PRE-SAFE® IMPULSE –
EARLY INTERACTING OCCUPANT RESTRAINT SYSTEM

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ABSTRACT

The safety level in modern vehicles is extremely high. Restraint systems that are currently used, consisting of the classic seat belt and airbag system, feature a mature level of optimization. In the investigation examined here, we shall leave behind the "classic" restraint system approach and discuss the question as to whether and how occupant restraint could be initiated in a hazardous situation even before the seat belt and airbag system responds. Could the valuable milliseconds between the start of the crash and the response of the occupant restraint system be used for dissipating energy?

The purpose of this investigation is to design a system for early occupant impact protection that reduces the forces to which occupants are subjected during a crash. The focus is on frontal collisions. By inputting energy in a targeted manner, occupants are already restrained at the point in time when vehicle deceleration has still had only minor or no effects on the occupants. Methods for inputting energy as well as implementing this are examined. Furthermore, the paper describes the differences in occupant kinematics caused by the system and highlights the potential this technology holds for reducing the forces to which occupants are subjected.

Based on the results of the preliminary investigation, the predevelopment of an approach for implementing an early occupant impact protection system that is fit for production is described. At the end of the paper, we present this system, with all the advantages it holds, as well as an outlook with regard to the potentials still to be exploited.

INTRODUCTION

The safety level in modern vehicles is already extremely high. The restraint systems that are used, consisting of the classic seat belt and airbag system, feature an advanced level of optimization. In the investigation examined here, we shall leave behind the "classic" restraint system approach and discuss the question as to whether and how occupant restraint could be initiated in a hazardous situation even before the seat belt and airbag system responds. Could the valuable milliseconds close to the start of collision (t_0) up to the deceleration of the occupants be used to dissipate energy?

Mercedes-Benz model series already have restraint systems for preventive occupant impact protection. The reversible belt pretensioner is part of the PRE-SAFE® system and has been in use since 2002 (S-class). If a critical situation is detected and the PRE-SAFE® system is triggered, the electromotive pretensioner is able to reduce the slack in seat belts and fix the occupants tighter to the seat. The force of the reversible belt tensioner may not distract the driver from the ongoing tasks, as the accident may still be prevented at the point in time when the belt tensioner is triggered. Further measures, such as seat adjustment, can be carried out for the front and rear seat passengers.

The current power level of the reversible belt pretensioner does not, however, suffice for moving occupants in the event of a crash.

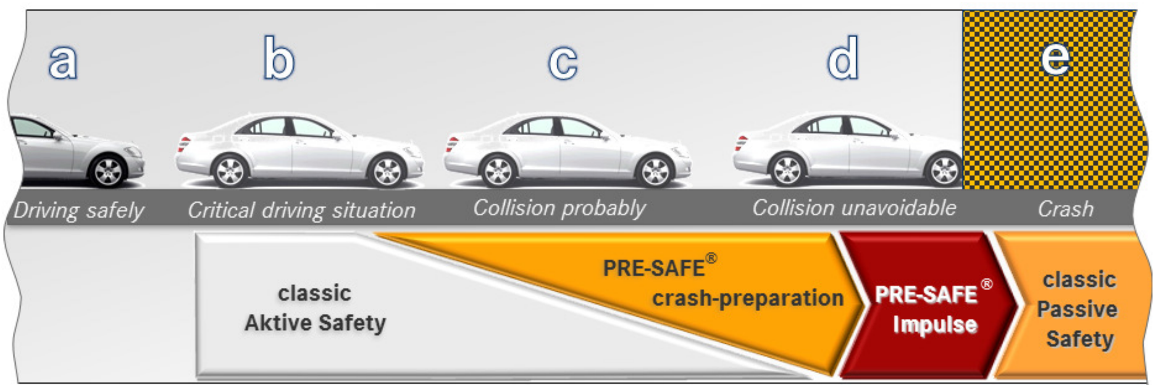

Figure 1: Head-on Collision – Chronological Sequence

HEAD-ON COLLISION – CHRONOLOGICAL SEQUENCE

In the classic description, a crash event starts when the vehicle comes into contact with the collision partner. Depending on the available sensor systems, today's vehicles already know the event history before a collision starts (e.g. driving condition, driver response, vehicle sensing electronics). For further consideration, it is helpful to organize the crash event into chronological phases and to classify the significance of the phases according to the crash event.

