INFLUENCE OF HIII 5% DUMMY TOLERANCES ON POSITIONING AND TEST RESULTS IN OUT-OF-POSITION LOAD CASES ACCORDING TO THE FMVSS 208

Steffen Sohr
Heiko Hofmann
Sascha Kutschenreuter
Heiko Ruck
TAKATA-PETRI
Germany
Paper Number 07-0340

ABSTRACT

With the introduction of the FMVSS 208 Final Rule, the requirements for occupant protection systems in frontal crashes have significantly increased. Especially the requirements regarding the airbag aggressiveness for "Low Risk Deployment" pose new challenges for both automobile manufacturers and suppliers.

The testing procedure detailed in § S26 of the FMVSS 208 is commonly referred to as "Out-of-Position" (OoP). This procedure considers the HIII 5% dummy on the driver side for two different positions (position 1: "Chin on Module", position 2: "Chin on Rim").

With the applied testing method, the test setup allows tolerances regarding the dummy positioning relative to the vehicle environment.

A comprehensive analysis of the influence of the dummy positioning has shown that particularly the head angle can vary among dummy manufacturers and may result in different OoP load characteristics.

Beside In addition to tolerances caused by the airbag module and the steering wheel design itself, the dummy's head angle is a significant factor for a variation of the OoP test results.

Out-of-position tests with identical module design have shown that the dummy positioning resulting from the head angle can lead to a misinterpretation of the test results. Depending on the dummy position, the OoP results range from far below the legal limits to a value exceeding them.

During the module development process, this scope of interpretations dramatically affects the assessment of the OoP performance and may lead to wrong conclusions.

INTRODUCTION

Recent years saw a number of developments for innovative occupant protection systems aimed to fulfil the increased requirements related to frontal and side protection. Specifically, the introduction of frontal and side airbags resulted in considerable improvements in automotive safety.

Although there are obvious positive effects of an improved protection potential for vehicle occupants, there are other aspects, mainly tracing back to airbag aggressiveness during its deployment phase.

The resulting features and requirements to the airbag design are commonly summarized under the term „Out-of-Position"-performance and address airbag-induced injuries mainly occurring in low speed areas.

Basing on the findings from real world accidents, the new „low risk deployment" requirements for frontal airbags have been included in the US legislation „49 CFR 571.208 (FMVSS 208): Occupant Crash Protection" in order to minimize the injury risk caused by airbag-supported restraint systems (See Appendix B).

On the driver side test with HIII 5%-dummy in two positions are required: Position 1: "Chin on Module" (See Figure 1) and Position 2: "Chin on Rim" (See Figure 2)

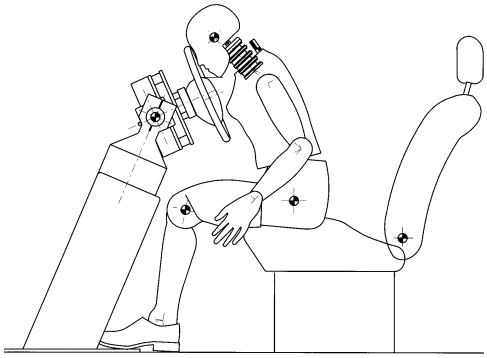

Figure 1. OoP-Test Configuration Position 1.

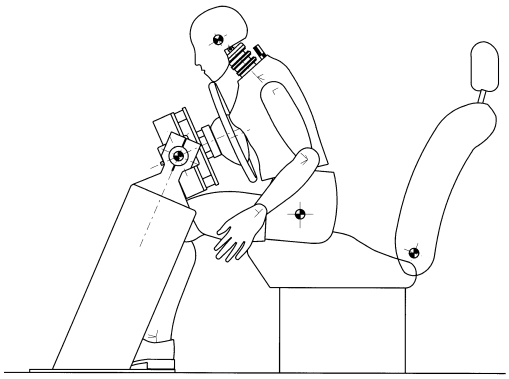

Figure 2. OoP-Test Configuration Position 2.

The applied test procedure to be used for the verification of OoP-Performance has to consider tolerances which are generally influenced by the following parameters:

1) Interpretation of seating regulation for dummy positioning in position 2
2) Specific vehicle characteristics
3) Airbag module characteristics
4) Specific differences in dummies

Following these tolerances and their influence on the assessment of OoP-performance will be described in further detail:

What kind of Tolerances exists?

<u>Tolerances due to legal text on positioning</u>

For Position 2, there is a difference between the description in FMVSS 208 S26.3 on positioning and the Test Procedure Protocol Data Sheet.

FMVS208 allows using the steering wheel adjustment to adjust the Chin Point on the Steering Wheel Point if possible. The Test Procedure Data Protocol Sheet already ends at that point where the Chin Point is within 10 mm +/3 mm of the Steering Wheel Point and switches straight to the airbag deployment preparation.

