

## SAFETY AND VISION IMPROVEMENTS BY EXPANDABLE A-PILLARS

### Pipkorn Bengt

Autoliv Research  
Sweden

### Lundström Jesper

Saab Automobile  
Sweden

### Ericsson Mattias

Epsilon  
Sweden  
Paper Number 11-0105

### ABSTRACT

In modern passenger vehicles the A-Pillar is an important structural safety component. In full frontal, frontal offset-, pole and rollover collisions the A-Pillar is carrying to a large load in order to minimize the deformation of the occupant compartment. Generally the larger the cross-section the more load the A-pillar can transfer. However, the A-pillars in general more or less reduce the forward vision angles for the driver. Therefore the width and strength of the A-Pillar are important vehicle safety parameters. The strength and size requirements on the A-Pillar are in contradiction. In an A-pillar design in which the cross section is folded and expands when needed the conflicting requirements can be combined in one component. As a normal state the cross-section of the component is folded, obscuring less of the driver's visibility compared to a state of the art A-pillar. In a crash the A-pillar expands which results in a significant increase in the cross section. The expanded cross section increases the strength of the A-pillar. An expanding A-pillar can be accomplished by pressurizing a folded structure. A cost- and weight-efficient way to generate over pressure is by pyrotechnics (gasgenerators)

An expandable A-pillar design was developed in which the conflicting requirements high strength and small cross section were combined in one component. The goal was to develop an A-pillar that obscure less of the driver's vision in the normal operation, is lighter and has the same crash performance as a state of the art A-pillar. The development was carried out by combining mathematical simulations and mechanical crash tests. For the development of the expandable A-Pillar a mathematical sub structure model was developed and validated. The model was validated by comparing predictions from the model to results from a mechanical crash test. The expandable

A-Pillar was mounted in the sub structure and the deformation performance was evaluated relative to the performance of a state of the art A-Pillar. The deformation force is less than or equal to the deformation force of a vehicle with a state of the art A-pillar. The obscuration angle is reduced by more than 25% (for left hand side A-Pillar from 12.3 – 8.9 degrees) and the mass is reduced by 8% (excluding mounting brackets and gasgenerator) relative to a state of the art A-pillar. The expandable A-pillar combines the conflicting goals, high strength, small cross section and low mass.

### INTRODUCTION

Rollover crashes critically injure and kill thousands of people every year through head and neck injuries [1]. Structurally weak roofs can be a primary cause of serious head, face and neck injuries to occupants who are not ejected in vehicle rollover. Due to the fact that belt is used by most passenger vehicle occupants today the number of ejected occupants is low and therefore the occupants are vulnerable to injury within the vehicle. In a rollover crash the roof can crush in a number of different ways depending on the design of the roof and the vehicle trajectory (Figure 1). The most severe breakdown is a complete pillar collapse.



Figure 1. Various Types of Roof Crush

A weak roof can collapse and buckle in this type of crash, imposing forces on and occupant's head that

are greater than those that would result from the vehicle drop itself. It was found that neck injuries occur and are exacerbated in a weak roof vehicle as opposed to a strong roof vehicle when subjected to a rollover crash [2]. The association between vehicle roof strength and occupant injury risk in rollover crashes appears robust across different vehicle groups and across roof strength-to-weight ratios measured at 5 inches (12.7 cm) (SWR5). The roof strength-to-ratios varies typically from just more than 1.5 to just less than 4.0 [3]. If roofs were to increase in strength by one SWR5, a 20-25% percent reduction in risk of serious injury in rollovers would be expected.

In the modified standard for roof strength, FMVSS 216, it states that a roof must withstand pressure equals to 3.5 times the vehicle weight and the roof may not contact the head or neck of a seated 50%-ile Hybrid III dummy [4]. NHTSA estimates that the new rule prevent 44 deaths a year [5]. The rule applies to all vehicles with a Gross Vehicle Weight of 2722 kg (6 000lbs).