Before Start of Collision

A crash event passes through phases a through e as shown in Figure 1. However, the sensors and algorithms available in current vehicles for early crash detection purposes cannot associate these with the crash before the start of the collision in every case. The duration of the phases also differs from crash to crash. It is not currently possible to reliably detect every crash early on. Thus, an early interacting occupant restraint system must currently also function without detecting the crash early on.

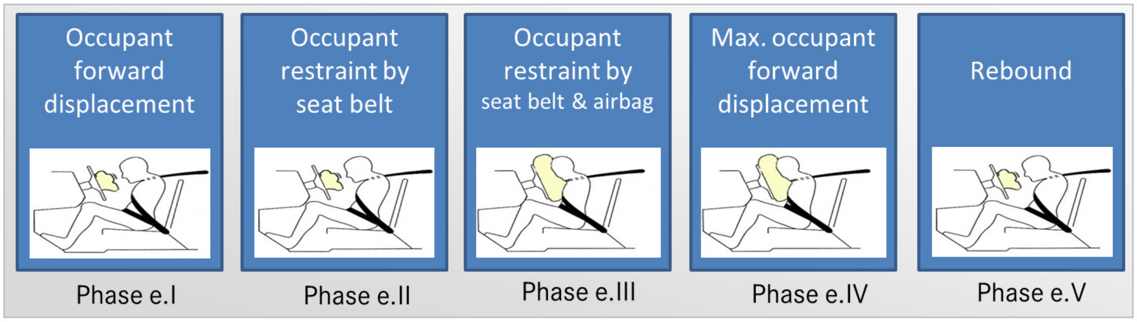

Figure 2: Phase (e) » Implementation of Restraint System over Course of Crash [2]

After Start of Collision

Phase (e) – the crash – starts when the vehicle comes into contact with the collision partner (t_0). At this point in time, the vehicle and occupant have the same speed. The vehicle starts to reduce its speed immediately afterwards. The occupant initially does not experience any deceleration (Figure 2, phase e.I) and is able to move forward. The deceleration of the occupant starts in a delayed manner, and he/she is restrained by the seat belt. Occupant deceleration commences (phase e.II). The occupant is restrained by the seat belt and airbag system over the further course of the crash (phase e.III). By means of airbag damping and belt force limiters, the available displacement path can be used to optimally reduce the kinetic energy of the occupant (phase e.IV).

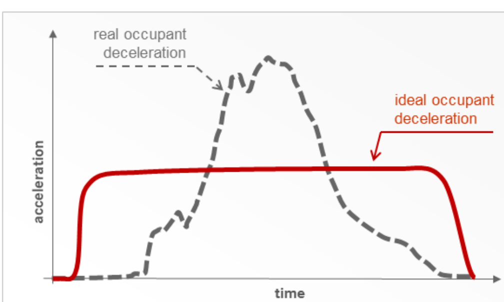

Figure 3: Idealized occupant acceleration curve

Based on the current restraint systems, the following approach applies for increasing the restraint system performance: The optimal restraint system load reduction can be achieved when the restraint system allows the occupant to participate in the vehicle deceleration as early as possible in the crash event and fully utilizes the available forward displacement path (see Figure 3).

BASIC IDEA OF EARLY INTERACTING OCCUPANT RESTRAINT SYSTEMS

The vehicle is in a phase in which it is already decelerating when the occupant restraint process starts. An uncontrolled forward displacement of the occupant is prevented by the seat belt and subsequently by the airbag (see Figure 2, phase e.I).

The chronological sequence is reversed in the theoretical consideration of the basic idea of an early interacting occupant restraint system. The occupant is jolted by the restraint system. The occupant perceives this as an acceleration impulse. This takes place in phase (e.I) of the accident, in which the vehicle deceleration has not yet acted on the occupant. This results in occupant deceleration; the occupant is briefly slower than the vehicle in which he is seated. The occupant is moved opposite the impact direction. The displacement path gained by the relative speed can be released again over the course of the accident via energy dissipation. This system is designated as an early interacting occupant restraint system in the following.

