OPTIMIZATION OF SEAT BELT BUCKLE MOTION FOR REDUCING CHEST DEFLECTION, USING RIB EYE SENSORS

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ABSTRACT

To achieve overall good ratings in frontal impacts according to US and Euro NCAP, low chest deflection values have to be obtained. Concerning belt induced chest deflection, belt forces as well as the geometry of the belt system have to be optimized. Hence, the objective of this study was to analyse the influence of the buckle position and motion during crash on chest deflection.

Theoretical investigations as well as simulations (software MADYMO / Facet - Q-dummy) were used to study the influence of the buckle position and motion on chest deflection. Sled tests, where the environment represents a middle class vehicle, were conducted to verify the findings. In order to obtain detailed insight regarding the deformation of the HIII 50% dummy's thorax and the load distribution, rib eye sensors were used showing the deformation of each individual rib during the crash.

As an outcome, the rib eye sensors show an unbalanced thorax deformation. Relevant differences in rib deformation are observed between left and right ribs of the thorax. Smaller differences are seen between upper and lower ribs. Concerning chest deflection, simulation and test results show an important influence of the buckle motion on chest deflection and on the energy absorption of the dummy. Significant differences in load distribution are detectable by the usage of rib eye sensors.

The retention of a Hybrid III 50% dummy with a 3-point belt leads to an unbalanced deformation of the thorax ribcage. To achieve low chest deflection values, the upper and lower diagonal belt force as well as the belt geometry have to be tuned. In fact, the belt geometry significantly influences the deflection of the ribcage. The buckle position and buckle motion during forward displacement of the dummy can be identified as significant tuning parameters.

1. INTRODUCTION

The risk of severe thorax injuries in frontal crashes is still relatively high compared to other body regions, cf. fig. 1. /1/. Chest deflection, measured with the HIII dummy has become more and more the important injury assessment value to evaluate the thorax injury risk in laboratory tests /2/. The rating of deflection instead of chest acceleration in the US NCAP frontal crash underlines this trend.

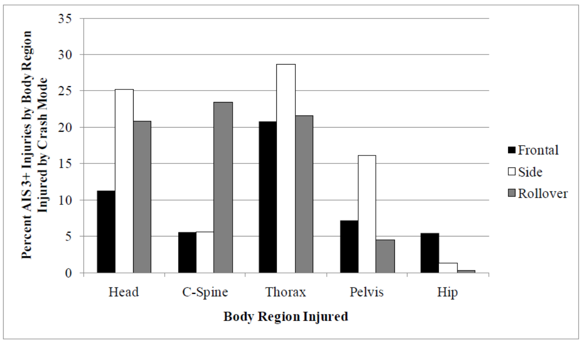


Figure 1. AIS3+ injury probability by body regions for frontal, side and rollover crashes in US /1/.

The measured chest deflection values of the Hybrid III dummy have to be interpreted with care. Due to a single measurement at the sternum with a slider, local penetrations of ribs cannot be identified. Furthermore, the deformation of the ribcage is different compared to the Human thorax /3/ /4/. As a result of these considerations, the deflection values should be interpreted under consideration of the loading conditions /5/.

In this paper, simulation and tests with rib eye sensors /6/ are used to describe belt induced thorax deformation. Furthermore, it is shown that a more balanced deformation of the thorax can be achieved by modification of the buckle tongue position.

2. THE BELT LOAD ON THE HYBRID III THORAX IN FRONTAL CRASHES

The diagonal belt load on the thorax can be described as a function of the belt forces F_{B3}, F_{B4} (cf. fig. 2) and the geometry. Concerning the thorax deceleration, a simplified calculation of the resultant force can be used, cf. figure 3 /7/. As a result, the load on the thorax increases during the forward displacement of the dummy due to geometry effects.

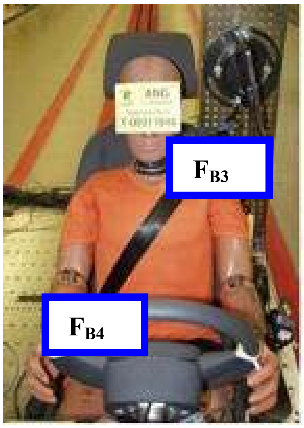
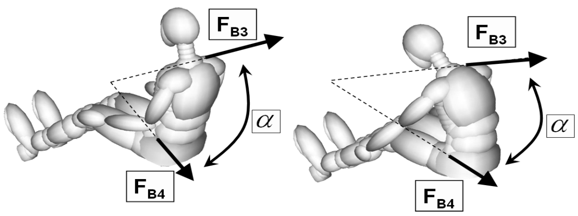


