A COMPARISON STUDY OF ACTIVE HEAD RESTRAINTS FOR NECK PROTECTION IN REAR-END COLLISIONS

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ABSTRACT

Neck injuries caused by rear-end collisions have become a major problem in traffic safety over the last two decades, however, surprisingly little effort has been made so far to improve car seat and head rest design. Several studies have shown, that whiplash injuries can be reduced by minimizing the gap between head and head restraint during the first phase of a rear-end impact. On the other hand, the requests for comfort from the car passengers limit the reduction of this distance. Various publications show that generally neither drivers nor passengers are aware of the necessity to adjust current head rests to the their head position. The conclusion is, the head rest should either be large enough to protect all occupants or should be automatically adjusted to protect all occupant sizes.

This study shows a comparison of different active head restraint concepts, which guarantee a reduction of the distance between head and head rest during a rear-end collision. In addition the size of the head rest is enlarged. Different concepts were validated by sled tests using Hybrid-III Dummies equipped with the newly developed TRID-neck. Also volunteer tests were performed to prove the effectiveness of the new concepts.

From these concepts, the inflatable head rest has proven to be the most efficient system. It is big enough to protect occupants up to the size of the 95th-percentile male, independently from the preadjusted position. If the head rest is positioned too low the upward increase in volume will be sufficient for occupant protection, whereas if the head rest is positioned too high the downward increase in volume will fill the gap between seat back and head rest. Thus the inflatable head rest concepts will be appropriate for almost all occupant sizes, independent from the preadjusted position.

The results have shown that relative motions between head and neck, as well as neck loads, were reduced significantly at all impact velocities and in all occupant positions. The inflation noise was reduced to a level that was hardly audible for the volunteers, at least when compared to the crash noise. Further sound pressure measurements in the cabine alpha showed a 99.99 % probability, that no hearing damage will occur.

This report shows that the inflatable head rest is a promising new concept that can reduce Whiplash Associated Disorders (WAD) following rear-end impacts especially in low speed collisions. It allows a comfortable head rest position and is suitable for almost all occupant sizes without the need for adjustment.

INTRODUCTION

So far the injury mechanism of soft tissue neck injuries, following rear end impacts has not been clarified even though a lot of research has been performed. Swedish research (Svensson 1993, Örtengren 1996, Boström 1996) claims that pressure effects in the spinal canal causes damage to spinal ganglia and is therefore responsible for Whiplash Associated Disorders (WAD). The injury is induced in a certain phase of the head neck movement, the so called S-shape. Several studies relate the injury to hyper-extension of the neck. Some studies indicate that the rebound phase could be responsible and explain the fact by increased seat belt usage, that may in turn increase neck loads in the rebound (vKoch, 1995). To summarize, it can be stated that any extensive relative motion between head and torso leads to loads exerted to the neck that are potentially dangerous. Therefore a neck protective system has to minimize the relative movement between head and torso during the whole impact and reduce neck loads to a minimum.

Safety concepts

An intensive study of different safety concepts was carried out. From these concepts the inflatable head rest was selected taking into account the following criteria:

- Feasibility
- Effectiveness of the system in regard to occupant protection
- Effort
- Maintenance and replacement

Mechanical Active Head Rests (Prototype 1 and 2)

An alternative to the inflatable active head rest are head rests containing a mechanism that is activated in the case of a rear end collision.

App. 30 different concepts were investigated and evaluated, taken into account the following parameters: function, effectiveness, cost, design, and safety. The two most promising concepts were built and tested.

Prototype 1 consists of a sophisticated mechanism for enlarging the head rest. The elements of the head rest are sliced and interlock in the non-activated position. The head rest is thus compact and its dimensions are similar to the standard head rest.