Not only rollover crashes exposes the A-pillar to excessive loading conditions [6]. Frontal collisions and in particular frontal offset collisions expose the A-pillar to high loading conditions [7]

Consider a transverse vertical plane in line with the dash. The resulting cross-section might include the A-pillars, side doors, door sills and floor. About 50% of the vehicle's weight will usually be rearward of this plane. The compression forces arising in these components due to a 40g deceleration are therefore equivalent to about 20 times the weight of the vehicle. This places a severe demand on the structure.

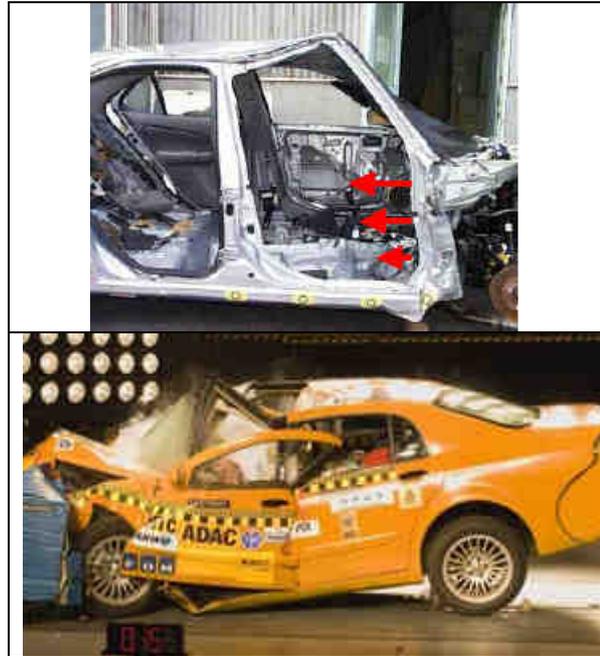


Figure 2. Offset Collisions Exposes the A-pillar to High Loading Conditions [7] and [8]

To obtain a strong roof one of the most important vehicle structural components is the A-pillar (Figure 3). There are conflicting requirements on the A-pillar of a passenger vehicle. For occupant protection the A-pillar needs to be stiff and strong to withstand the load in a rollover or a frontal impact at high impact velocity. However, the A-pillar obscures the vision for the driver. In an investigation carried out by Auto Motor und Sport it was found that the vehicle with smallest obscuration angle had an angle of 12 degrees and the worst obscuration angle was 16 degrees [9].

Therefore, for the vehicle driver to have good visibility the A-pillar needs to be slim (have a small cross section). In addition for the vehicle to have low fuel consumption the A-pillar needs to have low mass. The ideal A-pillar is one that is slim during normal driving and when added stiffness and strength is needed such as in a rollover crash the A-pillar expands and increases the cross section and crush resistance.

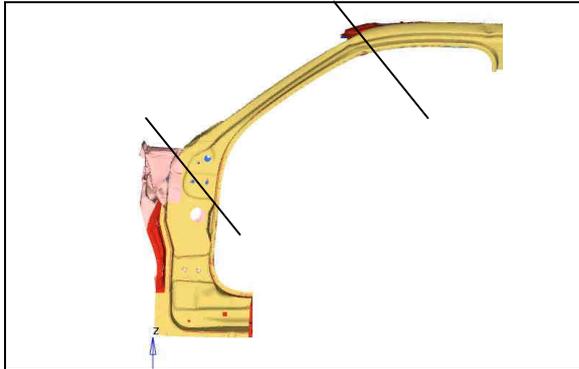


Figure 3 A-pillar

In an A-pillar with an expandable cross section the conflicting requirements can be combined in one component. As a normal state the cross-section of the component is folded providing the driver with good visibility. In a crash the A-pillar expands which results in a significant increase in the cross section and the greater cross section increases the strength of the A-pillar. Expansion of sealed folded steel components such as A-pillars can be accomplished by generating a high internal pressure. A cost- and weight-efficient way to generate over pressure is by using pyrotechnic gasgenerators.

An expandable A-Pillar was developed in a previous project [10]. In the project a great number of various A-Pillar designs were evaluated. The number of folds, the folding scheme, and the radius of the folds were evaluated. The deformation performance of the selected concept was evaluated by component bending tests. With the selected concept good potential to reduce mass, increase vision and maintain the level of safety was obtained. Therefore the next step in the development of an expandable A-Pillar was to evaluate the A-Pillar in a vehicle structure.