The interpretation of the Test Procedure Protocol may lead to a lower Chin Point position regarding the Steering Wheel Point. That means a harder interaction between chin and airbag which leads to a higher neck tension force Fz+.

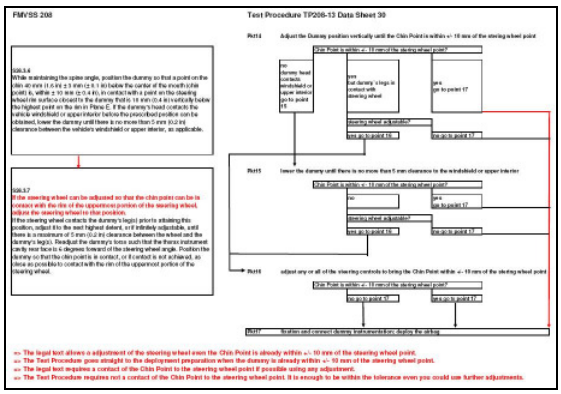

Figure 3. Differences between the positioning description in FMVSS 208 S26.3 and the Test Procedure Protocol Data Sheet; Pos. 2. [1;2] (see also appendix A).

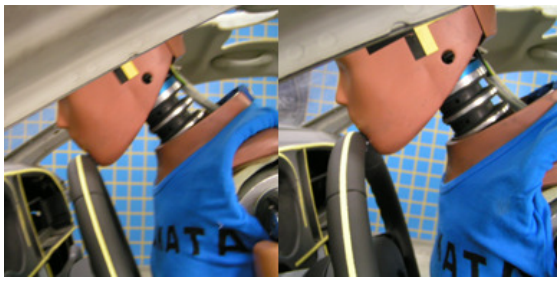

Figure 4. Example for different interpretation of FMVSS 208 S26.3 and the Test Procedure Protocol Data Sheet; Pos. 2.

The different chin position consequently results in a different position of the sternum to the airbag module in x- and z- direction, too.

<u>Tolerances on vehicle side</u>

Differences in the whole ergonomic tolerance chain may lead, for example, to different distances between the dashboard, steering wheel and windscreen.

Further tolerances are known for the steering column deformation force. A delayed deformation or a deformation on a high force level during the time may result in higher dummy measurement values because the dummy has to absorb more energy when the steering column is not running.

<u>Tolerances on airbag module</u>

Tolerances such as inflator pressure, airbag folding or gaps and expansions generated during the deployment are known. Especially the dynamical expansions during the deployment can lead to

different contact situations and variation of the lever arms in case a cover should contact the dummy.
The inflator performance is another parameter which might have influence on the variation of OoP results.
When using a robust module design the parameter variation does not play an important role. It is even possible to use serial modules with single stage inflators.

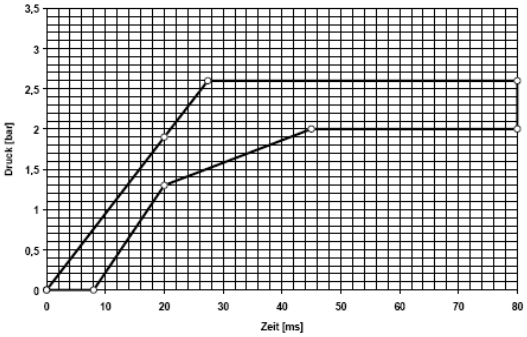

Figure 5. Example for an inflator tolerance +22°C. [3]

Tolerances on Dummy

There are two leading manufacturers for the H-III female. It is commonly known, however, that their dummy models are not really identical.

Even 2 dummies from one producer may differ in size (distances centre of gravity pelvis – centre of gravity chest – centre of gravity head).
Even differences in relative angles between head and chest are not unknown and may result in different chin distances to module in Position 1 and, furthermore, to different chest distances to the module cover and to different Chin Point positions to steering wheel point in position 2. That provokes different chest values and different neck forces and neck bending moments as well.
Beside the differences described above, the biggest difference between the two dummy manufacturers is the chest jacket they use. They differ both in design and stiffness. These differences lead to a different chest distance to the airbag module (esp. Position 2) and different chest deflection.

Calibration specifications produce additional tolerances. Corridors regarding hysteresis are defined for chest deflection, neck forces and neck moments.
Therefore, the OoP results for different dummies also vary.
There is also an interrelation between chest rip stiffness and neck values. The stiffer the dummy chest the higher is the axial neck force and neck bending moment, too, as to be seen in the graphs 6 to 9. They show the curves for 3 different dummies which are within the thorax calibration tolerances.