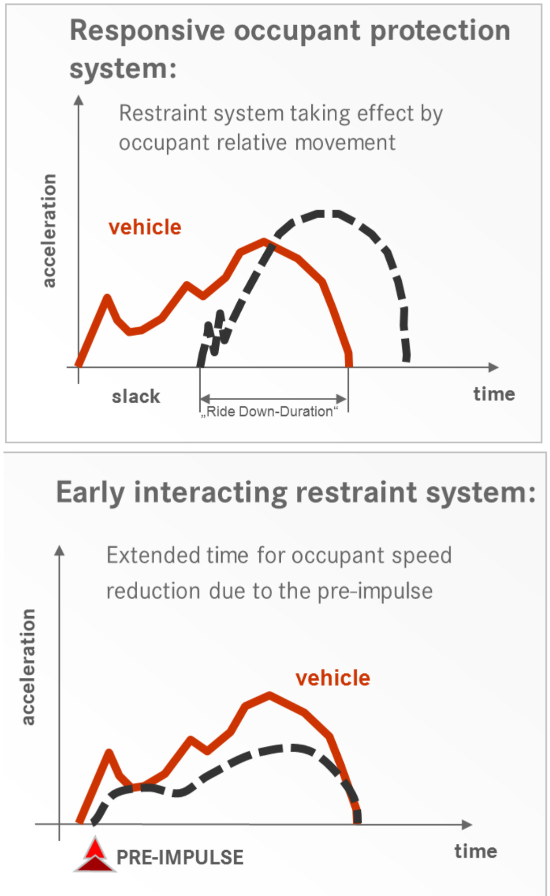

Figure 4:
Comparison of responsive occupant protection system and early interacting occupant restraint system [2]

Such a restraint system influences the ride-down effect and occupant kinematics and can reduce the occupant load values via the longer deceleration period. If you follow this train of thought, the potential arises for occupant kinematics that are fully decoupled from the crash impulse.

A demo test sled with two "occupants" with fastened safety belts was created to illustrate the theoretical approach. In the direct comparison, an "occupant" is pre-accelerated and has a longer displacement path available for deceleration. The difference in acceleration is shown using the mass heads mounted on deformable wires (see Figure 5).

FROM THE CONCEPT TO NEAR-STANDARD SOLUTION

Two central topics are important for the implementation of the basic idea. On the one hand, the following is required: A clear crash event detection, which occurs as early as possible. The sensors and algorithms must be suitable for this application. On the other hand, occupant protection components must be developed for an early interacting occupant restraint system.

Creation of the Infrastructure/Enabler

Even today, modern vehicles are already able to monitor their surroundings, detect possible collision objects and warn the driver and/or initiate partial and full brake applications (PRE-SAFE® BRAKE.) The prediction of the precise collision moment required for the ignition of the pyrotechnical protection systems and the determination of the required collision partner information represent a major challenge. Systems for faster crash severity detection as well as for improving the crash prediction capability are being developed.

An activation of the restraint system close to t_0 and the conventional restraint system response strategy were two approaches investigated during the design of the early interacting occupant restraint system components.

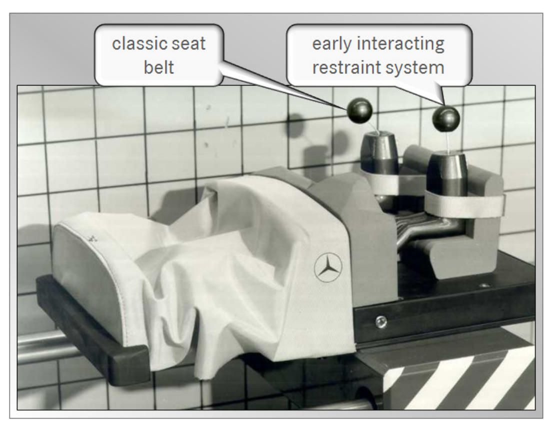

Figure 5: Demo test sled PRE-SAFE® Impulse

Components of an Early Interacting Occupant Restraint System

The components of an early interacting occupant restraint system must be able to appropriately respond to the acceleration impulse in a biomechanically compatible manner for the required duration.

Various approaches for an early interacting occupant restraint were examined during the design phase. This paper is focused on optimizing the existing restraint system components to satisfy the changed system requirements.

The airbag offers good preconditions for a low, local force introduction due to the large contact area. A "softer" airbag coupling is required in order to design an airbag as an early interacting occupant restraint system for head-on collisions. To do this, the precise seat position and occupant size must be known in real time. A very complex airbag size and damping control would be required in order to optimally address all load cases and occupant positions.

