HEAD IMPACT PROTECTION - NEW REQUIREMENTS AND SOLUTIONS

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ABSTRACT

The NHTSA has very substantially extended its existing Part 571 - FMVSS Standard No. 201 "Occupant Protection in Interior Impact" [1]. This extension to the Standard necessitates the development of energy-absorbing trimmings for protection of vehicle occupants in the event of an impact with components in the upper passenger compartment. The publication describes the requirements of the Standard. This paper illustrates development approaches, assisted by numerical simulation, and investigates these experimentally. Dynamic protection systems for reducing the loads on vehicle occupants in the event of an impact are not covered by this publication.

INTRODUCTION

To Porsche, passive safety has always been a very important development aim. The company develops vehicles for a worldwide market which therefore must comply with all worldwide, legally stipulated standards and requirements of the main consumer associations in respect of passive safety in the event of frontal and side impacts, oblique and rear impacts and rollovers.

Protection of the vehicle occupant in the passenger compartment is tested, amongst other things, to Standard FMVSS 201. The amendment to the Standard, which came into force in September 1995 and contains the technical safety requirements in respect of all interior components in the upper passenger compartment, represents an essential extension. The law foresees a step-by-step compliance for manufacturers of vehicles for the American market during the period 1998 through to 2002. Alternatively, the manufacturer may opt for a one-step compliance of the law for all vehicles which then comes into force in September 1999.

NEW REQUIREMENTS OF THE FMVSS 201 - FMH STANDARD

The extension of the Standard is aimed primarily at protecting the unbelted occupant in the event of an impact with components of the vehicle interior. If a vehicle occupant hits an interior component at a speed of up to 24 km/h owing to an accident, the head injury criterion HIC(d) must not exceed a limit value of 1000.

Experimental validation of the requirements is performed with the aid of a modified Hybrid III free-motion headform (FMH). The development and validation tests are conducted in the vehicle on a test stand designed specifically for this test. The following areas of the vehicle interior must be designed in such a manner as to comply with the head injury criterion in the event of an impact of the occupant's head:

- pillar trimmings (A-, B-, C-pillar, rearmost pillar)
- front / rear header
- side rail
- seat belt anchorages, fittings, height-adjuster
- upper roof
- sliding door track
- overhead rollbar
- braces or stiffeners for convertibles

In these areas, different numbers of points are defined which the FMH hits in free motion at a speed of 24 km/h.

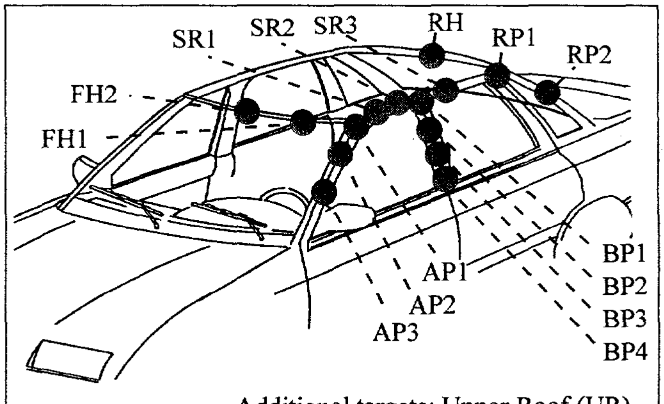

Figure 1. Targets of a conventional vehicle

The test headform must contact the target points with the forehead impact zone within a target radius. The trajectory vector of the FMH is defined by a vertical and horizontal impact angle each. These impact angles are not defined explicitly but as intervals. Consequently, the respective components of the passenger compartment must comply with the requirement criteria of the Standard within a wide variety of test angles. These test angles are determined by the various trajectory vectors of the free-motion headform.

Table 1.
Approach angle limits (only left side)

Target component	Horizontal angle α_H [°]	Vertical angle α_V [°]
Front header	180	0 - 50
Rear header	0 or 360	0 - 50
Side rail	270	0 - 50
Sliding door track	270	0 - 50
A-pillar	195 - 255	-5 - 50
B-pillar	195 - 345	-10 - 50
Other pillar	270	-10 - 50
Rearmost pillar	270 - 345	-10 - 50
Upper roof	any	0 - 50
Rollbar	0 or 180	0 - 50
Brace or stiffener	90 or 270	0 - 50
Seat belt anchorage	any	0 - 50