Figure 2. Location of belt force sensors.



$$F_{Res} = \sqrt{F_{B3}^2 + F_{B4}^2 - 2F_{B3}F_{B4}\cos(\pi - \alpha)}$$

Figure 3. Simplified computation of the resulting belt force on the occupant. Right: The forward displacement leads to higher forces acting on the dummy. Source: /7/

In contrast to this, belt induced chest deflections cannot be analysed with a simple calculation of the resultant belt force on the dummy. In fact, analysis about the loaded thorax regions of the dummy and the thorax deformation characteristic itself are necessary and -as a consequence- are part of the following investigation to evaluate favourable belt geometries.

3. METHODS

Theoretical considerations as well as simulation runs with MADYMO, sled-tests and static deployment tests were done in a generic environment. The used environment (fig. 4) can be described as the following:

- seat cushion on a rigid interface
- no airbag
- no instrument panel (no knee contact)
- belt system with load limiter and retractor pretensioning
- dummy Hybrid III 50th percentile with rib eye sensors
- pulse according ECE R-16

Figure 4. Generic environment, Hybrid III with rib eye sensors.

A rib eye sensors system was used as described in /6/. The sensors were mounted at a distance of +/- 9cm from the mid of the sternum, cf. figure 5. During testing, attention was paid to a correct belt fit and a constant dummy temperature.

Concerning simulation, the MADYMO Facet Q Dummy HIII 50% was used also supplemented with rib eye sensors at the same locations. To obtain most reasonable results, a belt fitting pre-simulation was conducted for each variation in order to achieve a correct belt fit on the dummy.

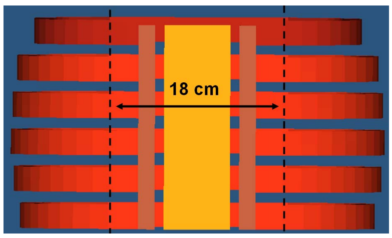


Figure 5. Locations of rib eye sensors.

4. SIMULATION AND TEST RESULTS

4.1 Actual thorax deformation and its measurement

To identify the difference between the slider measurement and the external deformation, static deployment tests were carried out. To eliminate the

Figure 6. Static deployment test with diagonal belt only and retractor pretensioning.

influence of the lap belt and abdomen, the dummy was loaded only by a diagonal belt with retractor pretensioning., cf. fig. 6. The result is given in fig. 7 where the webbing pay in and the chest deflection is plotted. As a result, the thorax deflection follows the webbing pull in with a delay reasoned by the viscoelastic deformation characteristic /8/. Furthermore, the difference between the web pay in and the deflection is not a result of the belt slack or

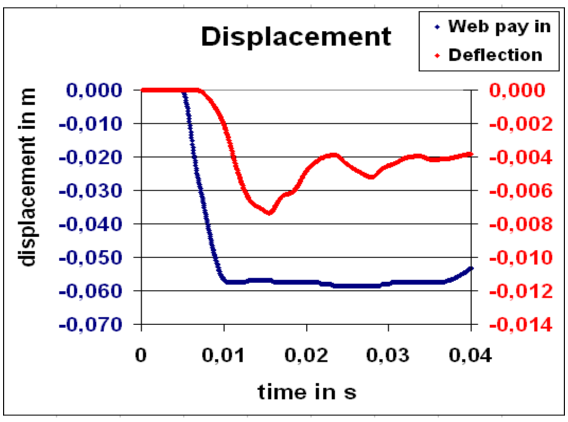


Figure 7. Web pay in by retractor pretensioning and chest deflection as a result.

belt elasticity only. In fact, a difference of the sternum deflection (measured with the slider) and external deformation can be noticed. As an example, a difference of about 10mm in the sternum area was

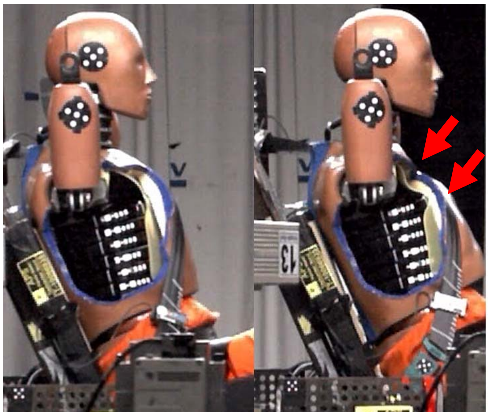


Figure 8. Foam deformation as a reason for different internal and external torso deformation.

found. To demonstrate the reason for this difference, tests with an open dummy jacket were carried out.

