Concept Design of an A-Pillar Mounted Airbag for Pedestrian Head Protection

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ABSTRACT:

Accident investigations have shown that in pedestrian-versus-vehicle accidents, windshield edges, A-pillars, cowls are the main sources for severe head injuries due to their high stiffness. To mitigate head injury severities, it is necessary to improve the safety performance of these structures.

An A-pillar mounted airbag system (AMAS) was devised with the aim to prevent head from directly impacting against stiff structures such as A-pillars, windshield frames and edges. The airbags of the AMAS are installed inside A-Pillars. When a car strikes with a pedestrian, the airbag will break the A-Pillar cover and deploy along the whole A-Pillar to cover the stiff structures. In this study, the safety performance that can be provided by this system was evaluated by mathematical simulations. A finite element (FE) Ford Taurus car model and an EEVC headform model were used to simulate the pedestrian headform tests as proposed by EEVC. FE airbag models were developed and the influence of airbag parameters, including airbag type, inflow mass rate, vent size and deploy timing, were investigated by mathematical simulations. The safety performance of the AMAS was also evaluated by an FE human head model. The results show that this system can greatly reduce the head injury severity in case a pedestrian head impacts with A-pillar areas.

Keywords:

Pedestrian safety, Airbag design, Head injury, FE model

INTRODUCTION

Pedestrian accidents have been a major cause of traffic induced fatalities. Although the amount of pedestrian fatalities has been reducing during the last 10 years especially in the European Union and in Japan, it still composes a huge social and economy burden.

In pedestrian accidents, head injury is the leading cause of lifelong disabilities and fatalities. Maki et al. [1] reviewed 4,416 fatal pedestrian accidents in Japan and the result showed that 64% fatalities were due to head injures. Farooq and Schuster [2] reviewed the accident cases in IRTAD and GIDAS databases and found that head injuries caused 62% of pedestrian fatalities. Past studies have also revealed that the major causes of severe head injuries (AIS3+) were due to the impact of pedestrian head against stiff car front structures such as bowls, windshield frames and A-pillars. IHRA [3] showed that windshield, windshield frames and A-pillars were responsible for 51% of AIS2+ head injuries.

EEVC WG17 has proposed a test method to evaluate the safety performance of vehicle front structures in pedestrian accidents [4]. For adult and child headform impacts, the headform is propelled to hit a vehicle at an impact speed of 40 km/h. The impact angle is 65 degrees relative to horizontal plane for the adult headform and 50 degrees for the child headform. The acceleration at the centre of gravity of the headform is measured. The HIC (36 ms) is calculated and a value lower than 1000 is regarded as acceptable. The A-pillars are not included in the current test method but would be taken into consideration in the near future.

In this study a protection system, A-Pillar Mounted Airbag System (AMAS), was devised to minimize the risk of head injuries in head-to-A-Pillar impacts. The aim of this paper was to evaluate the safety performance that could be provided by this system. Both headform model and human head model were used in this study.

METHOD AND MATERIALS

In this study, the design requirement of the AMAS was first described and an airbag model was designed based on these requirements. The performance of the airbag model was then evaluated by conducting mathematical simulations involving a headform model impacting against a ford Taurus car model. The protective performance of the airbag model was also evaluated using an FE human head model.

Description of AMAS

AMAS is composed of two airbags, an inflator module, sensors and an ECU. The whole system except the airbags and the sensors is placed in the dashboard. The A-Pillar will only contain the airbag in order to keep the system simple and also is due to the space limitation. The sensors are installed in the bumper which should be able to activate the system if and only if the car strikes with a pedestrian. The A-Pillar cover can break when the airbag is deployed in a similar way as the driver's airbag breaks the cover of the steering wheel. The design requirements of the AMAS are specified as following: (1) To cover the stiff area including A-pillars, windshield frames and windshield edges, (2) to reduce the HIC value to less than 1000 in headform tests for these areas, (3) not to impair the safety performance of the car in rollover accidents. In this study the focus is on the first two requirements while the third requirement would be considered in a continued study.

