following distribution is proposed:

- 50% frontal protection systems (driver, passenger and knee airbags)
- 25% lateral protection systems (head, thorax and window airbags)
- 25% seatbelt pyrotechnic retractor

The manufacturer establishes the value distribution in between the different components in the condition statement. The tests are carried out with a fully-equipped vehicle. These tests must be carried out as mentioned before in setups 1 and 2.

Measurement location The measurement of the gases is to be done in the front seat, in the dummy head area, on the side of the deployed airbags.

Test conditions

Temperature inside vehicle: 23ºC ± 5ºC
Atmospheric humidity: 40-60% relative humidity.

To determine the generated gases after airbag deployment, we have an infrared spectroscopy gas measurement machine (FTIR). Our equipment is designed to calculate the gases from the exhaust pipe from combustion engines; however some of the gases released from airbag activation are the same as those produced in the combustion of fuel.

The components we can analyse with our FTIR machine are:

Carbon monoxide	**CO**	**listed**
Carbon dioxide	**CO_2**	**listed**
Nitrogen oxide	**NO**	**listed**
Nitrogen dioxide	**NO_2**	**listed**
Nitrous oxide	N_2O	
Water	H_2O	
Ammonia	**NH_3**	**listed**
Sulphur dioxide	**SO_2**	**listed**
Formaldehyde	**HCHO**	**listed**
Formic acid	HCOOH	
Methane	CH_4	
Ethylene	C_2H_4	
Ethane	C_2H_6	
Propylene	C_3H_6	
1,3-Butadiene	1,3-C_4H_6	
Isobutylene	iso-C_4H_8	
Benzene	C_6H_6	
Toluene	C_7H_8	
Ethanol	C_2H_5OH	
Acetaldehyde	CH_3CHO	
Acetone	CH_3COCH_3	
Xylene	C_8H_{10}	
Ethyl benzene	$C_6H_5C_2H_5$	
HFC-134a	CH_2FCF_3	

The gas measurement can be done directly inside the vehicle or in a special chamber dedicated to the test.

The gases that we cannot measure with the FTIR machine are: Cl_2 (Chlorine), $COCl_2$ (Phosgene), HCl (Hydrogen chloride), H_2S (Hydrogen Sulphide), HCN (Hydrogen Cyanide).

The equipment readily available at IDIADA for this study was not capable of measuring all required gases, Consequently we will not be able to perform the tests established in the protocol. To this end, we need to use instrumentation or similar equipment, which indeed has the capabilities.

CONCLUSION

The work carried out during this project showed that airbags are very useful in reducing fatalities and serious injuries in road accidents. Nonetheless, their activation in near-threshold situations, where the dynamic requirements are not always met, may cause injuries to the occupants.

The most common injuries are directly to the face, to hearing and skin abrasion and possible inhalation or contact with toxic substances. During this project, we developed a set of tools that allowed us to investigate more deeply the effects of airbags and their interaction with the passengers. The designed tools aim at helping airbag designers and manufacturers along with automobile manufacturers to analyse the specific situations in which their product may or may not meet safety requirements in near-threshold situations.

The special dummy mask modified with pressure sensors showed very good results in measuring forces during accidents, these tests being carried out statically and dynamically in a sled and full frontal vehicle crash. The dynamic data were very well correlated and the difference between static tests and dynamic tests (both sled and car) showed a slight difference in pressure.

Regarding hearing damage, the installed microphones in the dummy heads were able to withstand the energy and dynamics of a crash and still provide accurate measurement of sound level and pressure. This fact makes them ideal for analysing the behaviour of sound waves and pressure distribution throughout the cockpit.

In the toxicity analysis, we discovered that important amounts of several gases are released, and each gas has a different toxicity level on the human being. In our special case, we were not able to measure all the required gases for the study. However, we now know what we need to measure and are searching for suitable equipment to do this. If possible, we will try to use equipment that can be fitted into vehicles and tested in the same run.

Further work needs to be done, and we are aiming to combine the pressure mask with the microphones to generate single test measurement equipment. We will also optimize the mask sensors, since not all of them may be required in the future.

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