The 3-point seat belt, along with belt tensioners, presents itself as a basic system with regard to position and adaptivity. The current belt tensioner technology is able to reduce seat belt slack almost immediately. Due to its characteristics, an impulse via the belt tensioner is, however, only suitable as an early interacting occupant restraint to a limited extent. The force increase can be realized more "gently" in an early interacting occupant restraint system; it must, however, be possible to maintain the force for a longer period. The simultaneous use of all 3-point seat belt anchor points presents itself for a preferably homogeneous force application.

Using force limiter elements on the shoulder and lap belts, the maximum possible forward displacement path is made available while dissipating energy.

A numeric simulation was used to evaluate the concepts and the preliminary system design. Based on a vehicle-related generic surrounding, the occupant load reduction potentials through an early interacting occupant restraint system were determined for differing crash scenarios. A significant load reduction could be achieved with the currently available restraint system activation strategy due to the force application at the shoulder belt in combination with the two anchor points in the pelvic area (belt buckle and belt end fitting). Just a few millimeters of occupant displacement influence are enough to achieve a significant effect.

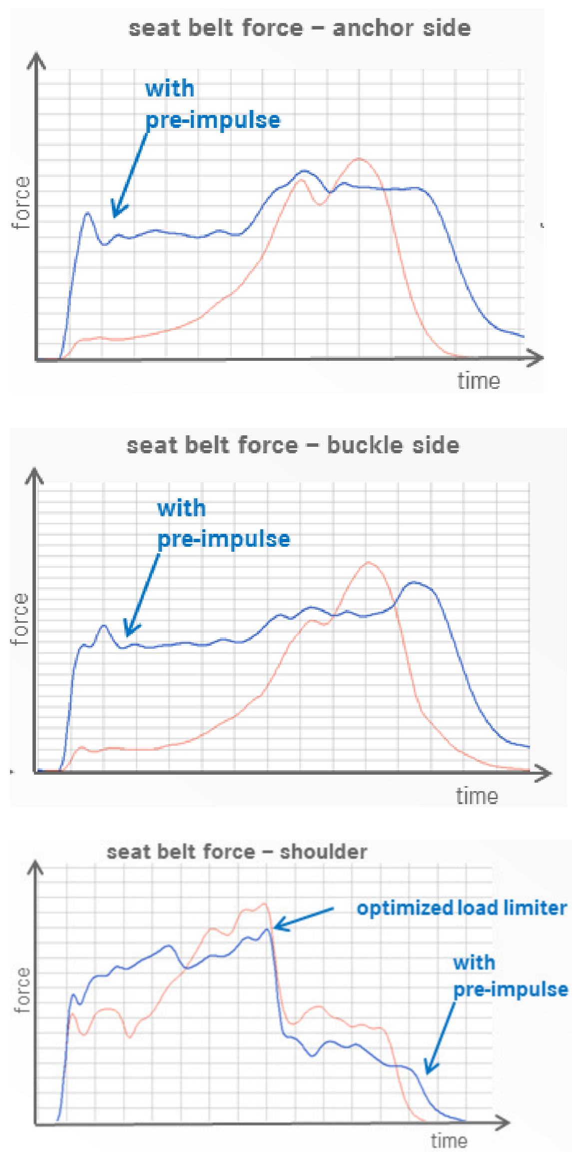

Figure 6: Comparison of belt forces with and without pre-impulse

Over the course of the development process, the preliminary investigation results served to concept components, which had to verify the theoretical potentials from the simulation in system tests of a substitute surrounding and in the basic vehicle. Based on the current pyrotechnical belt pretensioner, an actuator that has verified the theoretical potentials in testing has been developed via a design optimization. This actuator, designed as a pyrotechnical belt buckle- and anchor-pretensioner, is able to build up a force on the lap belt and maintain this over the duration of a head-on collision.

If the reaction force of the occupant during the crash is higher than the pretensioner force, the actuator is locking. In case of decreasing reaction force, the pretensioner will keep the force on the same level. When the defined maximum force level is reached, the load limiter provides forward displacement while dissipating energy.

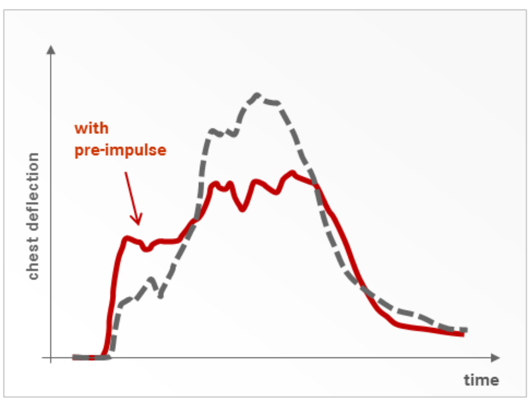

Figure 7: Reducing the chest load

Due to the homogeneous belt force load during the crash, the chest deflection can be reduced (Figure 8). The potential investigations for an early interacting restraint system are shown with conventional actuation strategy.

