Movement in the PRE-Crash situation

A simulation research with a reversible PRE-SAFE® Pulse system

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With innovative forward thrusting systems, last shown for side impact protection in the ESF, the Mercedes-Benz Experimental Safety Vehicle 2009, it is possible to reduce the loads for the occupants significantly. About two third of all accidents are frontal collisions, many of them have braking activities in advance, which means that these systems should be used in frontal crash situations as early as possible, in addition to the standard reactive restraint systems. To show the effectiveness of the, so called PRE-SAFE® Pulse (PRE-PULSE) events, one has to show the difference in the movement of the occupants with and without a forward thrusting system.

In this poster session the results of a research of occupant movement in frontal non-braking and braking situation will be shown. Through a reversible, still conceptual belt system, forces are used to accelerate the occupant torso in the opposite crash direction. Just before the occupant would reach his final seating position, still in the movement, the accident impact could occur. With this active pulse effect on the occupant in a possible PRE-Crash phase (right before the impact), a significant reduction of the resulting impact loads on the passenger may be reached.

To show this effect the movement and trajectories of a 50% HIII-Dummy as well as human test subjects are evaluated in tests and simulation studies. The research project reproduces the real HIII-Dummy movement in comparison to the human behavior through human body models. Thus, the study evaluates the behavior in the relatively long, low g PRE-Crash phase during the usage of the reversible PRE-PULSE system, which breaks completely new ground. Non-braking and braking situations are reconstructed and simulated. Thus the simulation models allow non-stop consideration from the PRE-Crash through to the crash phase during braking and non-braking situations using the innovative forward thrusting systems.
INTRODUCTION

Today, with a large number of active and interactive assistance systems, critical situations can very often be avoided. Thus, with active safety measures, the vision of accident free driving could become nearer and nearer.

Nevertheless, accidents unfortunately still happen every year, of course with a steady reduction of number and severity. According to Eurostat, the decrease of the killed people in accidents reached -57% (1991 to 2007 EU 27).

**Figure 1:** Fatalities in accidents EU 27 from 1991 to 2007

More detailed statistics show that frontal collisions remain the number one crash type, followed by side and rear impacts and finally the rollover crashes. The federal German statistics on road accidents, “German In-Depth Accident Study” (GIDAS),
stores about 20,000 representative road accidents with detailed information on research and statistics. Each year, more than 2,000 accidents in the geographical research area - the metropolitan areas around Hannover and Dresden - are documented in depth. A closer look into the data focused on car collision types shows 51 % frontal and 15.8 % side impacts with injured occupants (at 12/2009). 88.3 % of the occupants were using the primary restraint system, the seatbelt, during the accident. In such cases, consistent with ongoing enhanced safety development, the PRE-SAFE® Pulse (PRE-PULSE) can be used in the future to reduce the load acting on the occupant during an unavoidable accident.

The following paper shows the investigations with an active forward thrusting restraint system in frontal collisions. The system must be reversible and act as an additional measure to the conventional restraints. This represents the next episode in pioneering development with the integrated safety approach and is the logical continuance of the multiple award-winning PRE-SAFE® System.

**MOTIVATION**

As shown in the ESF Experimental Safety Vehicle this year, the use of a lateral PRE-PULSE can reduce the forces acting on the torso of the occupants during a lateral collision by around one-third. This result was reached by using air chambers in the side bolsters of the seat backrest. The question now follows: what can be done to obtain the PRE-PULSE effect in frontal collisions, in the PRE-Crash phase and before the impact occurs. Further question then arise as to how one investigate and obtain results regarding the effectiveness of PRE-PULSE with a future restraint system, which does not currently exist? This paper describes the methodology used, with the multibody simulation MADYMO, as well as the testing and the validation of the movement for the investigated load cases with an HIII Dummy, human test subjects, and human body models.

Investigated load cases frontal:

- PRE-Crash with non-braking and braking situation (low g–phase up to -1500 ms)
- IN-Crash (high g-phase) US-NCAP with non-braking and braking PRE-Phase
PRE-SAFE® Pulse frontal – Theory –

Through adaptive airbags and belts with load limiters and pyrotechnical pretensioners, as well as PRE-SAFE® activities immediately prior to impact, the forces acting on the occupants in a crash has been decreased significantly in the last years. To achieve further improvement, developers must break completely new ground. Since a great deal of information is obtained via current sensor technology before an accident occurs, it should be possible to implement predictive restraints even earlier and not only rely on reactive restraint systems.