Figure 8 shows the deformation of the foam which can be identified as the main reason.

4.2 Thoracic response to belt loading in sled tests

During forward displacement of the Hybrid III dummy in frontal crashes, an unbalanced forward displacement can often be noticed, cf. fig. 9. The belt loaded shoulder shows more forward displacement than the unloaded shoulder, which seems to be unexpected. The reason for this behaviour can be

Figure 9. Higher forward displacement of the left shoulder even though it is loaded by the belt.

explained in figure 10. The dummy chest is loaded asymmetrically by the belt. In addition to the loading of the left shoulder and the sternum, in particular the right ribs are loaded by the belt, leading to unsymmetrical thorax retention.

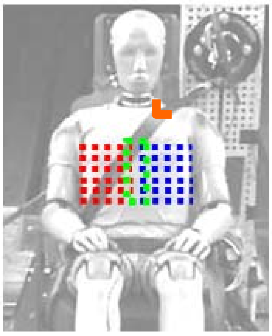


Figure 10. Belt load on the thorax: Mainly the right ribs and the left shoulder are loaded.

The unsymmetrical thorax deformation can be measured with the rib eye sensors in sled test, cf. figure 11. Main differences can be noticed between the left and right ribs. Furthermore, a difference between the upper and lower ribs can be found. While a decreasing in deflection of the unloaded left rib 1 to the left rib 6 can be measured, an increasing in deformation of the belt loaded ribs from the upper

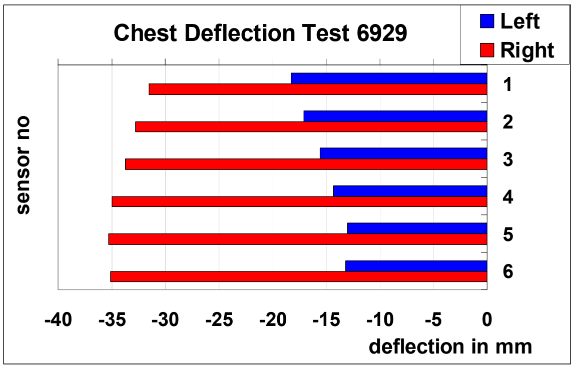


Figure 11. Ribs eye measurement results which show the unsymmetrical deformation.

ribs to the lower ones can be noticed. Figure 12 shows the simulation results. The difference between right and left ribs can also be shown. In contrast,

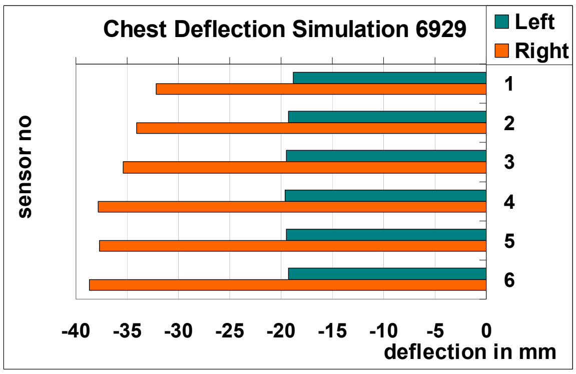


Figure 12. Simulation results of the rib deformation.

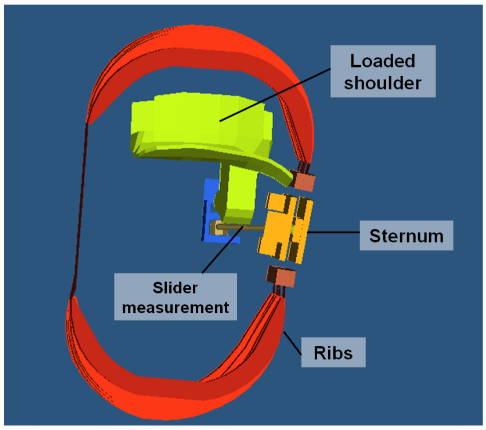


Figure 13. Loaded dummy ribcage in simulation.

differences between the 6 left ribs were not detected. In fig.13 the deformations of the ribs are visualized.