The aim of the project is to develop an expandable A-pillar that combines the conflicting requirements of good visibility, low mass and high strength. The A-pillar will, when expanded, have the same deformation force and deformation moment as a state of the art A-pillar. When expanded the deformation force and moment will increase relative to when it is unexpanded. When folded, the A-pillar will increase vision. The mass of the expandable A-pillar will be less than the mass of a state of the art A-pillar. Therefore, the goal was to develop an A-pillar that obscures less of the driver's vision in normal operation, is lighter and has the same crash performance as a state of the art A-pillar.

The goals with the expandable A-Pillar were to:

Reduce obscuration angle by 20% and the mass by 10% relative to a state of the art A-Pillar today.

When expanded have the same max deformation force and moment as a state of the art A-Pillar.

Increase max deformation force and moment by 50% when expanded relative to unexpanded.

## METHOD

The development of the expandable A-Pillar was carried out by means of combining mathematical simulations (finite element analysis) with mechanical crash tests.

For the development of the expandable A-Pillar a sub structure vehicle model was developed and validated (Figure 4). The sub structure consisted of a body in white of a modern passenger vehicle cut behind that B-Pillar and in front of the suspension tower. The corresponding model was validated by a crash test in which the sub structure was impacted by a moving barrier. The mass of the barrier was 1569 kg with and the impact velocity was 14.5 km/h (4.1 m/s). In the test the impact force and door opening distances were recorded.

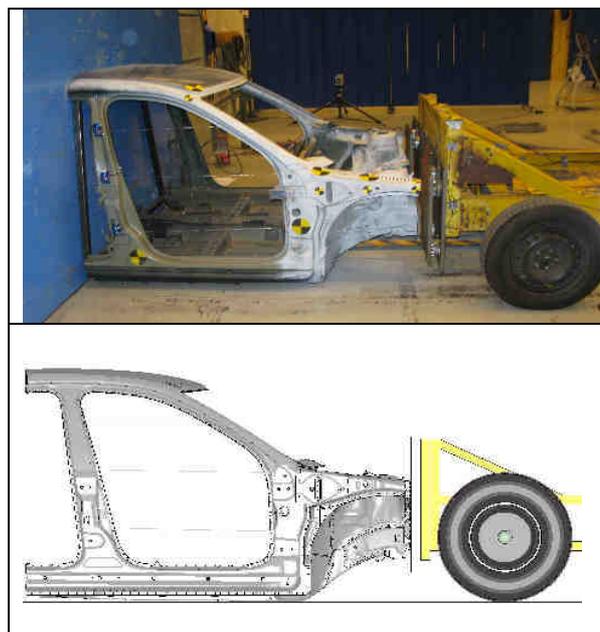


Figure 4. Sub Structure Test Method

Using the validated model various designs of the expandable A-Pillar were integrated into the vehicle structure and evaluated by means of crash simulations. The crash performances of both unexpanded and expanded A-Pillars were evaluated.

When the expandable A-Pillar fulfilled the performance goals in the frontal crash configuration the A-Pillar was evaluated for rollover. The rollover performance was evaluated by means of the roof crush test configuration. In the roof crush evaluation the roof of the vehicle was loaded with a rigid wall with the dimensions 1829x762mm (Figure 5). The angle of the wall was 25 degrees relative to the horizontal plane including the longitudinal axis of the vehicle and rotated 5 degrees relative to the transversal axis of the vehicle. The front end of the wall was 254mm forward of the forwardmost point of the roof of the vehicle.

The contact force between the wall and the structure, the displacement of the wall and the cross section force and moment at the A-Pillar bottom were recorded.