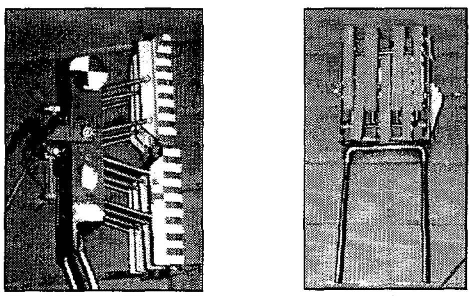

Fig. 1. Prototype 1 (Mechanism)

Prototype 2 - The mechanism is arranged in a V-shape. Two telescopic rods, with a tension band between the extremities, are extended during deployment to enlarge the headrest. The tension band is simultaneously tightened. The mechanism is driven by pretensioned springs that are released after app. 30ms.

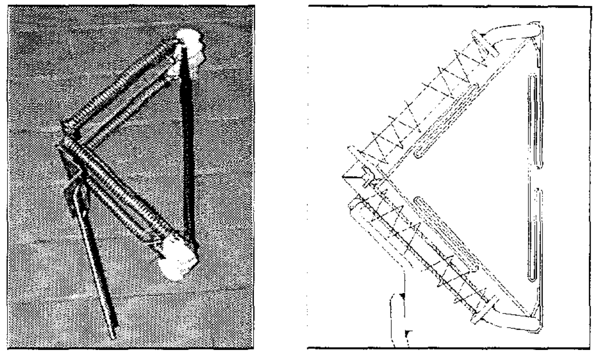

Fig. 2. Prototype 2 (Mechanism)

Both prototypes were tested in sled tests and compared to a standard head rest design.

Inflatable Head Restraint

After analysing the results of many math models a prototype of an inflatable head rest was designed. An airbag is integrated in a way that the whole head rest is enlarged (Fig. 3 and Fig. 4). The bag is covered by foam blocks so that the usual occupant comfort is guaranteed whilst keeping inflation noise to a non-injurious level. Fig. 4 shows the prototype of the inflatable head rest in the normal and in the expansed position.

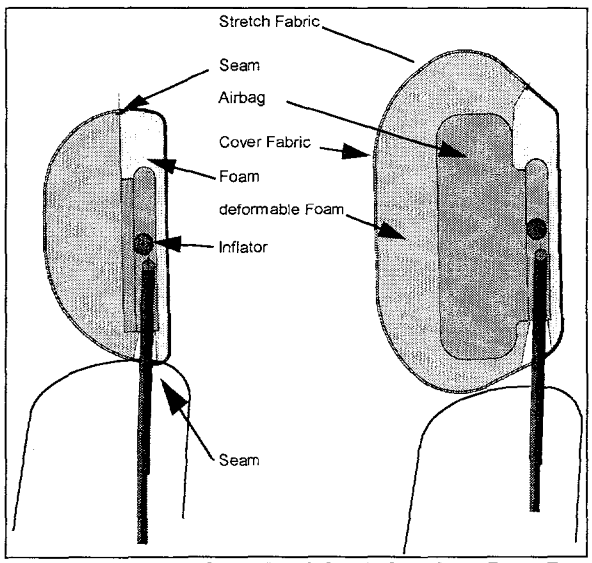

Fig. 3. Principle Sketch of the Inflatable Head Rest

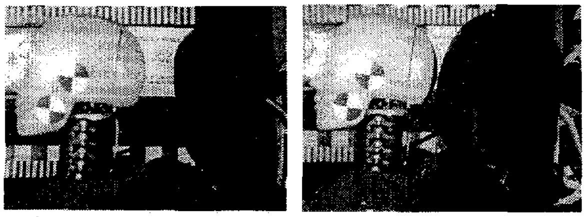

Fig. 4. Inflatable Head Rest in Non - Activated and Activated Position

METHODOLOGY

Computer mathematical simulations (MADYMO™) were performed to analyze the effectiveness of the system and detecting design parameters. From these simulations several prototypes were designed and tested in sled tests. The test setup and impact conditions were chosen comparable to common rear-end impact. Each test with an active head restraint system was repeated by a test using standard head rests. Conclusions were drawn by comparing the test results from the standard car seat with standard head rest to the new active head restraints.