Mizuno and Kajzer [5] conducted adult headform tests on windshield areas at an impact speed of 40 km/h and calculated the corresponding HIC value. The results showed that the HIC value varied according to the distance from boundaries, as shown in Figure 1. In our study, it was decided that the airbag should cover the A-pillars and the neighbouring windshield edges where HIC values exceed 1000. For this requirement, an airbag was designed with a width of 300 mm and a length of 800 mm which could cover these areas. The airbag is in a rectangular form, the main region is divided into several chambers by seams (Figure 2).

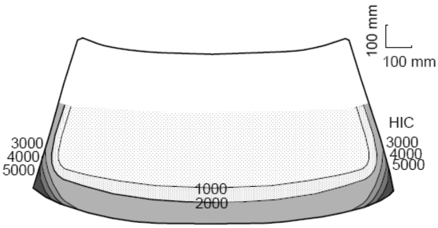


Figure 1: HIC distribution in windshield area [5]

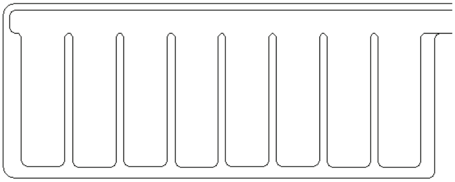


Figure 2: The sketch view of the airbag

Mathematical Simulation

The goal is to minimize the HIC value in headform impact tests by mathematical simulations. A finite element Ford Taurus vehicle model was used for the parameter study. The original model was simplified which only keeps the frontal part to decrease the computation time. The adult headform model used was developed and validated by

ARUP® which simulated the EEVC standard adult headform impactor with a weight of 4.8 kg. The simulations were setup according to the EEVC test requirements (Figure 3). The adult headform model was propelled to hit the A-pillar. The initial impact speed was 40 km/h and the impact angle was 65 degrees from the horizontal plane. The acceleration was measured at the impactor's centre of gravity. The HIC (36 ms) was then calculated based on the time history of the acceleration. In this study, the HIC value measured in the impact simulation without airbag protection is 5968.

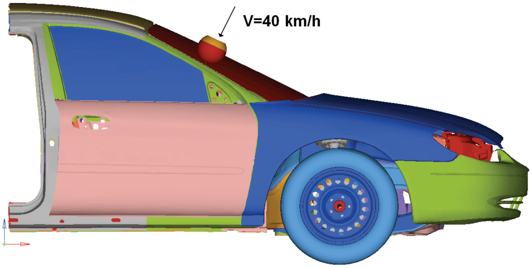


Figure 3: Simulation setup for headform impacting against A-pillar

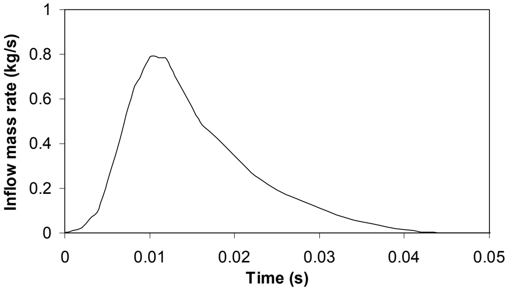


Figure 4: The basis inflow mass rate

To evaluate the safety performance provided by the airbag system, an FE airbag model was developed. The LS-DYNA airbag model used to define the airbag was the "simple_airbag_model". The inflow mass rate was controlled by a load curve as shown in Figure 4. This load curve was defined as the basis inflow mass rate. In LS-DYNA, a scale factor can be used together with this curve to control the total mass inflow. The other gas parameters used are listed as following:

- Heat capacity at constant volume: $8.36E08 \ \ N \cdot mm/(tonne \cdot K^o)$
- Heat capacity at constant volume: $1.17E09 \ \ N \cdot mm/(tonne \cdot K^o)$

- Gas Temperature: 800 K^o
- Ambient pressure: 1 bar
- Ambient density: $1E-12\ Tonne/mm^3$

The airbag material used was "Mat_fabric". The input for the airbag material was defined as following:

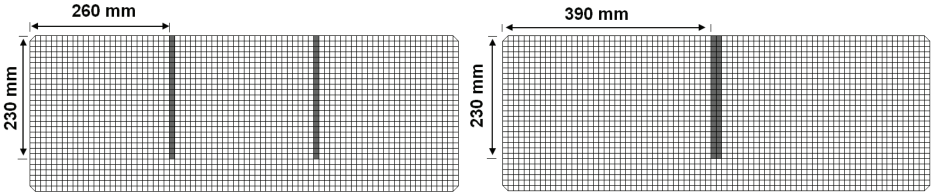
- Elastic modulus: 200 MPa
- Poisson's ratio: 0.3
- Thickness: 1 mm
- Permeability: 0

The airbag model was attached along the A-pillar by spring elements. The unfolding of the airbag was not considered. To acquire an HIC value of less than 100, the airbag should provide a reasonable deformation distance. Mizuno and Kajzer [5] derived the relationship between the HIC value and dynamic deformation by mathematic calculations and summarized as Equation 1.

$$HIC = 0.001882 \cdot {V_0}^4 \cdot {X_d}^{-1.5} \qquad \text{(Eq.1)}$$

Where V_0 is the initial velocity and X_d is the required dynamic deformation distance. Based on the above equation, the required dynamic deformation distance should be greater than 94 mm in order to get a HIC value lower than 1000 at an initial impact speed of 40 km/h.

The airbag models were first designed with small chamber size and no gas leakage. However, trial simulations found that it was impossible to achieve a HIC value lower than 1000 with this solution. At impact speed as high as 40 km/h, the rebound force due to gas compression is very large. Therefore, the ventilation of the airbag is necessary. A parameter study was carried out to understand the influence of the airbag parameters such as airbag type, inflow mass rate, vent size and ignition timing. Two types of airbag models were used: airbag type A has three chambers with each chamber size of 230x260 mm and airbag type B has two chambers with each chamber size of 230x390 mm as shown in Figure 5. Seven different vent sizes were investigated which ranged from 0 to 600 mm^2. Three different scale factor for inflow mass rates were used which were 0.7, 1.0 and 1.2. A simulation matrix was designed with the combination of these parameters, as shown in Table A1 which included a total of 42 simulations. The influence of gas ignition timing was also investigated with extra 6 simulations as shown in Table A2. Three different airbag ignition timings were investigated which were 0 ms, 5 ms and 10 ms.



(a) Type A (b) Type B

Figure 5: Sketch view of FE airbag models

Evaluation using FE head model

The airbag protection performance was also evaluated by using a validated FE human head model. The FE head model consists of a scalp, skull, CSF, meninges, cerebral, cerebellum, brain stem, falx and tentorium as shown in Figure 6. The model has a total of 35,616 elements and weighs 4.78 kg. It has been validated by Nahum's cadaver tests. Two simulations were carried out using the head model. In the first simulation, the head model impacted against A-pillar region without airbag. Then the airbag model produced the least HIC value from previous parameter study was used to evaluate the protection performance of the airbag for the head. In both two simulations, the head impact speed was defined as 40 km/h and the impact angle was defined as 65 degrees.

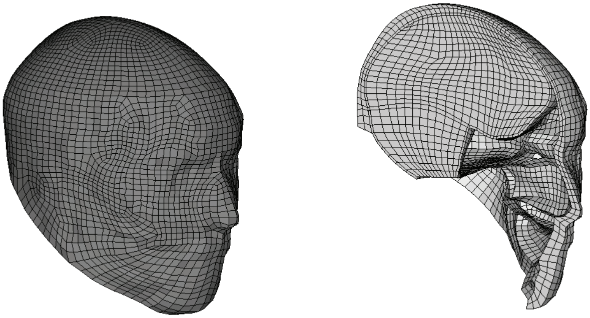


Figure 6: FE human head model

RESULTS AND DISCUSSION

Headform Impacting Simulation

The results of the mathematical simulations using FE headform model are presented in Appendix, as shown in Table A1-A2. Three parameters were measured: the airbag pressure at the moment of headform touching the airbag, the HIC value and maximum 3 ms acceleration of the headform. Analysis of the time history of headform acceleration found that typically there were three different kinds of loading condition as shown in Figure 7. Curve I happens when the airbag pressure or thickness is not large enough which will make the headform contact with the A-pillar. Curve III happens when the airbag pressure is too high which will results in a large rebound force and consequently lead to a large HIC value. Curve II is the desired acceleration history which only happens when the airbag has the proper inflow mass rate and vent size.