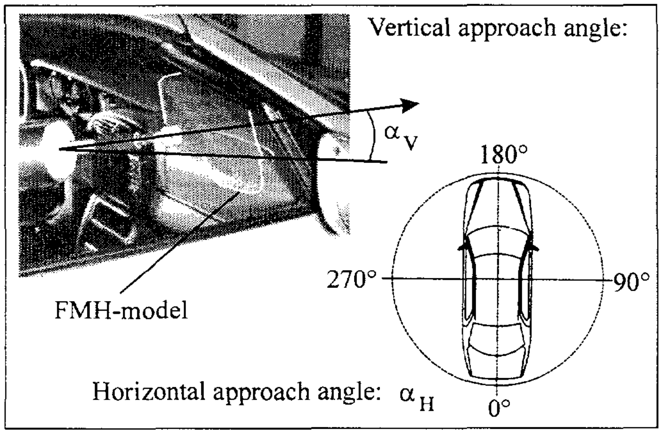

Figure 2. Approach angles of the FMH

DEVELOPMENT CONCEPT FOR COMPLIANCE WITH THE REQUIREMENTS

Developing measures to enhance vehicle safety necessitates the cross-functional cooperation between various technical departments. Styling, Bodyshell Design, Interior Equipment, Numerical Simulation and Safety Testing were included in the development for compliance with Standard FMVSS 201. The measures are aimed at absorbing the kinetic energy of an impacting occupant head by providing for suitable interior trimmings in such a manner that the resulting head accelerations are reduced, thus lowering the head injury criterion to less than 1000.

Basically, various problem-solving approaches are possible and combining them leads to suitable measures:

- The interior must be designed such that "hard areas" are out of reach or are grazed only tangentially.
- In potential impact areas, elements made of energy-absorbing materials must be used .
- Deformation elements optimized in respect of their energy absorption capacity must be used either alternatively or in combination.

Numerical simulation

Numerical simulation is used to reduce the number of possible design variants, optimize the selected variant and, thus shorten the development time.

Impact and crash calculations are conducted at Porsche using the LS-Dyna 3D Finite Element Program. The relevant bodyshell structure, deformation elements and trimmings to be integrated are discretized as finite elements. During simulation, a numerical idealized test headform is launched at a test speed of 24 km/h. Its trajectory vector ends at the target point on the interior structure.

The simulated accelerations at the center of gravity of the test headform and the deformation of the structure are evaluated, analogously to the test. The head injury criterion HIC(d) is determined on the basis of the head accelerations.

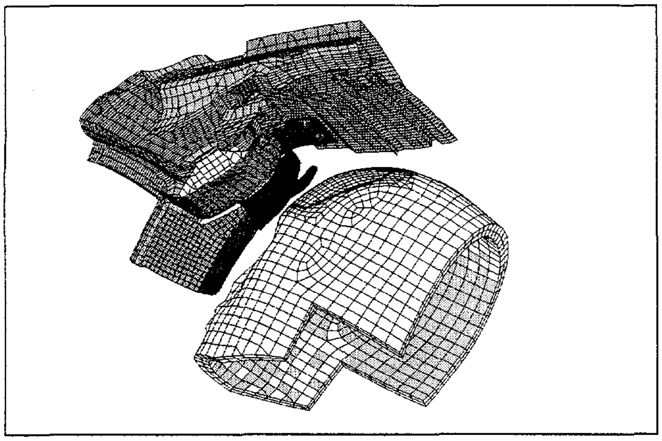

Figure 3. Simulation of a head impact in the area of the B-pillar area

The analysis of the dynamic deformation between the interior trimming and the bodyshell during head contact is of major advantage for design optimization. In the case of complex surfaces with non-constant transitions in particular, the movement of the free-motion headform after initial contact with the target point is influenced by the trajectory vector. This leads to differing head accelerations and, thus, also to differing HIC(d) values.

The concepts for the connection of trimmings, deformation elements and the bodyshell can be varied during the simulation process. Moreover, numerical simulation essential helps to establish the one test combination which - among the wide variety of possible impacts on a target point - leads to a maximum head injury criterion HIC(d).

Numerical simulation offers valuable assistance in impact analysis.

Experimental investigation

Compliance with the legally prescribed requirements in respect of impact protection is tested experimentally. Porsche uses a test bench which was developed specifically for Standard FMVSS 201 - FMH.

The vehicle is prepared for the test and set up on the test bench. With the aid of the test bench equipment, the target points are calibrated and marked in a vehicle-specific coordinate system, either in accordance with the respective CAD data or on the basis of corresponding in-vehicle measurements.