NUMERICAL SIMULATIONS

A generic seat was modeled using the multibody crash simulation software MADYMO. Characteristics of the seat were gained by simple seat loading tests. As test subject, the validated MADYMO database for the HYBRID-III Dummy equipped with the TRID neck was used. As a first step the standard seat was simulated and used for validation of the model. Sled tests were performed to correlate the accuracy of the model.

The head rest of the validated model was then replaced by different concepts for active head rests (Fig. 5 shows the numerical simulation of the inflatable head rest). Initial results have shown that neck loads can be reduced simply by closing down the initial gap between head and head rest in the early stage of a rear impact.

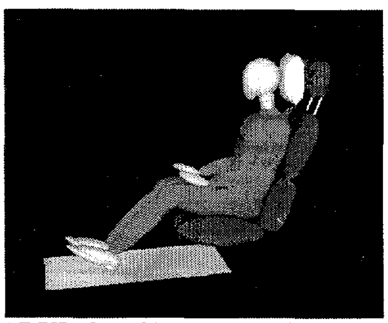

Fig. 5. MADYMO™ Simulation of the Inflatable Head Rest

The model parameters were optimized in order to gain design parameters for the active concepts, examples of which are the flow characteristics of the inflator, bag shape and size.

Several numeric simulations were also performed for the two mechanical concepts described before (Fig. 6). The activation process was optimized so that the neck loads were reduced to a minimum, without endangering the occupant by a high energy activation.

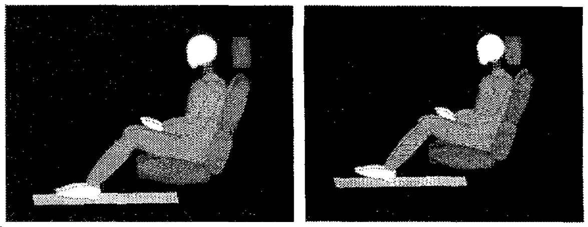

Fig. 6. MADYMO™ Model of Active Head rest

The numerical simulation showed in a very early stage of the research the most efficient way to reduce neck loads is to close down the horizontal gap between head and head rest and to adapt the height of the head rest to the occupant size. A further important result is that by the bending of the seat back (due to the loading of the torso) the head rest is moved away from the head, even if the initial horizontal gap is already rather low.

SLED TESTS

The sled tests have been performed at the University of Graz in Austria. The sled buck is driven by a bungy and the crash pulse is simulated with a friction brake system.

For the first series with the inflatable head rest, the inflator was not integrated in the head restraint but was designed as a gas container with an adjustable filling pressure (Fig. 7). It was necessary to adjust the gas volume in order to allow for a fast inflation as well as to modify the pressure in the airbag after inflation.

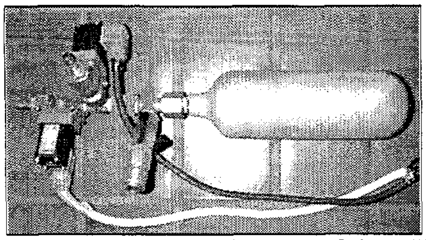

Fig. 7. Gas Container with Solenoid driven Valves

The airbag was activated by an adjustable trigger system that allows for variation of the ignition time. Usually an ignition time of 30ms was set.

DUMMY TESTS - Active head rests were tested in several sled tests under different impact conditions. Test object was a 50%ile Hybrid-III dummy equipped with the so-called TRID neck. This neck - developed by TNO - has proven to be more biofidelic than the standard Hybrid-III neck (Geigl 1995, Svensson 1993, Thunissen 1996).

The main parameters of the tests were:

- initial position of head rest
- sled impact velocity

Fig. 8 shows the comparison of the max. (3ms) head acceleration of the tests with the first inflatable head rest prototype.