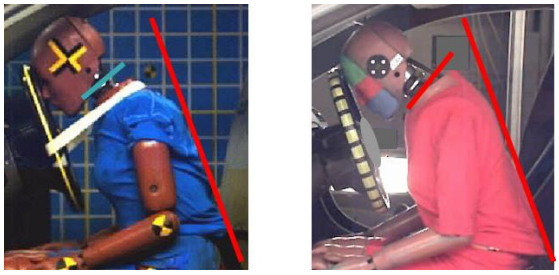

Figure 6. Example for different head angle by same thorax angle in same vehicle; Pos. 1.

Figure 7. Example for different distance to module in same vehicle by same thorax angle due to different chin point to steering wheel point caused by different head angles; Pos. 2.

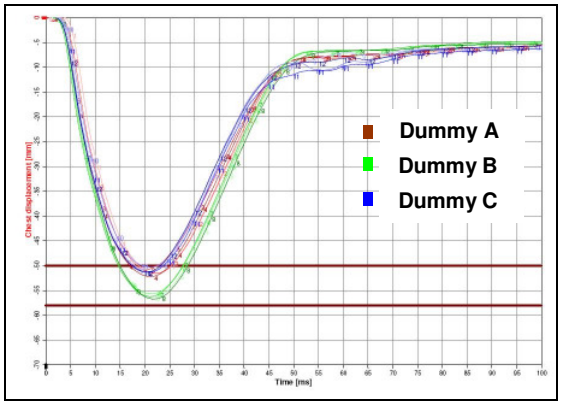

Figure 8. Chest deflection vs. time for thorax calibration for 3 different dummies; dummy B with softer rip set.

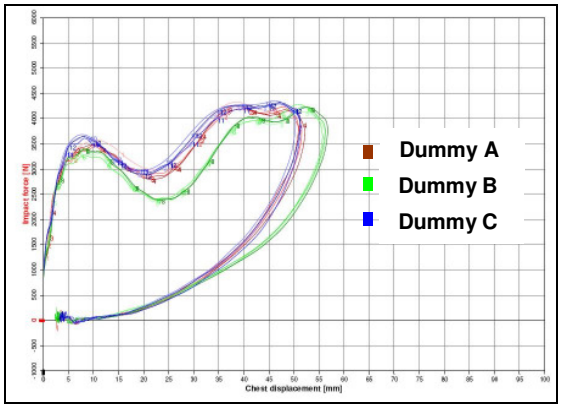

Figure 9. Impact force vs. chest deflection for thorax calibration for 3 different dummies; dummy B with softer rip set.

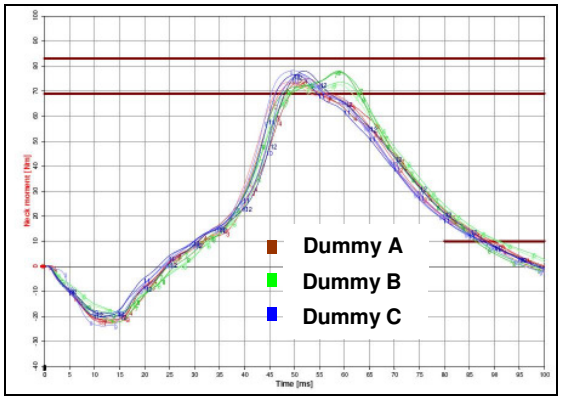

Figure 10. Thorax calibration: Neck moment My vs. time for 3 different dummies; dummy B with softer rip set.

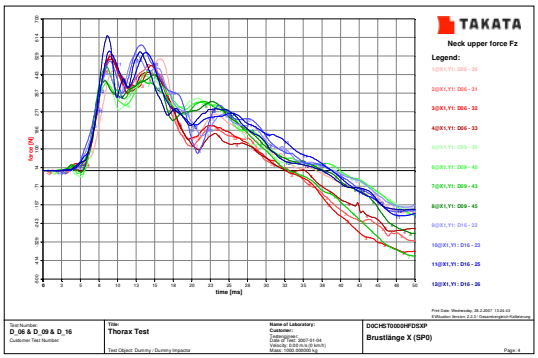

Figure 11. Thorax calibration test: Neck force Fz vs. time for 3 different dummies; dummy B (green curves) with softer rip set.

Considering the tolerances described before the question arises how to deal with them. To reduce all of them will not only produce costs which cannot be defended, but seems even to be impossible. Moreover, complicated mechanical mechanisms do not allow for a general solution.

The future will show whether it will be necessary to change vent position and cover opening geometry. Today, FMVSS 208 requires showing robustness whereas the low risk has to come from the airbag deployment.

What are the consequences of the Tolerances?

<u>Tolerances due to legal positioning text</u>

The interpretation of the test procedure protocol could lead into a lower dummy positioning of approximately 10mm in comparison to the FMVSS 208 legal text (See Figure 12). In general higher neck values (e.g. Nte) in Pos. 2 result from a lower chin position (See Figure 13).