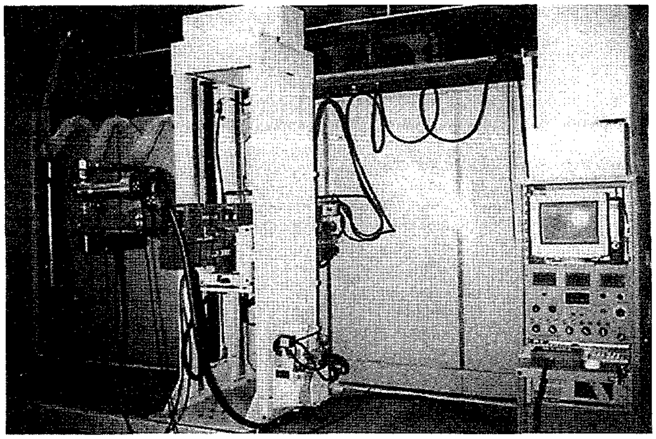

Figure 4. FMH-test facility

Approximately 35 target points must be defined for a conventional vehicle. The target points must be tested within horizontal and vertical impact angles to be determined which define the trajectory vector of the FMH. The Standard generally necessitates testing of a defined target point at differing approach angles (see Figure 2). The number of tests to be performed at a target point can be reduced by analyzing the bodyshell structure, the package conditions between trimming and bodyshell and the trimming contour assuming a "worst-case" situation.

In the vehicle, the test arm is positioned according to the trajectory vector in such a manner that the test headform at the end of the arm moves through an unguided, free-motion trajectory of at least 25 mm before its impact zone contacts the target point. The test headform is accelerated pneumatically. It consists of a modified Hybrid III dummy head with no nose contour. The speed of the test headform on the test bench can be set between 15 km/h and 40 km/h. The legally prescribed speed is 24 km/h.

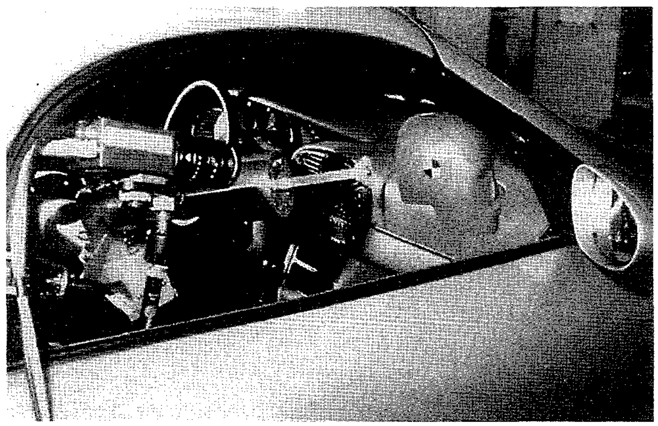

Figure 5. FMH-test

The tests are recorded with a high-speed video camera. The following information is available directly after the impact:

- the position of initial contact point of the test headform and trimming
- the movement of the test head during contact
- the visible deformation of the trimming surface during contact

The evaluation of the measured results covers the impact speed, the head injury criterion HIC(d), the accelerations in the coordinate directions of the trajectory and the resultant acceleration. In addition, the acceleration versus the intrusion depth can be obtained to evaluate the energy absorption quality.

Please refer to [2] for a detailed description of the test procedure.

APPROACHES FOR COMPLIANCE WITH THE REQUIREMENTS

Whilst having the same objectives, the requirements of the extended Standard FMVSS 201 - FMH lead to different measures for different interior components in the upper passenger compartment. Owing to their high stiffnesses and their shape, the pillars of the vehicle necessitate a greater deformation depth than other interior components in the event of a head impact. For reasons of active safety and in order to provide the driver with as unrestricted a field of view as possible, however, it is these components in particular which must retain their optically slim design.

Consequently, the task of Development is to minimize the intrusion depths required for absorbing the kinetic energy, allowing for the biomechanical occupant parameters and their limits. An 'ideal' deformation element consequently features a square-wave characteristic of the stress versus the intrusion depth. This response leads to a constant head acceleration and, thus, to a uniform deceleration of the occupant's head.

Deformation elements deviate from the ideal characteristic of acceleration versus the intrusion depth. The quality of the deformation elements is dependent on the design and the material used. The table below provides an overview.