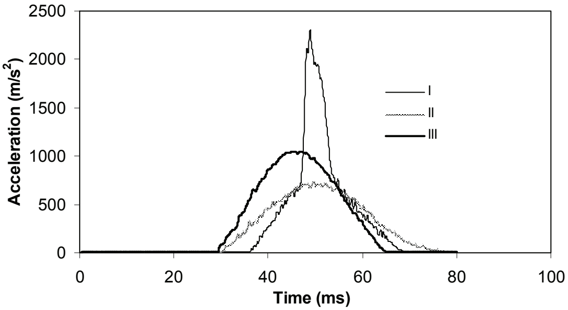
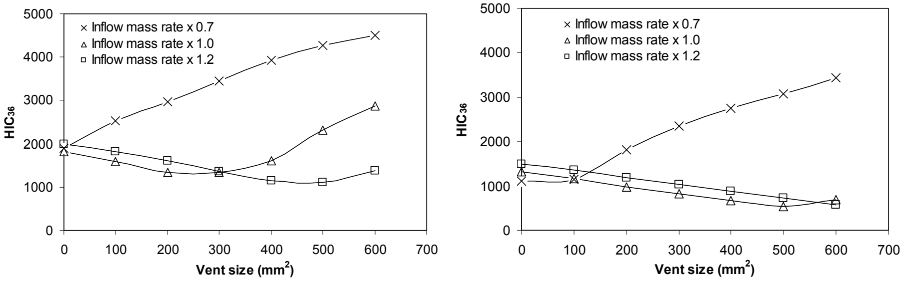


Figure 7: Typical time histories of headform acceleration

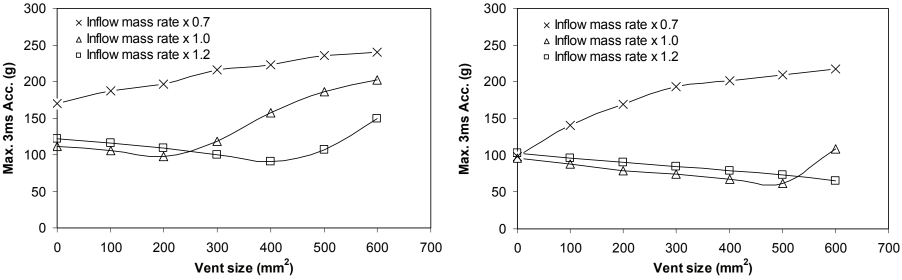
For airbag model A, no simulation can reach a HIC value lower than 1000. The minimum HIC value is 1120, which happens when the airbag has an inflow mass rate 1.2 times of the basis inflow mass rate, a vent size of 500 mm^2. The main reason of the high HIC value of airbag model A is that in most cases the headform would contact with the A-pillar. For airbag model B, 8 simulations can reach a HIC value lower than 1000. The minimum HIC value is 532, which happens when the airbag has the basis inflow mass rate, a vent size of 500 mm^2.

The influence of airbag parameters on the HIC value and maximum 3 ms acceleration was investigated as shown in Figure 8 and Figure 9. The influence of vent size on the resulting HIC value and maximum 3 ms acceleration is two fold. At relative low inflow mass rate, for example at inflow mass rate of 0.7 times of the basis inflow mass rate, the HIC value and maximum 3 ms acceleration will increase with the increasing of the vent size. This is because at low inflow mass rate, the airbag can not prevent the headform from impacting with A-pillar. Larger vent size will make the airbag pressure decrease faster which result in more severe head impact against A-pillar. At relative larger inflow mass rate, the HIC value and maximum 3 ms acceleration will first decrease with the increasing of vent size due to decreased rebound force. After a critical vent size, the HIC value and maximum 3 ms acceleration will increase with the increasing of vent size due to the contact with A-pillar. This critical value is usually the optimized vent size.