Via an active, reversible PRE-Crash impulse, which accelerates the occupant’s torso in the direction opposite the crash, the energy difference between the occupant and the vehicle can be reduced. In theory, to obtain optimal reduction, the maximum speed of the rearward movement of the dummy must coincide exactly with the time of impact. Through that occupant action, quasi along the collision energy path, a reduced relative speed to the occupant’s surroundings and relative to the driving speed can be achieved.

**Figure 2:**
- **PRE-CRASH:** Movement in direction of the oncoming collision energy
- **IN-CRASH:** Time of impact during the rearwards moving of the occupant torso

Thus, if such an additional, forward thrusting system can achieve the ideal operation point, the so called Ride-Down-Benefit could be improved. In this context, Ride-Down means the speed adaption of the vehicle or the occupant during an impact.

With current conventional restraint systems, only about 55% of the occupant’s forward movement during an impact can be used for protection and guided energy conversion. At the very beginning of an impact, inertia acting on the occupant causes...
the vehicle to decelerate much more quickly than the occupant, which means that at the beginning of an impact, deformation space and energy absorption as well as immediate deceleration is mainly being loaded on the vehicle. The occupant continues to move until the restraint systems become effective. Because it starts later, the “Ride Down” of the occupant is generally faster and harder than the vehicle deceleration. The Ride Down Benefit is the difference between the deceleration of the occupant and the vehicle, the so called speed adaption of both.

**Figure 3: IN CRASH:** car speed and occupant speed during the impact time path

Via occupant movement opposite to the crash direction, the reversible PRE-SAFE® Pulse (PRE-PULSE) effect creates a reduction of the energy difference on the one hand and a theoretical longer lasting impact time frame for the occupant on the other hand. Energy resorption can therefore take place at an earlier stage and there remains more time for longer guided energy absorption with lower restraint forces. The “Ride-Down” for the occupant becomes flatter and occurs closer to the beginning of the impact.

Last, but not least, the time and space benefit for the occupant could also be used for a better positioning (especially in critical OOP situations) and improved adaptivity of the airbag and belt restraint systems.
INVESTIGATION

How can developers achieve this timed impulse on the occupant in a crash situation and which methodology would be appropriate to investigate this? The analysis should contain simulation and testing in the PRE-Crash and the IN-Crash phase with different braking and non-braking situations.

Thus, the methodology used in this analysis arises out of the following conditions:

PRE-Crash
- Availability of mobile test equipment for pulsed belt retraction at the highest level, which is reversible, reproducible and repeatable
- Mobile measurement in a production car environment which can be used as validation data for simulation of the braking and non-braking situations
- Simulation tool for a long-lasting, low-g PRE-Phase up to 1500 ms before impact (t =0)
- Simulation tool that realistically copies the movement of HIII and human test subjects

IN-Crash
- Sled test equipment with braking during the Pre-Crash phase and a conceptual impulse retraction unit
- Simulation tool that allows analysis of the HIII Dummy crash injury values, e.g. used for US-NCAP, EURO-NCAP assessment
- Simulation tool that can run continuously from the PRE-Crash phase (-1500 ms) to the IN-Crash phase (+150 ms) without interruption

For testing, after a range of pretests, it was decided to create a reversible belt retraction unit for a passenger seat which was able to reproducibly pulse at a minimum of 300-400 N in 100 ms. This would apply an impulse to the occupant strong enough to accelerate the occupant's torso opposite the driving direction, independent of whether it was a braking or non-braking situation. The second requirement for the unit was the ability to maintain the force level for about 400-500 ms. The resultant system, including the mobile measuring equipment, was installed
in a production vehicle, and a realistic test situation and passenger positioning was achieved.

For simulation, after discussing the current simulation tools, MADYMO and LSDYNA, the solution was to use a combination of both.

First, the multibody-simulation tool MADYMO, with its long standing and proven HIII Dummy IN-Crash experience, seems to be the best solution. Also the expectation of a lower duration of the overall approximately 1500 ms simulation time was decisive. A review of data for known load cases with the Hybrid Dummy, validation data of original sled tests and the vehicle environment confirmed the decision.