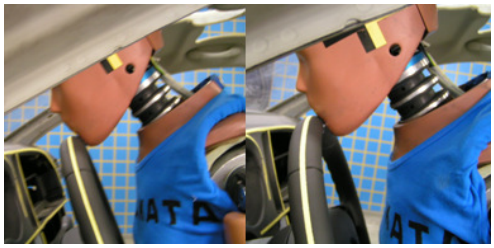

Figure 12. Interpretation of legal text vs. interpretation of test procedure protocol (chin point ca. 10 mm lower than steering wheel point).

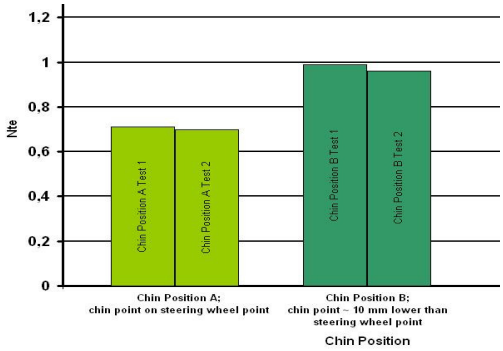

Figure 13. Influence of chin position on Neck value (Nte) in pos. 2.

The measurements show that the values are higher when the chin position is lower, as there is more interaction between chin and airbag in this position.

Tolerances on Dummy side

<u>Example for different head angle relative to chest Position 1</u>

As already shown, different head angles for different dummies are possible.
The diagram below shows the neck moment My time histories for 4 different dummies with different neck angles. The tests Position 1 were conducted with a comparable airbag module in the same car environment. Steering wheel angle and chest angle were always the same.

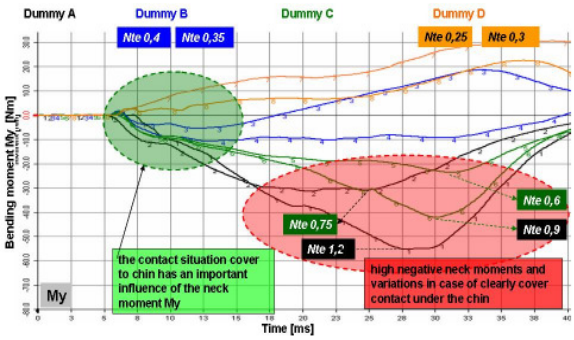

Figure 14. Neck bending moment vs. time depending on 4 different dummies; OoP Pos. 1. [4]

The graphs show a big variation in the neck bending moment maxima. The negative extension (-my) maxima are the higher the more the cover hits under the chin. The contact situation itself depends on the head angle, i.e. on the chin distance to the airbag module.

It is also possible to change completely the bending moment characteristic. This makes it possible to induce a flexion moment (dummy B and D) or to induce an extension moment (dummy A and C) just by varying the dummy.

The next diagram displays the head angles of the 4 dummies relative to the thorax angle. Moreover, it is shown in which way the Nte depends on the difference between angle head – thorax. All tests had exactly the same testing conditions. The Nte is the higher the lower the relative angle head to thorax is.

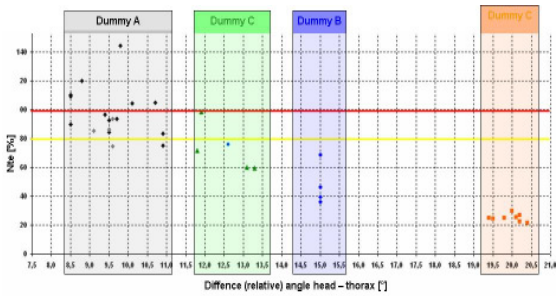

Figure 15. Neck load (Nte) vs. head angle for 4 different dummies; OoP Pos. 1. [4]

Chapter 4 describes which effects occur and what consequences result for a robust module design.

Especially for dummy A, it will not be possible to find a robust solution. Airbag folding optimizing is not the solution, as the resultant force will always be applied in z-direction. Hence, the dummy will always react with axial neck tension force and neck bending extension. As a result the Nte will always be dominant with high maxima. All further system tolerances, especially inflator variation, will be reflected in the Nte value.

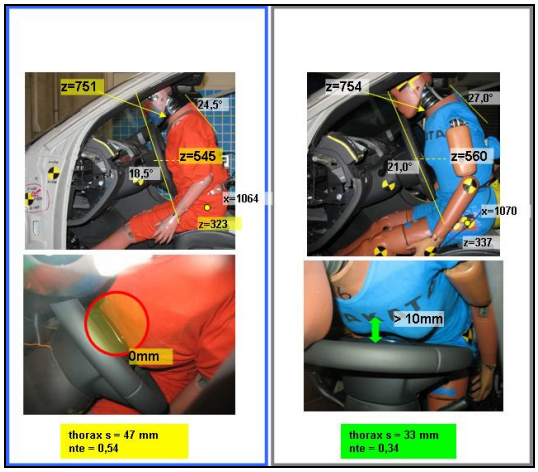

Figure 16. Example for different chin and sternum positions due to different dummy geometries; OoP Pos. 2.