(a) Airbag type A (b) Airbag type B

Figure 8: Influence of airbag parameters on HIC value



(a) Airbag type A (b) Airbag type B

Figure 9: Influence of airbag parameters on maximum 3 ms head acceleration

The influence of ignition timing on the resultant HIC value was also investigated as shown in Figure 10. The basic configuration is airbag type B with the basis inflow mass rate. The HIC value at gas ignition timing of 0 ms, 5 ms and 10 ms were calculated. The results show that due to the delay of ignition timing, the HIC value will have a small increase.

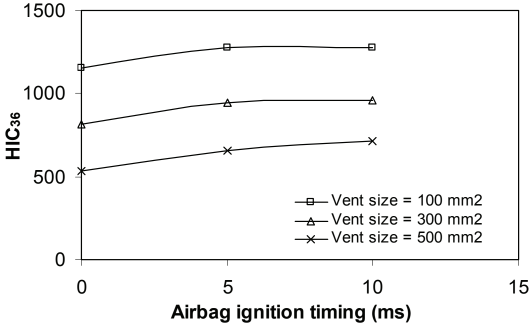


Figure 10: Influence of airbag ignition

The influence of airbag type, inflow mass rate and vent size on the airbag pressure was also investigated as depicted in Figure 11. Under the same condition, airbag type A has a higher pressure than airbag type B. This indicates that with the increase of chamber number, the pressure will also increase. The airbag pressure also increases with the increasing of inflow mass rate and decreases with the increasing of vent size.

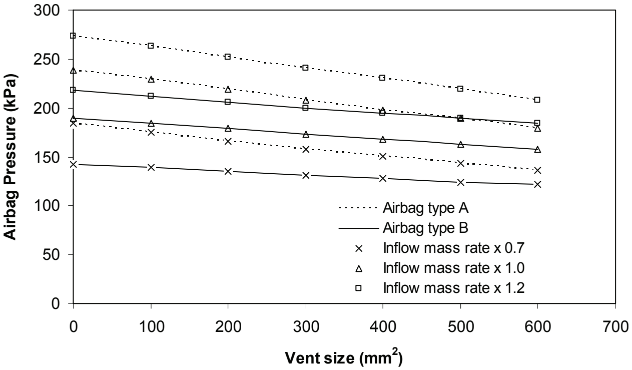
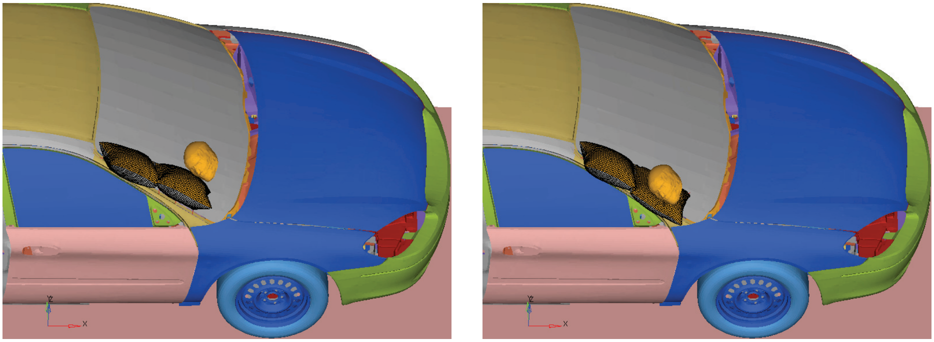


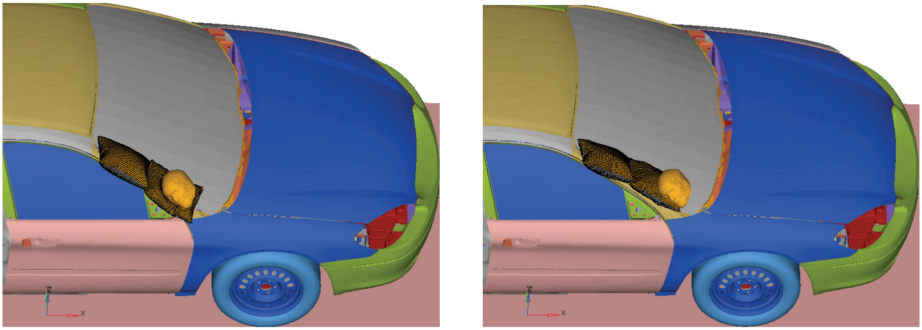
Figure 11: Influence of airbag parameters on the airbag pressure prior to impact

Head Impacting Simulation

Figure 12 shows the motion of the FE head model when it impacts against the A-pillar covered by the airbag model. The results showed that the airbag could prevent head from impacting directly against stiff A-pillar. Also due to the deflating of the airbag, the head has no large rebound motion.