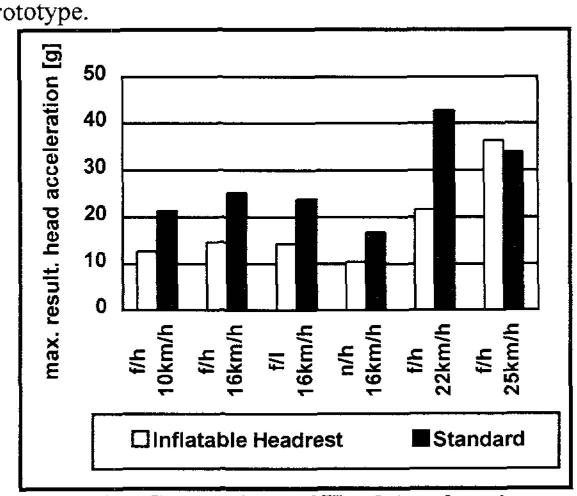

Fig. 8. Comparison of Head Accelerations

Tests were performed at different sled impact speeds (10, 16, 22, 25 km/h) and different initial head rest positions (f...far[1], n...near[2], h...high[3], l...low[4]).

[1] horizontal distance head to head rest: 80mm
[2] horizontal distance head to head rest: 0mm
[3] vertical distance top of head to top of head rest: 30mm
[4] vertical distance top of head to top of head rest: 80mm

Head accelerations were reduced significantly by 30% to 50%. Only at higher speeds is the benefit reduced due to the seat back yielding.

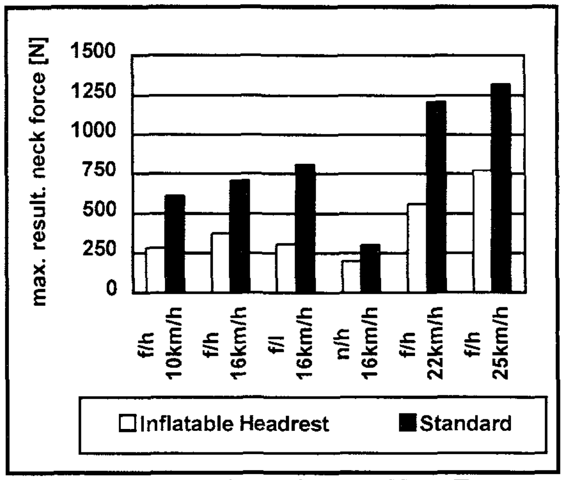

Fig. 9. Comparison of Upper Neck Forces

Maximum resulting neck forces and moments were also reduced significantly (Fig. 9 and Fig. 10).

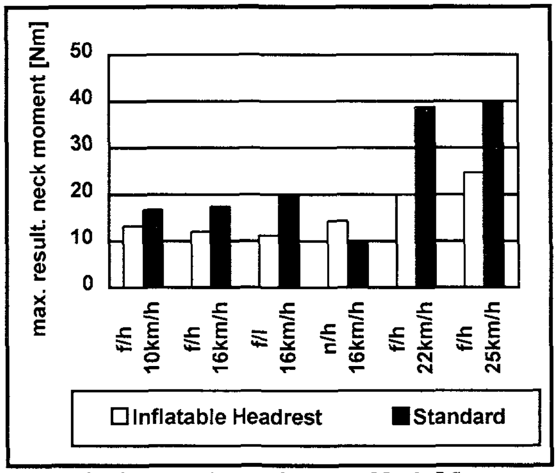

Fig. 10. Comparison of Upper Neck Moments

Recently, Swedish research has proposed a new criterion for Whiplash Associated Disorders (WAD) following rear-end collisions. This criterion is not validated on human beings - so no critical limit of the Neck Injury Criterion (NIC) exists. This criterion was calculated for all tests according to the formula:

$$NIC = 0.2 \cdot a_{rel} + v_{rel}^2$$

a_{rel} ...relative acceleration between torso (T1) and head (C1)

v_{rel}...relative velocity between torso (T1) and head (C1)

The NIC was defined as the maximum value at the so called maximum retraction phase (immediately before the head rotation starts). Fig. 11 shows results of the NIC calculation. The NIC is reduced significantly at all impact conditions, especially at medium speeds. Even in tests with initial head to head rest contact, the inflatable head rest is beneficial because of the head rest displacement due to the bending of the seat back. This effect is compensated by the inflatable head rest.