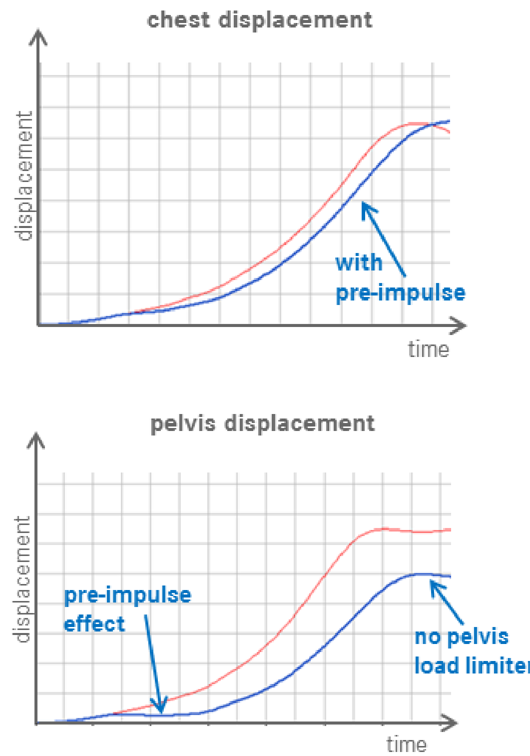

Figure 8: Comparison of chest and pelvis displacement with and without pre-impulse

The impulse of the new designed pretensioners pulls the occupant deeper into the seat. The seat cushion is compressed and the occupant is moved in the opposite direction of the impact. This is reflected in the chest and pelvic area forward displacement, shown in Figure 8.

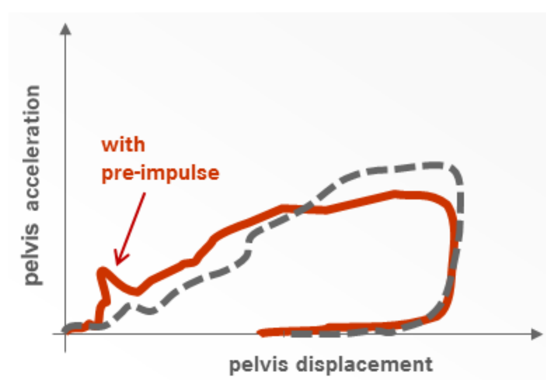

Figure 9: Potential of Early Interacting Occupant Restraint Systems

The reduced displacement of the occupant in the early crash phase (Figure 2, phase I & II) can be used in the phase of the maximum deceleration of the vehicle by a load limiter device that is optimized for an early interacting restraint system. This is illustrated in Figure 9, which shows the pelvic area forward displacement over the acceleration with and without an early interacting occupant restraint system with a conventional activation strategy. The forward displacement path gained in the first milliseconds of the crash can be released via the activation of a force limiter in the pelvic area and thus reduce the maximum loads with approximately the same forward displacement path.

CONCLUSION AND OUTLOOK

The results of the developments tests show that the basic concept of an early interacting occupant restraint system can be implemented in the vehicle. Occupant impact load reductions of over 20% in individual body regions (chest, lower extremities) could be achieved with conventional activation times in standard load cases with early interacting occupant restraint system components in the near-standard vehicle environment.

In the case of an actual accident, the event history before the crash is used in order to activate the system directly after a definite detection of the impact load case. For this purpose, the activation algorithm is sensitized based on the previous PRE-SAFE® activation via the Mercedes-Benz PRE-SENSE system [6].

Higher potentials can theoretically be achieved if the actuators could be activated before t_0. The possible timeframe here is the phase before a collision when the driver cannot prevent the collision either by a steering maneuver or brake application up to the collision with the predetermined collision object (see Figure 1, phase (d)). Development work is still required for the activation of pyrotechnical protective systems based on vehicle environment data. The current hurdle in development is to identify, on the one hand, the largest possible number of impact load cases, and at the same time reduce the number of incorrect system activations to an acceptable amount. A sensor system redundancy is, at least, required to achieve this according to the current as-is configuration. It is, in the meantime, already possible to interpret the vehicle environment data due to a merger of radar- and camera-based systems.