20 ms 40 ms



60 ms 80 ms

Figure 12: Head impacting with airbag covered A-pillar

The head injury parameters in terms of intracranial coup/counter coup pressure, von Mises and shear stress were calculated for the simulations with and without airbag protection. The calculated the results are listed in Table 1. The results showed that without airbag, the coup pressure can reach as high as 2950 kPa and counter coup pressure can reach as high as -2462 kPa. Due to the almost translational motion of the head model, the Von Mises and shear stress was relative small. With the protection of the airbag, the coup pressure decreased to 117 kPa and counter coup pressure decreased to -131 kPa. There is also an obvious decrease for Von Mises and shear stress. Ward et al. [6] proposed a coup pressure tolerance of 235 kPa and countercoup pressure tolerance of -186 kPa for serious brain injuries. Thus in this case, with the protection of airbag, the brain can avoid to be seriously injured.

Table 1: Calculated head injury parameters

	Coup Pressure (kPa)	Counter Coup Pressure (kPa)	Von Mises (kPa)	Shear Stress (kPa)
Without airbag	2950	-2462	10.7	6.1
With airbag	117	-131	1.8	1.0

Conclusions

A theoretical study of pedestrian headform impacts to vehicle A-pillar regions has been performed. The preliminary results predict that a lower HIC value could be achieved during pedestrian headform impacts by using an airbag deploying along the A-pillar. In addition, it was also found that serious brain injuries can be avoided by using the AMAS. The airbag type, inflow mass rate, vent size are important parameters that would affect the safety performance of the airbag. Two design principles are concluded from this study: (1) Deflation of the airbag is necessary, (2) relative larger chamber size was needed to provide enough deformation distance and to lower the airbag pressure.

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Appendix

Table A1:

Airbag type	Scale factor for mass flow	Vent size	Pressure* (kPa)	HIC$_{36}$	Max 3ms Acc. (g)
A	0.7	0	184	1906	170
		100	175	2522	187
		200	166	2964	196
		300	158	3443	216
		400	151	3922	223
		500	143	4268	236
		600	136	4503	240
	1.0	0	239	1812	112
		100	229	1593	106
		200	219	1333	98
		300	208	1335	118
		400	198	1600	157
		500	189	2313	186
		600	179	2873	202
	1.2	0	273	1991	122
		100	263	1816	116
		200	252	1602	109
		300	241	1368	100
		400	230	1149	91
		500	219	1120	107
		600	208	1385	149
B	0.7	0	142	1104	98
		100	139	1136	141
		200	135	1815	170
		300	131	2350	193
		400	128	2754	202
		500	124	3075	210
		600	122	3426	217
	1.0	0	189	1309	96
		100	184	1157	88
		200	179	982	79
		300	173	816	75
		400	168	667	68
		500	163	532	62
		600	158	683	109
	1.2	0	218	1490	103
		100	212	1351	96
		200	206	1179	90
		300	200	1037	85
		400	195	878	79
		500	189	733	73
		600	184	580	65

* Airbag pressure measured at the moment headform impact against airbag

Table A2

Airbag type	Scale factor for mass flow	Vent size	Ignition timing (ms)	Pressure* (kPa)	HIC36	Max 3ms Acc. (g)
B	1	100	0	184	1157	88
			5	177	1275	92
			10	160	1279	95
		300	0	173	816	75
			5	169	948	81
			10	155	960	83
		500	0	163	532	62
			5	161	657	67
			10	150	711	74

* Airbag pressure measured at the moment headform impact against airbag