As mentioned before, at higher speeds the benefit of the inflatable head rest is lower, because of seat back collapsing. It is still possible to compensate the "displacement" effect of the head rest.

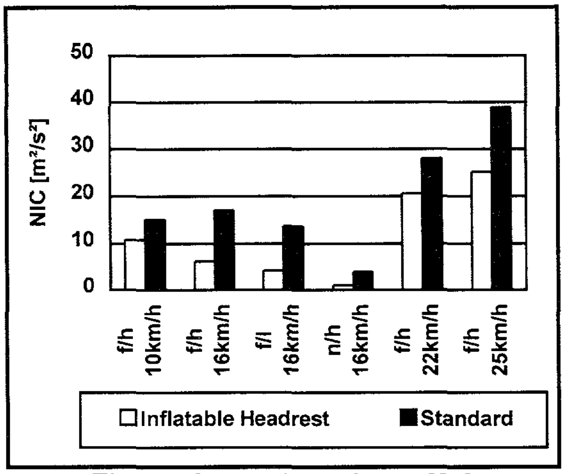

Fig. 11. Comparison of max. NIC

Fig 12 and Fig 13 show the results and the kinematics of a dynamic test with a ΔV of 16 km/h. The initial head rest to head distance was in this case 80 mm. The reduction of relative head motion can be observed in Fig. 12. The relative head rotation is reduced significantly in tests where the head rest is unfavorable positioned for the occupant.

Fig. 13 shows the comparison between the inflatable head rest and the standard head rest. The inflatable head rest is activated just in time (approximately 50 ms after first contact), so that an extensive relative head motion can be prevented.