Nevertheless, the HIII Dummy was not the best choice to copy the low-g movement in the Pre-Crash phase. HIII-Dummies are built to reproduce the high-g acceleration IN-Crash phase very well. Only with several adjustments in the MADYMO input deck, was it finally possible to reach an acceptable validation for the PRE-Crash-movement. The mode and the validation will be explained later in this paper.

The final argument for the use of that tool is the current availability of a human model with active human behavior. With that model and its stabilized muscles, the comparison of the test subjects’ PRE-Crash-movement could complement the study later on.

In a final supplementary step, with THUMS, another human body model and the corresponding FE-models, further comparable results in LSDYNA can round up the whole analysis.

In summary, the object of investigation for the Pre-Crash and IN-Crash movement in non-braking and braking situations for 50th percentile occupants contains:

1. HIII Hybrid Male Dummy - testing and simulation (MADYMO – HIII model)
2. Human volunteers - testing and simulation (MADYMO – human active model)
3. THUMS with LSDYNA

This paper includes the description and results of the PRE-Crash testing and the PRE- and IN-Crash simulation of number 1, including the methodology and the explanation of the further proceedings.
TEST CONFIGURATION PRE-CRASH

The tests were conducted in a production car at the front passenger seat, which was adapted to the additional reversible retractor unit. Measuring equipment was installed inside the car to assess all driving conditions, including the braking situation. In the non-braking as well as the braking situations, after a trigger signal, the dummy or test subject receives a belt retraction impulse of about 600 N. The forces of the retraction should not be released until the test situation, e.g. 400-500 ms, is over. Through this activation, the occupant or dummy torso accelerated rearwards, opposite to the driving direction. To support a flexible hip for a more realistic rearward rotation of the HIII Dummy torso, the hip screws were released as far as possible during the tests. The triggered measurements are explained in the following figure, which had to be reproduced exactly in the simulation and validation process.

Figure 4 Test Layout: PRE CRASH Tests

Important for the validation of the PRE-Simulation are the following values:

Acceleration sensor:  \( \mathbf{a}_{\text{head}} \),  
Braking: \( \mathbf{a}_{\text{car}} \) + Triggersignal Brakepedal
Distance measurement: \( S_x \text{ Neck}, \ S_{\text{res seat}^*}, \ S_{\text{Belt reduction}} \) (B-Pillar),

\(^*\) \( s_{\text{res seat}} = s_2 \times 0.286 + s_N \times 0.98 \) calculated with intercept and trigonomtric theorem

Belt Forces: \( F_{\text{Belt Shoulder}}, \ F_{\text{Belt Fixation}} \)

Camera: \( Y\)- Direction

Additionally in the simulation analysis, the measure point \( S_x \text{ Neck} \) (positioned near the chest) was also used for the evaluation of the velocity of the HIII torso movement.

**SIMULATION METHODOLOGY**

The MADYMO Simulation model, created primarily for measuring high-g acceleration in IN-Crash analyses, must be adjusted in several items of the input deck. The stiffness of the unadjusted HIII model, especially in the hips, legs and femur, caused unrealistic movement in the simulation, which was not shown in the PRE-Crash HIII Tests. Also the early longitudinal movement of the whole dummy, standard in high-g load cases, must be changed to an immediate start of hip rotation for the low g-phase. Here again the inflexibility of the HIII simulation model leads to limitations, which should be more comfortable with a human body model design. Adaptions to the seats, frictions and switches made the results acceptable in the end. Modifications, such as a specially-developed 0,3 g sensor, for a retractor acceleration sensor were made to copy seatbelt locking which closely mirrored reality. Lastly, with a second acceleration sensor for the dummy, as well as restraints for the prevention of upward rotation of the leg, the model design was successfully completed. After the final adaption for non-braking and braking pulses and the addition of the points of test measurements, the validation process with the PRE-Crash Test results could begin.

To illustrate the validation methodology, 3 symbols will be used to classify the entire validation process. To better understand, we must differentiate between three activities or time frames:

- **PRE-Crash**
  (-1200 ms to 0 ms)

- **PRE-Phase and Crash-Phase**
  (-1200 ms to +120 ms)

- **IN-Crash**
  (0 ms to + 120 ms)
Each phase or activity was validated separately, and a final validation loop was done of both the PRE- and IN-Crash phase combined: 1\textsuperscript{st} - validation before the impact, 2\textsuperscript{nd} - validation after the impact, 3\textsuperscript{rd} - validation without interruption from 1\textsuperscript{st} to 2\textsuperscript{nd}.