Example for further Tolerances

The following graphs show the Nte and neck force Fz vs. the steering wheel column deformation. The tendency reveals that the dummy neck values increase with lower steering column deformation.

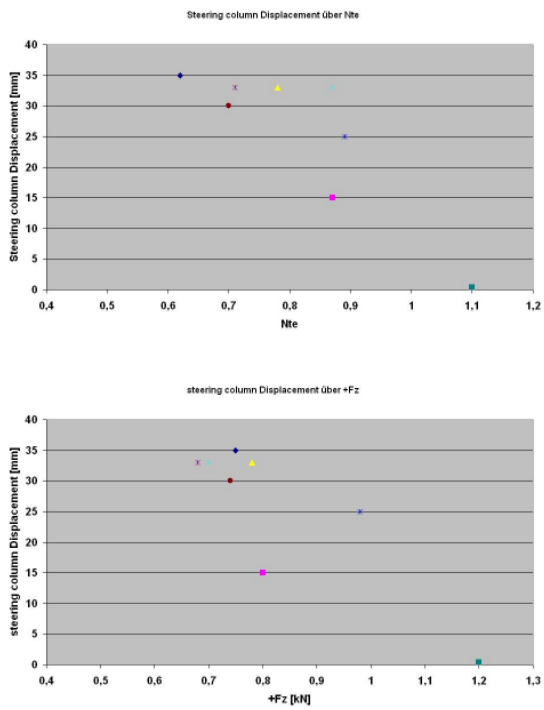

Figure 17. Neck tension force and Nte depending on steering column deformation; OoP Pos. 2. [5]

WHAT ARE THE REASONS FOR DIFFERENCES IN OOP LOADS?

The relative position of the dummy in front of the module leads to typical loads in its neck. The proximity of the dummy to the module makes it very complicated to identify the applied forces on the dummy. Numerical simulation offers the possibility to define forces acting on the dummy in a determined direction. Doing so, the measured forces and torques (reactions of the dummy) can be allocated to the impact forces, and, hence, the interrelationship between action and reaction can be recognized and understood.

Impact force in the x direction of the dummy head

In an OoP test, it is very important to affect the forces acting on the head of the dummy. The only possibility to evoke a flexion moment in the neck of the dummy during an OoP-Test is to impact the chin in x direction.

A lane from the module to the face of the occupant is necessary to let the airbag act on the described direction.

This is the reason why Dummy B and Dummy D react with a flexion moment (See Figure 11). Due to different chin positions, the airbag deploys in front of the chin. The resultant airbag force is impacting the chin in x direction.

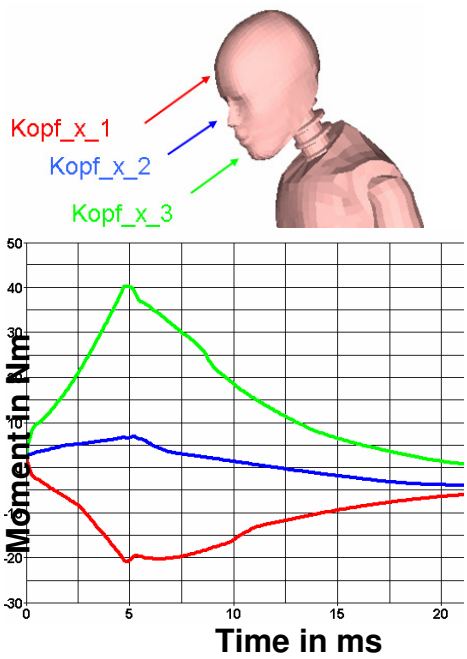

Figure 18: neck bending moment over time; lever variation for impact force 1200 kN [6]

Impact force in the z direction of the dummy head

This is the most uncontrollably direction of the impact forces. An impact force acting in this direction always causes a negative neck bending moment. The maximum of this moment depends on the lever between the impact force and the revolute joint of the neck.