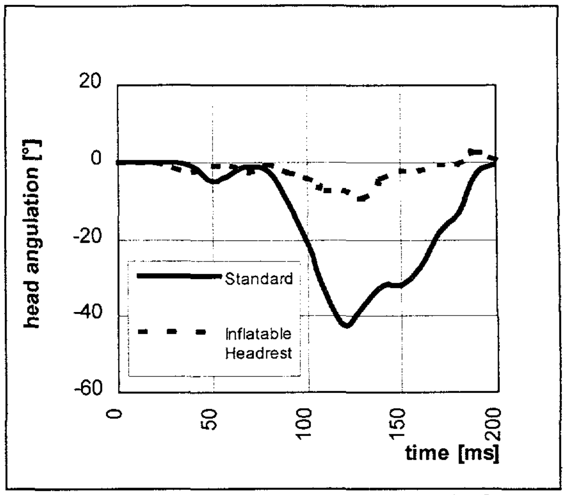

Fig. 12. Comparison of Angular Head Displacement

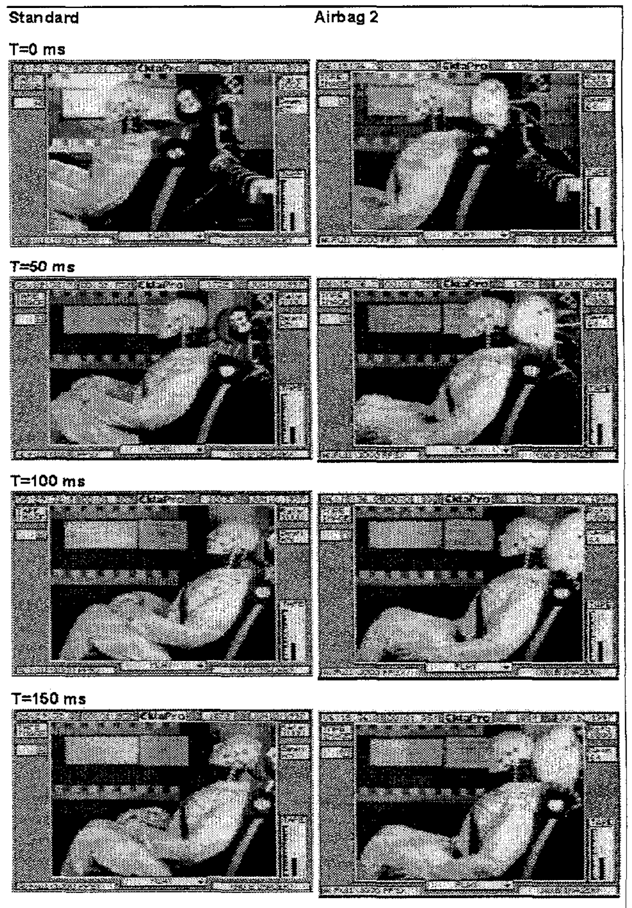

Fig. 13. Comparison of Standard and Active Head Rest

VOLUNTEER TESTS - In order to prove the harmlessness of the system several volunteer tests were performed. The volunteers were not instrumented but asked to tell about their subjective feeling to the activation of the inflatable head rest. An impact speed of app. 10 km/h was chosen. No volunteer complaints of any injuries were noted immediately after the test nor some days later. The inflatable head rest was felt subjectively comfortable, no inflation noise could be observed by the subjects, because the crash noise seemed to be louder than the inflation noise. Even in a test where the head was in direct contact to the head rest no negative effect could be observed. In Fig. 14 some sequences from volunteer tests are illustrated.

Fig. 14. Volunteer Tests at Different Head Rest Positions

Sled tests with a stored gas inflator - as a next step, the inflator was integrated into the head rest. The inflator consist of a bottle filled with compressed air (special mixture of inert gas) and an opening mechanism. The results of sled tests, which have been done in the same configuration like before (ΔV 16 km/h, 80 mm distance head to head rest) can be observed in Fig. 15. NIC, neck moment and forces of the internal inflator prototype were reduced to a level that is comparable to the external inflator. An optimization of the inflation process itself could further reduce the loads exerted to the neck.