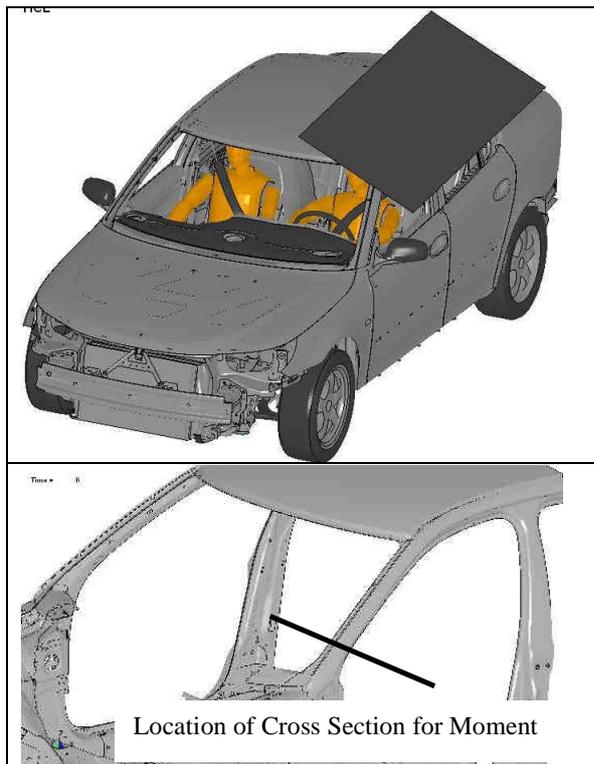


Figure 5. Roof Crush Set Up

## RESULTS

The A-Pillar developed in previous project was modified when integrated into the vehicle structure. The expandable A-Pillar was a folded and sealed. It was tightly folded with one fold and sealed by means of seam welding. The wall thickness was 1.5 mm and the material was steel CR340. The design of the reference A-Pillar and the expandable A-Pillar can be observed in Figure 6. Both unexpanded and expanded expandable A-Pillar can be observed. When unexpanded the cross section of the A-Pillar was significantly reduced relative to the state of the art A-Pillar. When expanded the deformation force and moment were significantly increased. The expansion was accomplished by means of pressurizing the folded A-Pillar using a pyrotechnic gasgenerator.

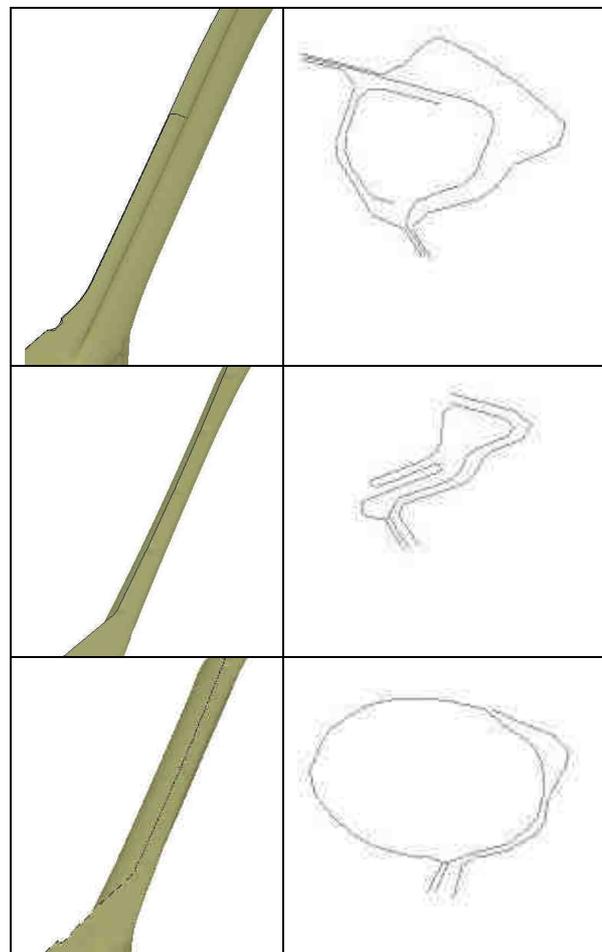


Figure 6. Reference, Unexpanded and expanded A-Pillar

The reduced obscuration angle for the folded expandable A-Pillar relative to the reference state of the art A-Pillar can be observed in Figure 7.



Figure 7. State of the art A-Pillar and UnExpanded Expandable A-Pillar

The obscuration angle was for the left hand side A-Pillar reduced from 12.3 to 8.9 and for the right hand side from 9.3 to 7.2 degrees (Figure 8).