Figure 5 overview “PATCHWORK VALIDATION” - braking/non-braking load case
For the purpose of this analysis, we introduce the term “PATCHWORK VALIDATION” (overview: Figure 5) to describe this validation procedure. The result of this approach was a MADYMO simulation model, which was able to run the simulation overall from -1500 ms, at a maximum to +120 ms without interruption!

**PRE-Crash Validation (non-braking model):**

The test results from the PRE-Phase in the non-braking and braking situation form the basis for the validation for the PRE-Crash phase ($t = -1500$ ms to the impact $t = 0$ ms). With these results, in particular the shoulder belt force and the neck and body movement, the validation loops between the tests and the simulation model begin. Figure 6 shows the validated curves of the HIII PRE-Phase movement. The simulation curves are in-between the corridor of the different test curves (3 tests) and fit to the measured movement. The graphic shows the neck movement rearwards, with a maximum of 32 mm at ca. 600 N shoulder force. It is also shown that retraction starts at -400 ms before impact and is maintained to impact without force reduction. The optimal theoretical retraction trigger point necessary to maximize the energy difference with the PRE-PULSE effect and how to achieve it will be explained later in this paper.

After finishing the validation of the PRE-Phase, the model is used to validate the IN-Crash phase. The original sled test results of the injury criteria in US-NCAP and EURO-NCAP tests and the previously-validated HIII simulation curves, form the basis for the IN-Crash validation.

**IN-Crash Validation (non-braking model):**

With the PRE-Phase model validated, the simulation must run from the impact ($t = 0$) to $t = +120$ ms. The resulting IN-Crash curves were evaluated and the simulation model was changed and adapted, mostly with contact definitions and switch allocations until the curves fit together. The validation values used are the assessment figures and curves of the original tests without the reversible PRE-PULSE activation. Figure 7 shows an extract of the
validation results IN-Crash for US- and EURO-NCAP injury criterias. The following criteria for the HIII Dummy were considered for the assessment and the validation loops:

Forces: \( F_{\text{Belt}}, F_{\text{Femur}} \)

Distance: \( S_{\text{belt}}, S_{\text{Chest}} \)

Acceleration: \( a_{\text{head}}, a_{\text{Chest}}, a_{\text{Pelvis}} \)

Neck: NIJ

Figure 6 PRE-Phase movement – non-braking tests/validation
Comparison of injury criteria between the different results – test curves and simulation (original and PREPULSE model): Head, Chest, Pelvis: $a_x, a_y, a_z, a_{res}$, Femur $F_x, F_z$, Tibia $F_{x,y,z}$, Belt-Forces: $F_{shoulder, pelvis}$, Belt reduction, Chest compression

**Excerpt:**

After completing validation of the discrete models of PRE- and IN-Crash, the next step is to validate the entire loop: during and after the impact ($0 < t < 0$).
**PRE-Phase and Crash-Phase without interruption:**

The completed simulation model runs from $t = -1500$ ms to $t = +120$ ms without interruption. Through final adaptations in the input deck, the validation is completed. To demonstrate this validation result, the curves for the shoulder force and the chest compression are shown nearby (fig. 8). The curves of the three different simulation models indeed overlap and confirm the validity of the simulation model.

After completing the validation, the optimization phase of the investigation for different load cases can occur. The important question for the optimization now is to find the trigger point for the reversible PRE-PULSE retraction. The goal is to find the operation point which maximizes the rearward speed of the occupant torso during the crash.

Before addressing trigger point optimization, the validation of the braking model, completed using the same “Patchwork - Validation” methodology, should be illustrated. The differences in braking versus non-braking situations are the longer lasting PRE-Phase and the different behavior of the occupants torso in this low-g phase.
PRE-Crash Validation (braking model):

During braking the occupant’s torso moves forward relatively gently and experiences a forward displacement of about 1 g, during which PRE-PULSE retraction can occur. Further, activation of the 0.3 g locking of the retractor must be considered. At the beginning of the brake maneuver, the torso rotates around the hip joint and stops the occupant’s movement through belt locking in the retractor. Assuming that the brake maneuver does not stop until the impact occurs, the occupant’s displaced torso experiences a permanent load. This shoulderforce level, depending on the occupant at mostly about 200-300 N, must be reconstructed and validated in the simulation model. This is the reason for the long simulation time, up to 1500 ms before impact (t = 0). In the tests and later in the simulation model, 3 different braking scenarios took place. To make the model robust, the validation had to effectively replicate these different situations.