4.3 Modification of the buckle tongue position during crash

To investigate the influence of buckle tongue position during crash, sled tests were carried out. The variation parameter in these tests was different buckle motion during testing. Figure 14 shows the

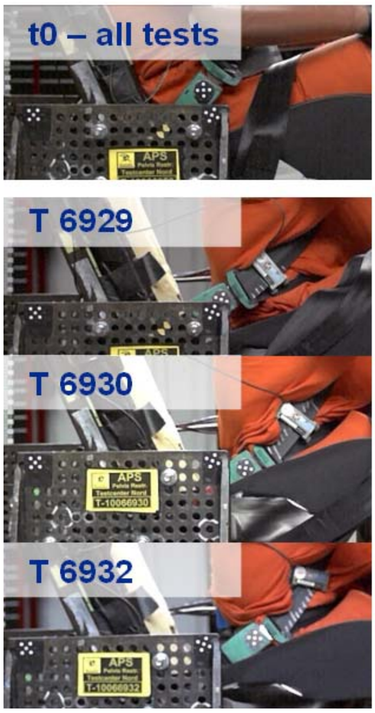


Figure 14. Different buckle motion during testing. Initial buckle position and the position at maximum dummy forward displacement is shown.

differences in three tests as an example. The initial buckle position at t0 is identical; at maximal forward displacement of the dummy differences are evident.

As a result, relevant differences in chest deflection and load distribution are noticeable. In test 6929 the highest deflection values were measured. In test 6930 the differences between the loaded right and the unloaded left ribs decrease. Furthermore, the comparison between the loaded right ribs shows in test 6930 no increase in deflection from the upper to the lower ribs. An emphasis of this trend is given by the results of test 6931. It has to be mentioned, that the forward displacement of the dummy thorax was about 35 mm higher in test 6930 compared to test

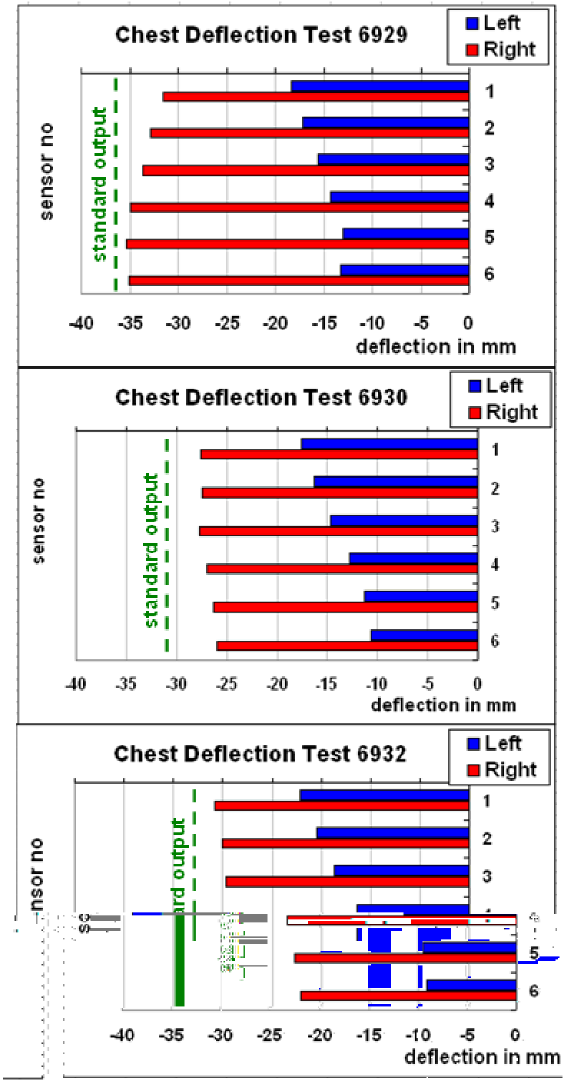


Figure 15. Influence of different buckle motion on rib deformation. Maximum value of each rib. Dotted line: dummy standard output (measured with slider)

6929. Test 6932 shows an increase in thorax forward displacement of about 51mm compared to test 6929. For all tests, the shoulder belt force F_{B3} was about 4.3kN, the belt force inner F_{B4} was measured in the range of 3.5kN to 4kN at the maximum chest deflection.

The simulation results of the tested configurations 6930 and 6932 also show a reduction of deflection values. On the other hand, the influence on the differences between the loaded upper and lower right ribs were smaller than in tests.