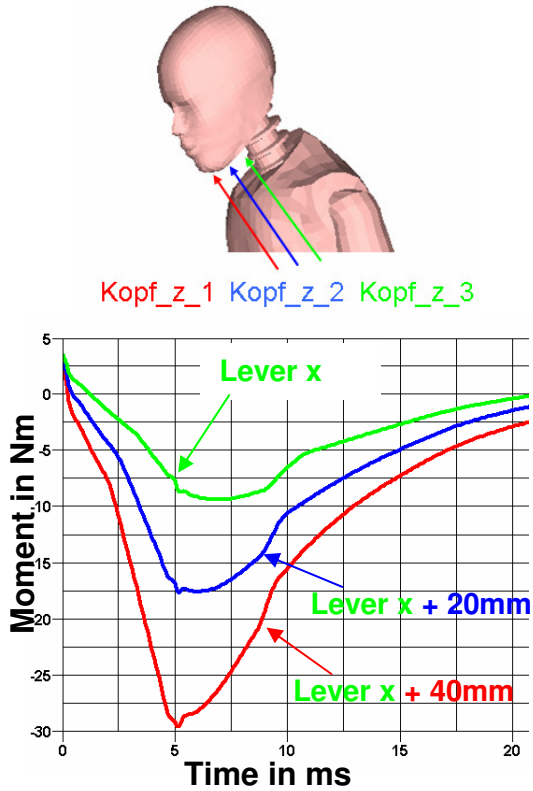

Figure 19: neck bending moment over time; lever variation for impact force 1200 kN [6]

The lever difference of the shown curves is only 40 mm. In addition to the high extension moment, the impact load causes a tension force in the neck. The combination of this force and the moment leads to serious N_{TE}. This relationship is responsible for the described differences of dummy A and dummy C for the OoP test setup "chin on module" (See Figure 11). For this reason it is absolutely necessary to avoid forces acting in this direction.

Impact force in the x direction of the dummy thorax

That load condition is typical for the OoP Position 2. An impact load working in x direction on the thorax of the occupant causes a chest deflection. The maximum of this deflection depends on the position where the load attacks.

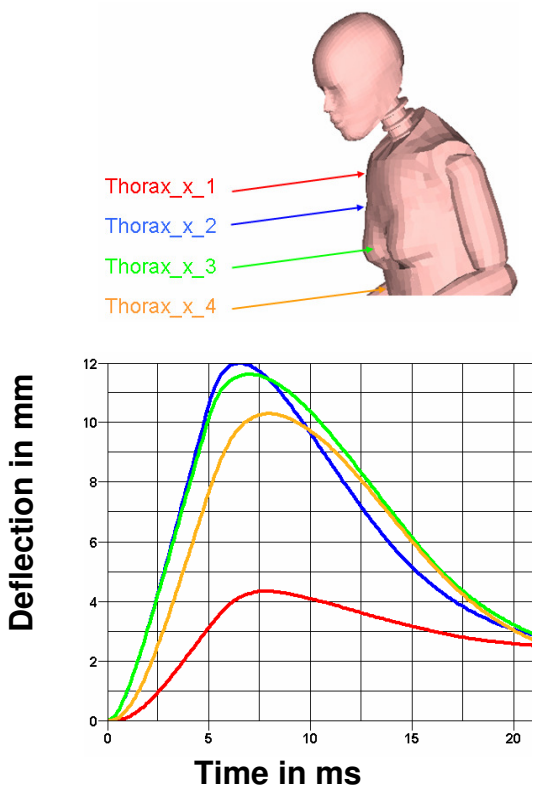

Figure 20: chest deflection over time; lever variation for impact force 1200 kN [6]

Furthermore, an impact load on the thorax in the described direction always causes an extension moment. This becomes especially true in the OoP test "chin on rim".

The occupant is jeopardized as an extension moment combined with a chest deflection will always occur. An example for this can be found in Figure 20.

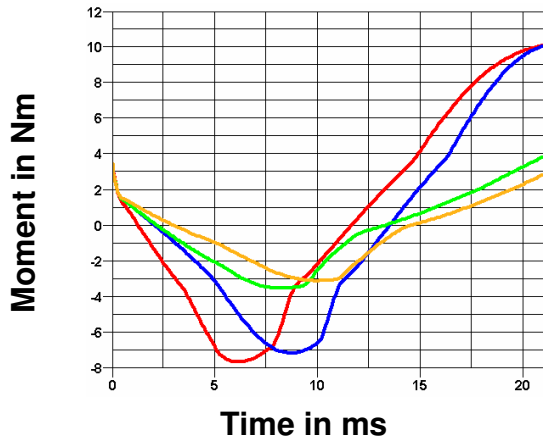

Figure 21: neck bending moment over time; lever variation for impact force 1200 kN [6]

The neck extension moment is less when the resultant airbag force is applied in a lower thorax or abdominal area.

Without a module designed for the OoP loading conditions, it is extremely difficult to fulfil the requirements of the OoP-test "chin on rim". During the deployment of the airbag cushion it is necessary to avoid contact between the airbag or parts of the module with the dummy chin because this might result in an impact force in z direction to the head of the dummy. This force causes an additional extension moment which superposes the moment caused by the thorax impact force.