Figure 9 shows the filtered deceleration of the PRE-Phase braking scenario’s.

Figure 10 illustrates the validated corridor of the known validation values with occupant movement. Due to the ongoing shoulderforce level resulting from belt locking, the occupant torso experiences loading before the PRE-PULSE retraction
can be triggered and the optimal trigger point identified. The forward displacement, limited by the 0.3 g locking retractor and particularly the rearward rotation of the occupant torso, is of course greater than in the non-braking event. In the braking event, neck movement of about 100 mm would have to be pulled back by a triggered reversible PRE-PULSE retraction. The conceptual retraction unit managed this requirement. This can be seen in the neck movement graphic.

Figure 10 PRE-Phase movement – braking tests/validation
In the following section, the movement (of the neck up to 100 mm) in the PRE-Phase brake scenario 01 can be compared in the testing and simulation scenarios.

Figure 11 PRE Phase movement braking – HIII: simulation and testing
Sequence I to IV - PRE Crash: -1300 ms < t < -400 ms
Braking maneuver, appr. 1 g and locking 0.3 g sensor. Forward displacement and shoulder force level of about 200 -300 N, which is ongoing until the impact occurs.

<table>
<thead>
<tr>
<th>Time: 0.5</th>
<th>Time: 1.5</th>
<th>Time: 2.0</th>
<th>Time: 3.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>II</td>
<td>II</td>
<td>IV</td>
</tr>
</tbody>
</table>

Forward displacement through brake pulse (01), appr. 1 g and locking 0.3 g sensor

Sequence V to VIII - PRE-Crash: -400 ms < t < 0 ms
During an ongoing braking maneuver, reversible retraction to move and accelerate the occupant torso opposite to the driving direction until the impact occurs.

<table>
<thead>
<tr>
<th>Time: 3.0</th>
<th>Time: 4.5</th>
<th>Time: 6.0</th>
<th>Time: 8.5</th>
</tr>
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<tbody>
<tr>
<td>V</td>
<td>VI</td>
<td>VII</td>
<td>VIII</td>
</tr>
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</table>

Rearward displacement through reversible PRE-PULSE retraction, ongoing until t =0
The further validation steps for the braking model parallel the non-braking model discussed above and will not be repeated here. Finally, the final validation loop leads to a model which runs from the beginning of the PRE-Phase, \( t = -1500 \) ms to the end of the impact, IN-Crash phase, \( t = +120 \) ms. Additionally evaluations can be succeeded via the previously-discussed human body model in comparison to the test subjects and additionally by the THUMS model.

The results of the validated simulation model IN-CRASH with the US-NCAP load case will now be discussed.

**RESULTS SIMULATION PRE- and IN-Crash with US-NCAP**

To find the operation point where the maximum torso speed rearwards and the synchronous time of impact occurs, the models should run several times with different PRE-PULSE activation points. The pretriggering analysis starts at \(-400\) ms in steps of 20 ms, which means that one run pulsed the occupant at the trigger time \( t = -400 \) ms (PRE-Crash), after that retraction, 400 ms later, the US-NCAP crash pulse (IN-Crash) took place. The next run pretriggered with 380 ms and so on. After evaluating the results, the first localization could be done.

\[ \Rightarrow \textbf{Non-braking PRE-Crash and US-NCAP – IN-Crash:} \]

Figure 12 shows the results of the overall running time for the load cases with the US-NCAP pulse over the pretriggering of \( t = -400 \) ms to \( t = 0 \) ms. Injury criteria (e.g. HIC, chest compression) were used to locate the range of the PRE-PULSE operation point for the non-braking PRE-Phase. The first localization shows a range of 120-160 ms before impact. At this point, the injury assessments were improved up to 10 %, compared to the original test and simulation results, depending on the assessment parameter considered.