Table 2.
Deformation elements of different designs

Designation	Parameters
Shell structure	■ material ■ material quality ■ geometry / contour ■ shell thickness ■ joining methods
Rib structure	■ material ■ shape ■ rib thickness ■ distribution
Honeycomb structure	■ material ■ shape ■ cell sizes / radius ■ thickness

Besides the various designs, the material plays a crucial role, too:

Table 3.
Material variants for a deformation element

Material	Parameter
Plastic	■ quality ■ fracture behaviour
Foam	■ quality ■ density
Metal	■ material ■ strength / quality ■ joining behaviour

The selection of a suitable deformation element and material depends on the packaging, the styling of the trimming, the bodyshell structure and the position of the impact area. The properties of certain designs and materials are listed below. The results are based both on quasi-static tests and on head-pendulum and impact tests.

Deformation elements made of foam can be designed and built at low cost. The constancy and amount of stress is dependent on the respective material. 70% max. of the geometrical thickness of the deformation element can made use of. Higher deformation leads to blocking of the foam and, thus, to a progressively increasing stress response. The parameters of foams are largely temperature-dependent. The foam elements are attached to the trimming elements for easy installation.

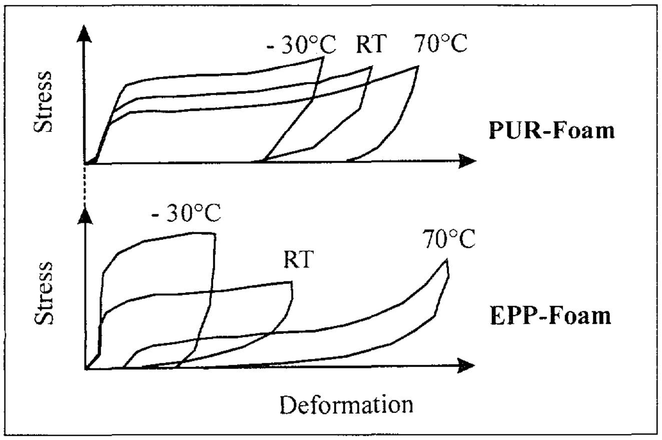

Figure 6. Stress/strain diagram of different foam materials when subject to impact loading [source: Bayer AG]

Metallic deformation elements of shell design absorb energy as a result of local and global deformation. The essential design parameters are the cross-sectional contour and the wall thickness of the shell element. For a given packaging space, these parameters allow high energy absorption with good efficiency at different impact angles. Attachment of the deformation elements is generally complex and performed on the bodyshell. The joining method is dependent on the material and must be adapted to the deformation areas.

When developing a new vehicle, energy-absorbing elements can be integrated in the bodyshell for enhanced stiffness. This helps to further minimize the volume of the energy-absorbing trimmings.

Metallic deformation elements consisting of thin layers are also under investigation. The layers are keyed together. The stress level is homogeneous up to a deformation of 90 % of the element thickness. The stress level can be adjusted as a function of the number of layers. Various concepts are available for attaching the elements. The application of the elements is restricted by packaging considerations and, in particular, by the contour of the bodyshell, trimming and required lead-throughs.

Honeycomb elements are available in various shapes and materials. The honeycombs may consist of aluminum or plastic. The energy absorption results from local collapsing of the honeycomb assembly. The stress/deformation behavior can be adjusted as a function of the diameter resp. the width and the thickness of the honeycombs. The elements respond with a pronounced, virtually constant stress level versus the intrusion depth. The folding zone at this level amounts to approx. 80 % of the honeycomb height. Any stress peaks occurring prior to the initial folding of the honeycombs can be minimized by pre-compression. The application of honeycomb elements is primarily restricted by their shape and, as a result, by producibility considerations. Honeycomb elements with variable honeycomb height can be produced only at very high cost. Honeycomb elements are well-suited for virtually flat areas. For one-dimensionally curved surfaces over-expanding honeycombs, only can be used within certain limits. The diagram below compares some selected designs:

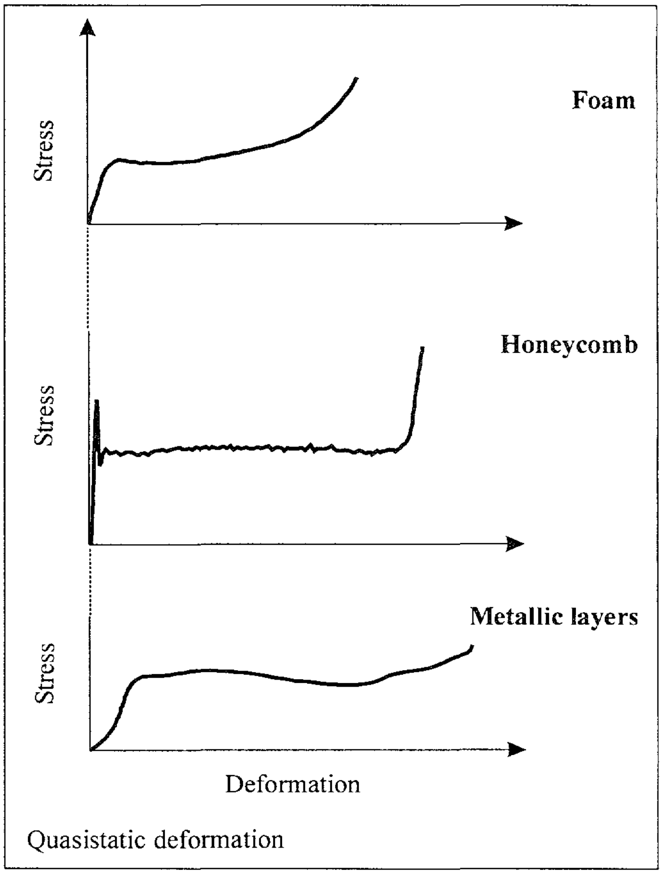

Figure 7. Standardized stress/deformation diagram for various designs

Dynamic investigations of the absorption behavior of the differing designs in an FMH test must always be conducted complete with the trimming elements. Firstly, the trimming element distributes the local loads applied to the target point over the deformation element. Secondly, the shape of the trimming contributes to the overall stiffness of the structure.

One example of an energy-absorption element is the trimming of the rollbar in the Porsche Boxster. Being an open-top vehicle, the Porsche Boxster features an effective roll-over protection system consisting of a high-strength windshield frame and a rollbar. The rigid rollbar made of high-strength, stainless steel is manufactured using an internal high-pressure compression forming process. It's task is to preserve the integrity of the passenger compartment in rollover accidents. In order to further protect the occupant's head in the event of an impact with the rollbar in a rear-end crash, the rollbar has been provided with an energy-absorbing trimming.

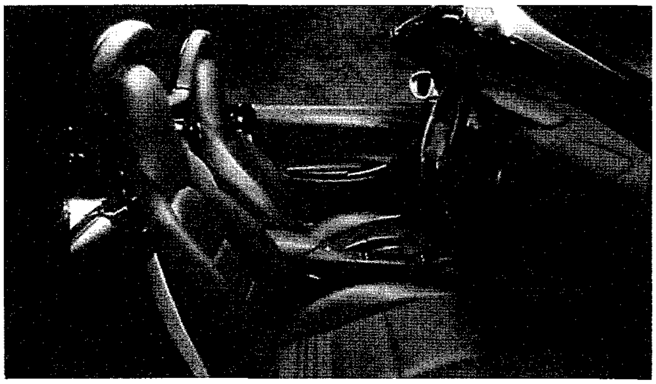

Figure 8. Rollbar of the Porsche Boxsters

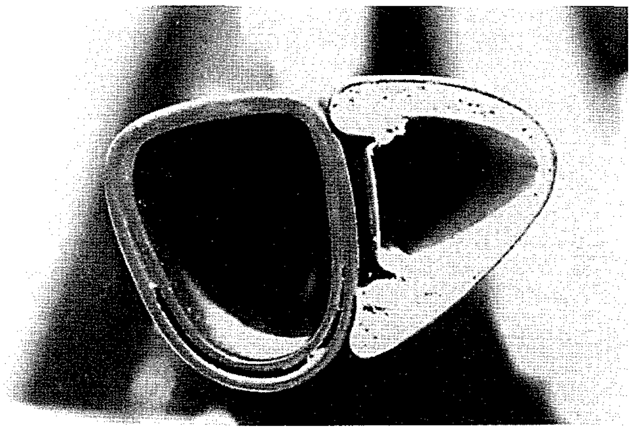

Figure 9: Section through the rollbar and rollbar trimming

The rollbar trimming consists of a metallic deformation element which is provided with a TPO film or leather with expanded plastic on the side facing the occupants. The deformation element is mounted directly on the rollbar structure.