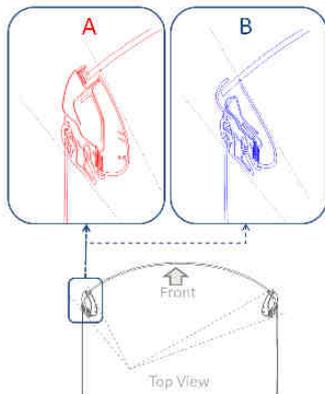


Figure 8. Obscuration angle for State of the Art (A) and folded expandable A-Pillar (B)

For the expandable A-Pillar the, mass of the A-Pillar alone was reduced by 8%. For the whole vehicle the reduction was 0.6 kg. However, the figures do not include gasgenerator, connectors and wires.

The substructure model used for development of the expandable A-Pillar was initially validated by means of a crash test in which the substructure was impacted by a moving barrier. Door opening displacements and barrier force was recorded. There was good agreement between the model predictions and test results (Figure 9). Generally the measured displacements were somewhat smaller than the predicted displacements. The greatest difference between the predicted and measured displacements was 3 mm. It was for the middle door displacement.

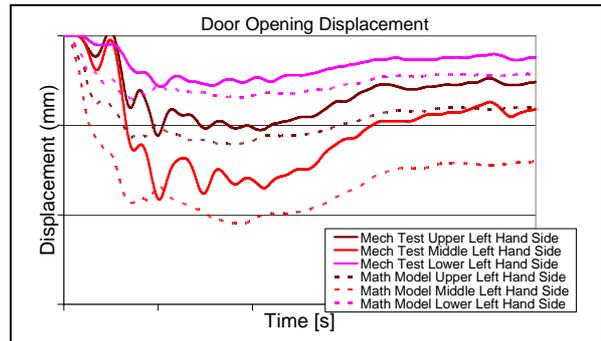


Figure 9. Door Opening Displacement Validation

For the barrier force there was also good agreement between the predicted and measured force (Figure 10). Greatest difference between the predicted and measured peak force was 12% and that was for the right hand side force. However the left side mechanical test force was lagging the predicted force.

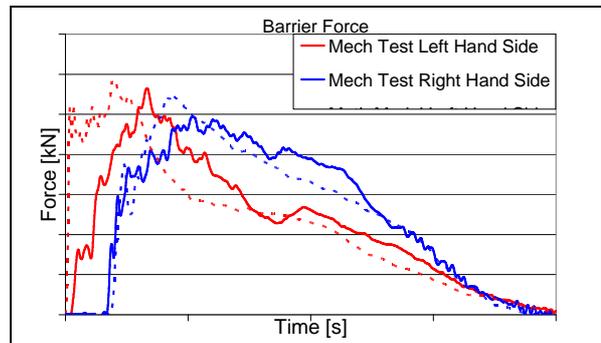


Figure 10. Barrier Impact Force Validation

In the validated substructure model the various concepts of the expandable A-Pillar were evaluated. Evaluations for both unexpanded and expanded A-Pillar were carried out (Figure 11).