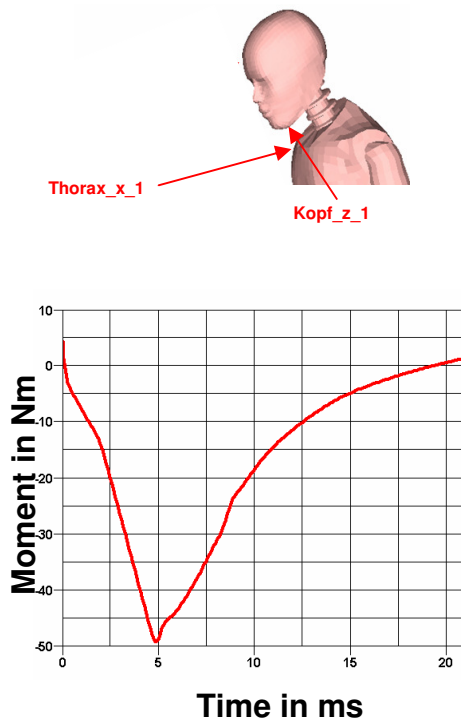

Figure 22: resultant neck bending moment over time caused by force thorax x and force head z (1200 N each) [6]

The loads on the dummy during an OoP test can be controlled if it is possible to apply the impact loads on determined regions of the dummy.

The only possibility to achieve a flexion moment is to apply a force in x direction on the chin.
Impact loads acting in z direction on the head always lead to extension moments with a high maximum.

Loads on the thorax cause an extension moment, too.

With a module designed for the loading conditions of an OoP test the described relations can be benefited.

LOAD MECHANISMS IN OUT-OF-POSITION SITUATIONS

Impulse-like force application

An impulse-like force application on the dummy under OoP conditions mainly results from:

- High inner pressure at the beginning of the airbag deployment as a result of inflator ignition; shortly after opening of the airbag cover the gas output hits the dummy that is still bearing the accumulated pressure („punch-out"-effect)
  Temporarily, there are high forces, specially in the head and thorax area.
- The opening airbag cover is accelerated by the airbag and produces an impulse on the dummy, the results are peaks in head and thorax area and high tensile neck forces.
- Parts of the folded fabric which are ejected as a concentrated mass out of the airbag module produce shock-like loads on the dummy

Loads caused by airbag membrane forces

OoP loads as a result of airbag membrane forces are mainly caused by:

- Loads during the airbag interaction phase which are only caused by the pressure-loaded airbag and generally lead to high neck forces and neck moments as well as to head and chest accelerations
- Loads during the airbag interaction phase induced by the airbag itself and in connection with the cover contact; the cover segments adjacent to the dummy (e.g., at the chin) increase the lever effect of the deploying airbag.
- Interaction with the airbag during the entire deployment phase, dummy loads result from the impact on the seat rest or other rear structures

CONCLUSIONS

There are a number of tolerances that influence the results of OoP tests. These tolerances result from the interpretation of the dummy seating procedure, from the airbag module and from the dummies themselves. Here, small changes sometimes might have big effects.

It is common knowledge that it is not the amount of energy application caused by the airbag which becomes the decisive parameter.

The simplified presentation of the load mechanisms shows which forces in positions 1 and 2 should be applied controlled by a robust and OoP-optimized airbag module design.

REFERENCES

[1] USA/Federal: 49 CFR 571.208 (FMVSS 208). 2005.

[2] Data Sheet 30 Test Procedure TP208-13 – Low Risk Deployment Test Using an Unbelted 5th Percentile Female Dummy

[3] Example for tank pressure field (ambient) based on the MTG 5, AK - LV 03. 2005

[4] Internal project documents. 2007. (not published)

[5] Internal project documents. 2006. (not published)

[6] Kutschenreuter, S. 2006. "Analytical Investigation on phenomenon of Out-of-Position load cases on driver side." Diploma theses (not published)