A detailed PRE-Phase analysis of the occupant’s velocity and movement of the neck (point \( \mathbf{s}_{\text{Neck}} \)), as well as the acceleration and shoulder forces confirmed the first results. Neck velocity, for instance, is at a maximum for these triggerpoints.
Extract: precrash movement with PREPULSE activation 160, 140, 120 ms:
Variations around the operation point – non-braking model:
Once the optimum trigger range has been determined by means of the simulation results, the effect may be further improved with additional adjustments to the conventional restraint systems. Using the simulation tool, the investigation was enriched with the following analysis:

A) Investigation of pyrotechnical amplification of the reversible PRE-PULSE:
Change of the trigger point of the conventional pyrotechnical belt pretensioner with the goal to amplify the pre-acceleration of the occupant torso with an optimized pyrotechnical IN-Crash activation.

![Graph showing increased neck velocity in the Prephase through earlier Pyrotriggering](image)

**Figure 13** Increased neck velocity in the Prephase through earlier Pyrotriggering

It was determined, with the use of the PRE-PULSE activation time and an earlier pyrotechnical pretensioner activation, that no additional improvement to the existing PRE-PULSE effect can be achieved, despite an increase in the velocity of the occupant shortly before impact. The pyrotechnic retraction is too short to achieve a significant increase in the injury criteria values. → Result: No additional improvement with this type of pyrotechnical pretensioner impulse!

B) Increased PRE-PULSE loading/force:
Through an increase of the reversible PRE-PULSE retraction force, loaded on the occupant, the acceleration and the PRE-PULSE effect could be increased.
As a result, it can be said that the use of a PRE-PULSE with higher forces allows activation nearer in time to the impact (t = 0). The ideal activation range changes
from -140 ms (required 450 N) to -80 ms (required 775 N). The assessment of the head, neck and chest values could likewise be improved. Nevertheless, it will be very difficult to implement such high Pre-retraction power in production vehicles.

Figure 14 Increased PRE- Forces and neck movement in the PRE-Phase (t = -80 ms)

→ Result: theoretical improvement, if a retraction unit is able to build up and maintain this power in a PRE-Crash phase.

⇒ Braking PRE-Crash and US-NCAP - IN-Crash:

Just as for the non-braking analysis, the operation point for the braking situation also had to be determined. The process starts again at the first PRE-PULSE retraction point t = -400 ms. Due to the torso’s forward displacement in braking events, the simulation now must start about 1000 ms before the PRE-PULSE retraction. Figure 15 shows the results of the overall running time for the load cases with the US-NCAP pulse with the pretriggering of t = -400ms in 20 ms-steps to the impact (t =0 ms). Injury criteria (e.g. HIC, chest compression) again were used to locate the range of the PRE-PULSE operation point for the braking PRE-Phase. In the braking case, the range around t = -200 ms for PRE-triggering creates improvement in the injury criteria. In this 200 ms before the impact occurs, a shoulder force up to 400 N accelerates the occupant torso back to the seat rest. By maintaining this force level until impact, forward displacement of about 100 mm will be reduced up to 60 %.
**US NCAP RISK SCORE (FH):** Percentage of changes of the injury criteria in crash through PRE-PULSE activation between -400 ms to 0 ms:

- **Improved risk score up to 20%**
- Declined
- Improved

**Fig. 15 Results injury criteria IN-Crash with reversible PRE-PULSE triggering**

Overall improvement for the most part of the injury criteria reaches 10-20%, vis-à-vis the considered values.
MODIFICATION OF CURRENT CONVENTIONAL RESTRAINTS

The current conventional restraints were not changed during the entire analysis. An optimization of the size and adaptivity for airbag deployment after PRE-PULSE activation may reach further improvement (the distance between the occupant torso and the airbag could remain equal after the PRE-PULSE retraction took place). Airbag vent and load limitation also are means to achieve a relatively soft impact for the occupant, which now can be changed after the rearwards movement of the torso.

Variations around the operation point – braking model:
Similiar to the analysis for the non-braking US-NCAP load cases, variations for additional improvement were done with the simulation tool.

A) Change of conventional restraint systems additional to the PRE-PULSE effect
After PRE-PULSE activation, the occupant’s distance to the instrument panel is larger. Softer and longer energy resorption is possible. Changes in the vent hole and belt load limiter can help soften the impact for the occupant after PRE-PULSE activation. Simulation results show that a larger airbag vent diameter can lead to the described positive effect. The HIC and the neck compression values are reduced up to 10-12 % compared to the existing PRE-PULSE improvement at the derived operation point.