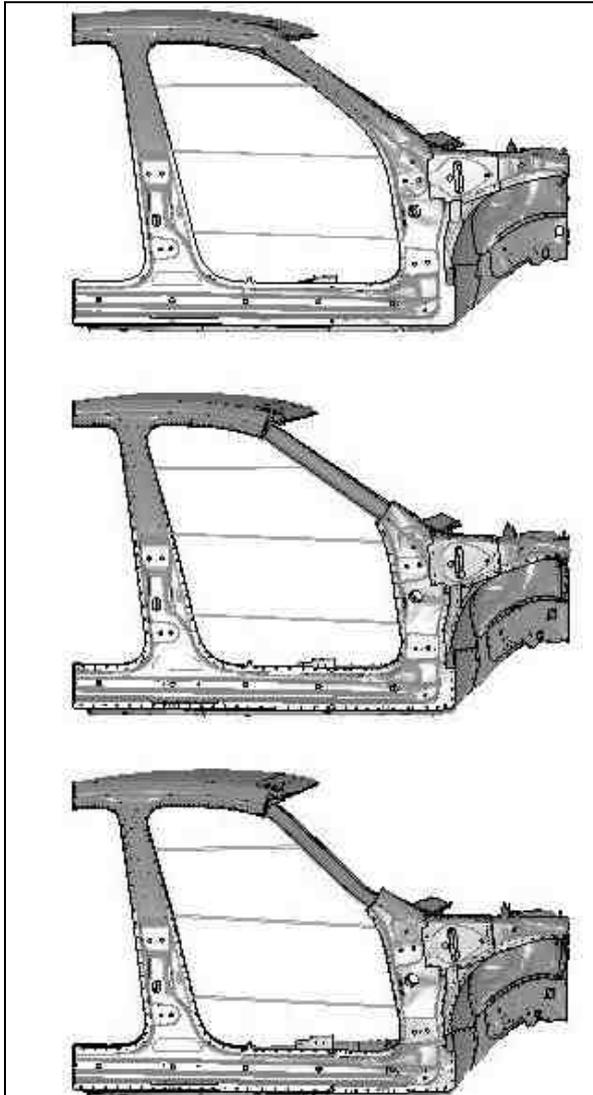


Figure 11. Reference, Expanded and UnExpanded expandable A-Pillar at 60 ms (max deflection)

The door opening displacements were very similar for the reference structure with a state of the art A-Pillar and the structure with an expanded expandable A-Pillar (Table 1). For the expanded A-Pillar all displacements were somewhat higher than for the reference A-Pillar. Greatest difference was for the middle door opening in which the door displacement was 7 mm greater for the expanded A-Pillar. For the unexpanded expandable A-Pillar all door opening displacements were significantly greater than for both the reference and the expanded A-Pillar.

Table 1. Peak Door Opening Displacements Left Hand Side

Door Opening Displacement			
	Upper	Middle	Lower
	(mm)	(mm)	(mm)
Reference	12	21	7
UnExpanded	25	60	21
Expanded	15	28	10

In the roof crush analysis there were no significant variation in the contact force between the vehicle and the rigid wall for the state of the art, for the unexpanded and the expanded A-Pillar (Figure 12). However the contact force was somewhat higher for the Reference A-Pillar than for the expanded A-Pillar and somewhat higher for the expanded A-Pillar than for the unexpanded.

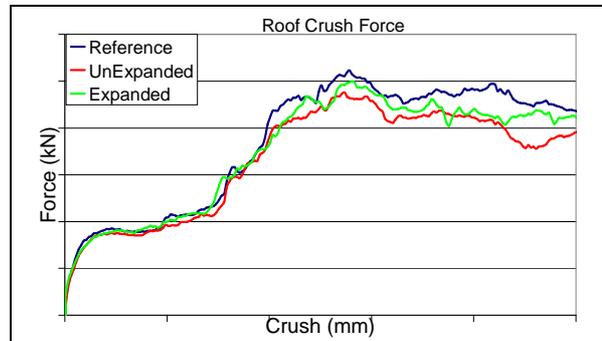


Figure 12. Force vs. Crush for Roof Crush Evaluation

For the bending moment evaluation the highest moment was for the reference A-Pillar while the moment for the expanded A-Pillar was significantly higher than for the unexpanded (Figure 13).

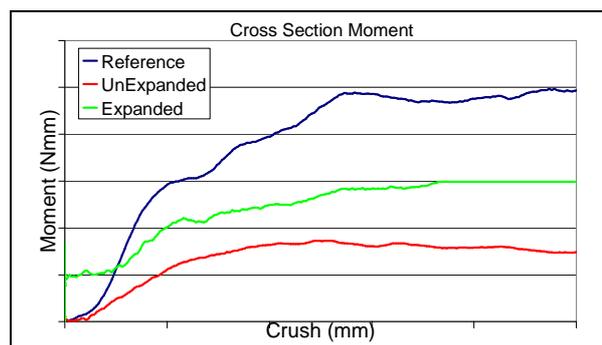


Figure 13. Cross Section Moment in Roof Crush Evaluation

## DISCUSSION

An expandable A-Pillar was developed that was evaluated for frontal crash and for rollover. Goals were defined which were used to judge the various proposed expandable A-Pillar designs and to select the most promising concept. The goals were reached. The obscuration angle was reduced by more than 25%, the mass of the A-Pillar was reduced by 8% (excluding gasgenerator) and the crash performance of the expandable A-Pillar when expanded was the same as for a state of the art A-Pillar on a modern vehicle on the roads today.