To compare the test configuration 6929 with 6930 correctly, the belt force on the shoulder was increased in simulation with configuration 6930 to

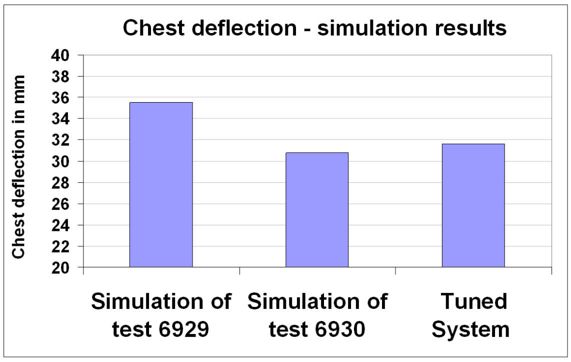


Figure 16. Simulation results of the maximal deflection (standard measurement). A benefit of about 4mm in chest deflection can be achieved with comparable dummy forward displacement.

achieve the same forward displacement as in run 6929. As a result, the benefit in deflection decreases down to 4mm, cf. figure 16.

Closing, in the chosen positions of the rib eye sensors the maximum values of all ribs were comparable or lower compared to the slider measurements of the dummy in all tested configurations, cf. fig 15.

5. DISCUSSION

To evaluate and optimize the thorax deformation by the belt, several items have to be taken into account. First, the viscoelastic thorax deformation characteristic can be seen as expected during the static deployment test (fig. 7). In addition, the differences between external and internal dummy deformation can be noticed which are not the result of the sternum deflection measurement alone. In fact, the foam of the jacket has a relevant influence on the external deformation, as demonstrated in figure 8.

Furthermore, the thorax is loaded by the belt mainly on the shoulder, the sternum and on one side of the ribs, due to dummy design (fig. 10). This loading condition leads to an unsymmetrical thorax deflection (fig. 11). A relevant difference between the loaded and unloaded rib side can be noticed, in this test series it was up to 22mm (fig. 11). As a result of this deformation, an unsymmetrical forward displacement of the thorax follows, which can be an indicator for the unequally distributed load on the thorax. (fig. 9).

The advanced simulation model with the Facet Q MADYMO HIII 50% dummy shows also the difference between the left and right ribs (fig. 12), however, the used simulation model is less sensitive to altered belt geometries than the hardware dummy. This is true especially for the less loaded side of the ribcage. As the general behaviour of individual rib deflection is also seen in the simulation model, it is justified to using it for principle simulation runs.

To achieve a more uniform chest deformation, the belt geometry should be analysed and -if possible- optimized, in addition to the control over the shoulder belt forces F_{B3} and F_{B4}, cf. /9/. In this test series the buckle movement was modified as shown in figure 14 to point out the influence of the belt geometry on the deformation. Of course, the belt forces are influenced by the different buckle motion. In this test series the differences in belt forces at the maximum chest deflection are too small to be the reason for the different deflection values, if usual errors are assumed. In fact, the chest deflection is mainly influenced by the buckle tongue movement, which results in different belt geometries. A high influence of the tongue motion can be expected, especially by an unsymmetrical loading of the belt loaded ribs, cf. fig. 15.

During an optimization of the belt system concerning chest deflection, the forward displacement of the dummy has to be monitored to achieve comparable boundary conditions as done in simulation by increasing the shoulder belt load limiter. Furthermore, the coupling of the dummy, the pelvis retention (e.g. avoiding submarining) has to be taken into account. To achieve an optimum buckle movement, further investigations should be carried out in this direction.

Closing, this investigation was done in a generic environment without airbag and knee contact. Further investigations should be made to evaluate the benefit of an optimized buckle position and buckle motion in different vehicle environments with airbag and knee contact to the instrument panel. Furthermore, a variation of the rib eye sensor positions could give more information about the thorax deformation and answer the question whether such positions lead to measure the maximum deflection values of the ribs.

6. CONCLUSIONS

During the retention of a dummy in a frontal crash with a 3 point belt, the thorax deforms in an unsymmetrical manner. The reason for this is the unequal loading of the dummy. The belt loads one shoulder, a part of the dummy sternum and one side of the ribcage.

In the environment investigated, the used rib eye sensors show the expected different rib deformations. On the one hand, high differences between left and right ribs can be noticed. On the other hand, differences in deformation between upper and lower ribs can be measured. The latter indicates an unbalanced tuning of the belt system. Furthermore, the relevance of the lower diagonal belt concerning chest deflection can be noticed.

With the used simulation model, the principle rib thorax deformation can be calculated; however, the model shows less sensitivity to altered thorax loading than the hardware dummy.

To reduce the thorax deformation, the belt forces F_{B3} and F_{B4} as well as the belt geometry -which changes during dummy forward displacement- have to be optimized. Concerning that the webbing is re-routed in the buckle tongue, an improved buckle motion seems to be beneficial. In this investigation, a reduction in chest deflection of about 4mm could be achieved.

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