APPENDIX A

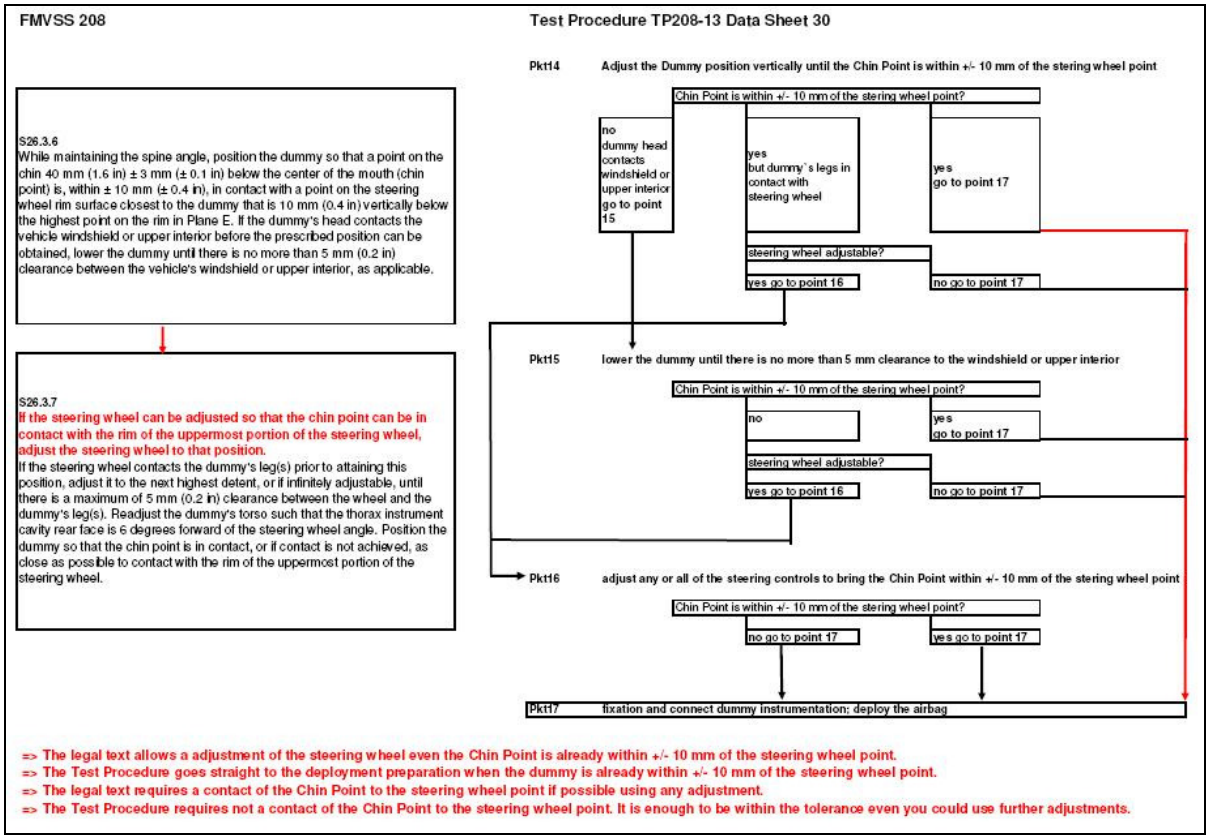

Figure A1. Differences between the positioning description in FMVSS 208 S26.3 and the Test Procedure Protocol Data Sheet; Pos. 2. [1;2]

APPENDIX B

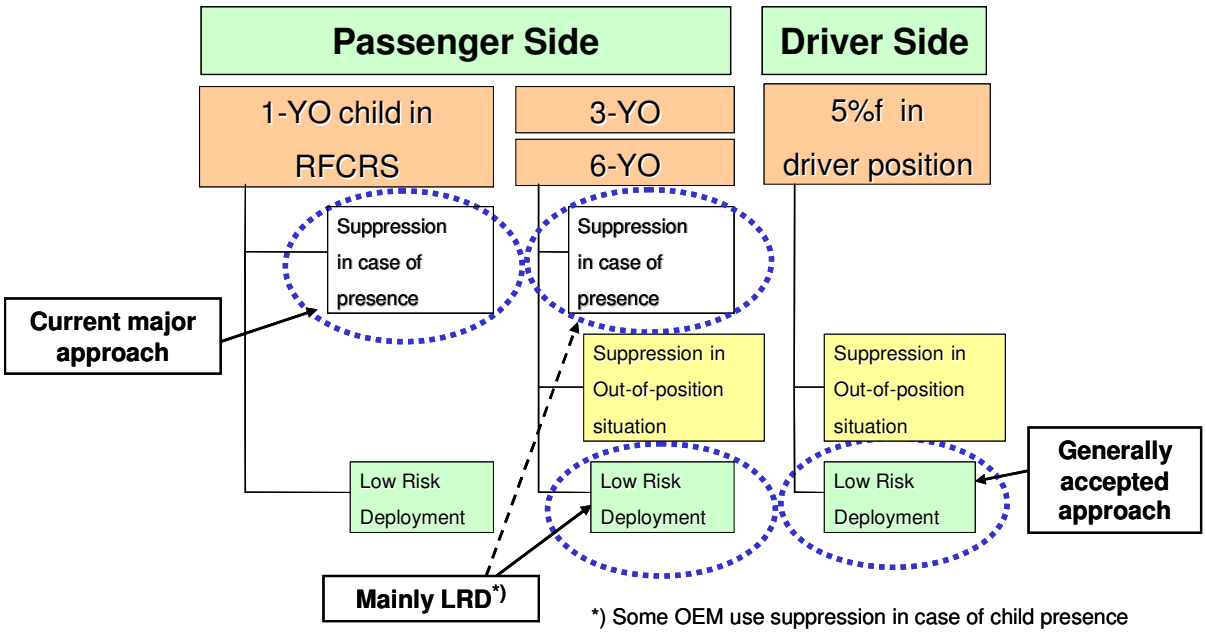

Figure B1. „Out-of-position“ requirements according to the Federal Regulation 49 CFR 571.208 (FMVSS 208).