During development, impact tests with the free-motion headform were conducted at an impact speed of 24/h in order to determine the dynamic energy absorption capacity. The results of the FMH test are shown in the following diagrams:

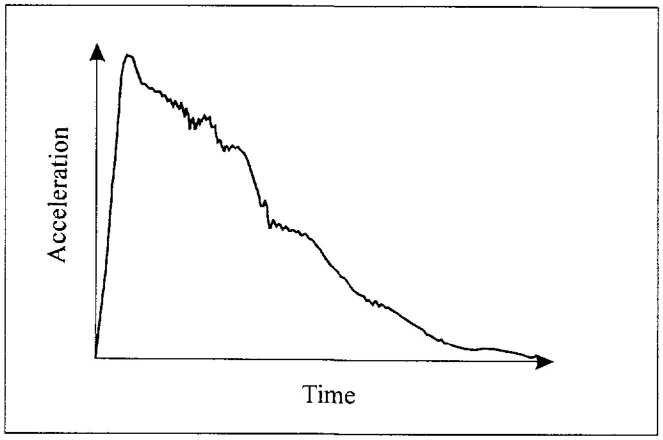

Figure 10: Rollbar: resultant head acceleration versus time

By integrating the characteristic twice, it becomes possible to plot the resultant force versus the intrusion depth on the basis of the head acceleration. The area beneath the curve corresponds to the absorbed kinetic energy of the head.

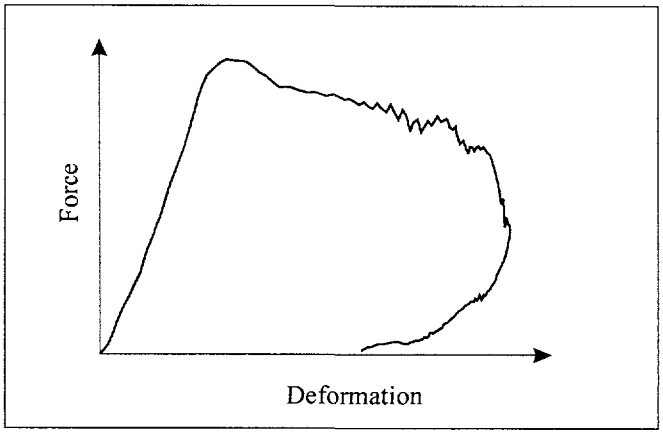

Figure 11. Force/deformation characteristic of the head impact

The complete intrusion depth comprises the plastic deformation of the deformation element, the compression in the connecting area and the elastic deformation of the rollbar.

The diagram also shows a rapid increase in force and a virtually constant force level in the dynamic test. The requirements of the extended Standard FMVSS 201 are met with an adequate safety margin.

CONCLUSION

The extension of Standard FMVSS 201 for protection of the vehicle occupants in the event of an impact with elements in the upper passenger compartment places stringent requirements on interior components in terms of design and energy absorption.

Consequently, the development must be performed in close cooperation between the various technical departments, such as Packaging, Styling, Simulation, Equipment and Safety Testing. The defined development targets are often conflicting ones. For improved energy-absorption and occupant protection, the interior elements must be provided with appropriate intrusion depths, this demand having a considerable influence on styling. At the same time, the occupants' field of view must be as unrestricted as possible and their comfort of movement be preserved.

In the course of preliminary tests, it was possible to acquire know-how as to the particular materials and designs suitable for deformation elements in the interior. To begin with, detailed design investigations and optimizations in the upper passenger compartment are conducted with the aid of numerical simulation. The results of this simulation are then validated and further developed in dynamic vehicle tests on the FMH test bench. These development efforts have led to solutions which allow the additional packaging space required for compliance with the requirements of the extended Standard to be minimized.

In the future, one of the main tasks will be to integrate the required intrusion depths into the packaging of existing subassemblies as far as this is possible, and, at the same time, reduce the number and height of required deformation elements.

REFERENCES

[1] *Code of Federal Regulations - Transportation:* " Standard No. 201: Occupant protection in interior impact", 49 CFR§571.201, 08.04.1997

[2] *U.S Department of Transportation, NHTSA:* "Laboratory Test Procedure for FMVSS 201U", TP201U-01, 1998

[3] *Menking:* "Aufprallschutz für Insassen im Fahrzeuginnenraum", HdT-Tagung "Passive Sicherheit", Essen - Germany, 1997