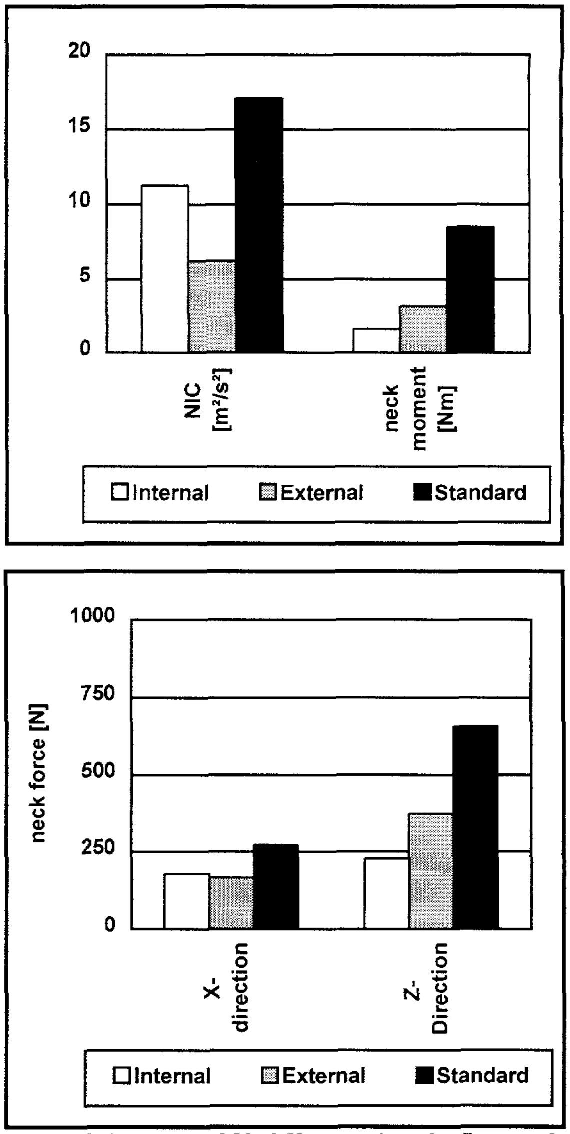

Fig. 15. Results of Sled Tests using the Internal Inflator

Head Rest Design with a Pyrotechnical Inflator

A pyrotechnical inflator (Fig. 16) has also been tested in a prototype head rest.

The inflator and the airbag are attached to the plastic element of the head rest. The bag will be covered by a foam element to allow comfort and good feeling for the occupant, as well as damping the deployment noise and the contact forces. The volume increase of the "class A" cover material is realized with 2 different approaches, either a tear seam with elongation fabric or a stretchable cover material over the entire head rest. Dynamic tests also show with this inflators benefits in occupant loads and improved dummy kinematics.

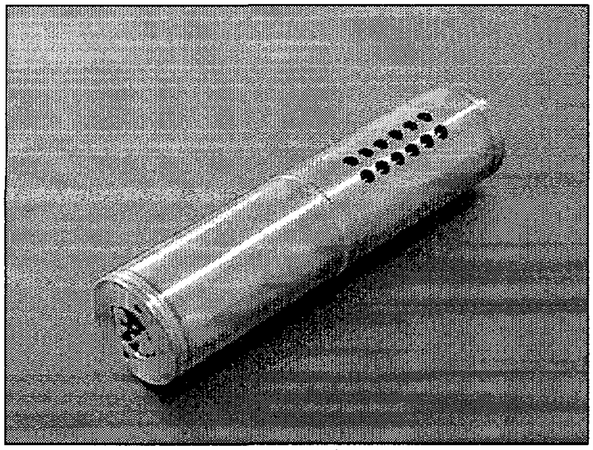

Fig. 16. Prototype Pyrotechnical Head Rest Inflator

DEPLOYMENT NOISE

Sound pressure measurements have been performed with the latest design status, as described earlier. That means the head rest was equipped with a pyrotechnical inflator. The measurement was made in a cabine alpha and showed acceptable results (Table 1). By looking to all the static and dynamic tests with this design, the deployment noise was absolutely not felt dangerous or showed any evidence of hearing damage.

Table 1.

Sound Pressure Measurements from the Cabine Alpha

	EAR	DURATION TIME [ms]	MAX. LEVEL [dB]
A - Duration	Left	3,5	147,4
	Right	2,8	149,8
B - Duration	Left	14,2	147,7
	Right	13,9	149,9

CONCLUSION

The inflatable head rest has proven to be a promising alternative for active head restraint systems. Effectiveness in regard to occupant loads and kinematics is excellent and also the deployment noise has been reduced to a non dangerous level. In sled tests it has proven to work safe and efficient. No negative effects to the occupant could be observed. Also there are no restrictions for comfort, styling and safety due to the fact, that the airbag and the inflator is below the styling cover and the foam bolster of the head rest.

Active head rests on a mechanical basis are more complicated in design and function. The mechanism has to be highly sophisticated in order to avoid larger head rests. This means that a lot of additional parts are required compared to the inflatable head rest. For the described mechanical solutions the optimization of the operating parts is quite difficult. Also a too aggressive mechanical system results in additional neck loads, especially in situations where the head is close to the head rest, compared to the inflatable design, where serious loads to the occupant were never reached in a various number of tests in different head to head rest positions were found.

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