In the sub structure model validation there was some disagreement between the predicted and measured impact force. The reason for the disagreement was that the left front member was 27 mm longer than the right front member (Figure 10). Therefore the moving barrier impacted the left hand side before the right hand side and there was a gradual increase of structure engagement in the mechanical test.

For the roof crush evaluation there was no great difference in the crush force for the various A-Pillars (Figure 12). The reason was that the plane that impacts the vehicle in addition to loading the A-Pillar a significant amount of the load was also transferred to the B-Pillar. Therefore, for the weak unexpanded A-Pillar the B-Pillar carried more load than for the more stiff reference A-Pillar and expanded A-Pillar. The deformation moment for the expanded expandable A-Pillar was significantly higher than for the unexpanded (Figure 13). However highest deformation moment was for the state of the art A-Pillar.

For the expansion of the expandable A-Pillar a very compact and light prototype gasgenerator was developed (Figure 14). The length of the gasgenerator was 150 mm and the width was 15 mm. Due to the small dimensions of the gasgenerator it fit inside the folded expandable A-Pillar. Mass of the gasgenerator was in the range of 0.05 – 0.2 kg.

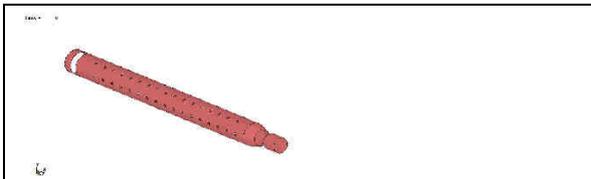


Figure 14. Gasgenerator for expandable A-Pillar

## CONCLUSION

An expandable A-Pillar can:

Reduce the mass of the A-Pillar by 8%

When folded increase the obscuration angle by 25%

When expanded have the same deformation force and moment as a state-of-the art A-Pillar

## ACKNOWLEDGEMENT

The authors acknowledge Fordonsstrategisk Forskning och Innovation (FFI) for partially financing this study.

## REFERENCES

- [1] A. Morris, *et al.*, "Effectiveness of ADR 69: A Case-Control Study of Crashed Vehicles Equipped with Airbags," A. T. S. Bureau, Ed., ed, 2001.
- [2] R. H. Grzebieta, *et al.*, "How Stronger Roofs Prevent Diving Injuries In Rollover Crashes," in *ICRASH 2010*, Washington D.C., 2010.
- [3] L. Brumbelow, M, and E. Teoh, R, "Roof Strength and Injury Risk in Rollover Crashes of Passenger Cars and Suvs," in *21:st Conference on Enhanced Safety of Vehicles*, Stuttgart, Germany, 2009.
- [4] "Federal Motor Vehicle Standards (FMVSS 216) ", D. o. Transportation, Ed., ed. Washington DC, 2005.
- [5] "NHTSA roof rule comes under attack," in *Automotive News*, ed, 2005.
- [6] M. Paine, P., *et al.*, "Offset Crash Tests - Observations About Vehicle Design and Structural Performance," *16:international Conference on Enhanced Safety of Vehicles*, vol. Paper Number 98-S1-W-21, 1998.
- [7] H. Saeki, *et al.*, "A Fundamental Study of Frontal Oblique Offset Impacts," in *18:th Conference on Enhanced Safety of Vehicles*, Kyoto, Japan, 2003.
- [8] <http://www.allworldauto.com>.
- [9] C. Bangeman. (2010) Shauen Wir Mal. *Auto Motor und Sport*. 62-63.
- [10] B. Pipkorn and J. Lundström, "Expandable A-pillar for Improved Occupant Safety and Vision," in *ICRASH 2010*, Washington D.C., 2010.