B) Investigation of pyrotechnical amplification of the reversible PRE-PULSE:

Figure 16 Increased neck movement in the PRE-Phase due to earlier Pyrotriggering
Despite the increase in occupant acceleration from 0.5 m/s to 1 m/s, the effect of earlier pyrotechnical pretensioning achieves no significant additional improvement. Similar to the non-braking situation, the effect is to brief. The torso movement rearwards increased as a whole of 15 %, or about 12 mm. Figure 16, above, shows the effect of pyrotechnical pretensioner activation on shoulder forces and the resulting neck movement.

C) Increased PRE-PULSE loading/force:

Figure 17 Increased PRE- Forces and neck movement in the PRE-Phase (t = -80ms)

The results for higher PRE-PULSE forces in the braking scenario are again similar. They create an increased positive PRE-PULSE effect in theory. However, such systems are currently not viable in automotive applications. Important once again is the ability to maintain the retraction force for a longer period. The additional improvement for the injury criteria due to the resulting rearwards movement of the torso are higher than in the non-braking load case. The desired PRE-PULSE trigger point again would then be shortly before the impact. Therefore, given higher PRE-PULSE forces, the operation point comes earlier and reaches a greater theoretical improvement. The additional improvement of the injury criteria between the previous PRE-PULSE activation forces to the higher forces (up to 100 % increased) does not lead to a proven advantage. The effort needed to achieve the final small percentages in additional improvement does not legitimate the great effort required to develop an even more complex retraction unit.
SUMMARY and FORECAST Human Body active model

According to GIDAS, frontal collisions remain the most frequently accident type (51%). Since the primary seatbelt restraint systems were used up to 88% of the time in accidents, the belt could be used for additional reversible PRE-PULSE tensioning in the longer lasting PRE-Phase. With sophisticated adaptations in the MADYMO input deck and a procedure, introduced as a “PATCHWORK VALIDATION”, it is possible to simulate the low-g phase up to 1500 ms before impact and the high-g phase during the impact without interruption. With this approach, it is possible to obtain results for the injury criteria with HIII Hybrid Dummies for load cases, e.g. US-NCAP. According to the results of this investigation, conducted with dummies and volunteers in tests and simulations, the effect of additional reversible PRE-PULSE retraction in the longer PRE-CRASH phase has been confirmed. With the derived optimal theoretical operation point of PRE-PULSE determined, it is possible to reduce the loads on the occupant significantly. The optimal theoretical operation point means that the maximum speed of the occupant torso rearwards must simultaneously coincide with the point of impact \((t = 0)\). In non-braking situations at about \(t = -140\) ms and in braking situations up to \(t = -200\) ms before the impact, a belt tensioning followed by maintenance of the retraction force is able to accelerate the occupant torso rearwards. With torso speed of 0.5 - 1 m/s in the braking situation and a neck movement back to the seat rest of up to 100 mm, it is possible to improve the Ride-Down for the occupant. Via additional PRE-PULSE activation at the optimal theoretical operation point, e.g. in braking situations, injury criteria for the US-NCAP load case can be reduced 10-20 %, depending on the criteria considered. Variations around the operation point for the PRE-PULSE activation have shown that still higher forces intensify the effect and approach the impact. An attempt to amplify the PRE-PULSE effect, through changing the trigger point of the conventional pyrotechnical pretensioner, did not bring any additional benefit. Standard pyrotechnical retraction is too short for decisive amplification of the beneficial effect. Further improvement may be reached through specific adjustments and adaptations to the conventional airbags and belt restraint systems. Due to torso movement rearwards and the larger distance to the instrument panel, longer lasting and guided energy absorption is possible. In a next step, further simulations with human active models in MADYMO and
LSDDYNA with THUMS will allow comparison of the previous results as well as the human test results.

Figure 18 HIII simulation and test, Human model simulation and test

Finally, sled tests with the additional PRE-PULSE activation in the operation points, e.g. in braking situations, can further confirm the best application for future car integration. Given these activities, the next step in the course of an integrated safety approach to an unavoidable accident is set.

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