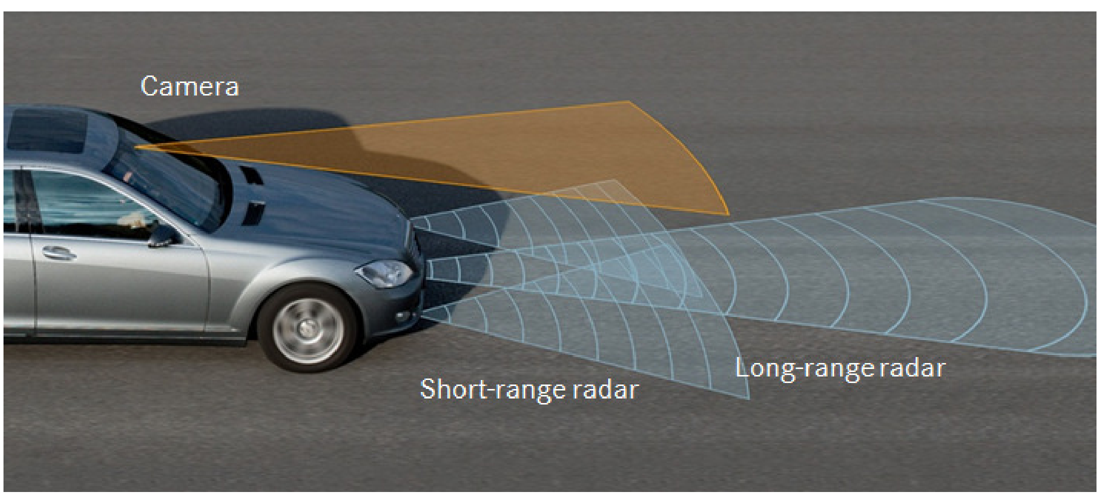

Figure 1: Vehicle environment detection systems [5]

In this connection, the systems "learn" the vehicle environment and situation evaluation based on sample situations and movement profiles.

The algorithms must also be able to clearly forecast the crash severity and collision time for a situation-appropriate activation of the early interacting occupant restraint systems. This is currently also a field of action, as information about the "collision partner" cannot be fully determined by these systems. The vehicle front and rear end profiles can thus be "taught-in" via a camera-based system; the collision energy information (among other things, the collision object weight) can, however, only be roughly estimated. This information gap could be closed by systems focused on data exchange between the vehicles. Vehicle communication shortly before a collision (achieved, for example, by wireless transmission or RFID tags and which provides information about the vehicle type, mass, rigidity, geometry, speed and direction of travel of the collision partner) would be conceivable. These systems are, however, still in an early development stage.

A further challenge is a concept consisting of the restraint system and vehicle components that can make the required displacement paths (against the crash direction) available to the occupants in order to exploit the potential of an early interacting occupant restraint system and a corresponding adaptivity in terms of the involved restraint system component design (such as airbag-size and -damping, belt force limiters) in order to cover the resulting variation options.

REFERENCES

[1] U. Mellinghoff, Prof. Dr. Ing. T. Breitling, Prof. Dr. Ing. R. Schöneburg, H.G. Metzler: „The Mercedes-Benz Experimental Safety Vehicle 2009“, Daimler AG, Paper Number 09-0165, ESF Conference 2009.

[2] F. Kramer: „Passive Sicherheit von Kraftfahrzeugen“, 2. Auflage Mai 2006, Vieweg Verlag, Braunschweig/Wiesbaden.

[3] M. Woldrich: “Movement in the PRE-Crash situation – A simulation research with a reversible PRE-SAFE® Pulse system”, Daimler AG, Abstract for the poster session, Airbag Conference 2010, Karlsruhe.

[4] K.-H. Baumann, Prof. Dr. Ing. R. Schöneburg: “PRE-SAFE Pulse: Die Erweiterung des Insassenschutzes durch Nutzung der Vorunfallphase”, Daimler AG, 12. VDA Technical Congress 2010, Ludwigsburg.

[5] Prof. Dr.-Ing. R. Schöneburg, K.-H. Baumann: “ Auf dem Weg zur virtuellen Knautschzone – Möglichkeiten des präventiven Energieabbaus und Auswirkungen auf Fahrzeug und Insassen in der Vorunfallphase”, Daimler AG, 11. Braunschweiger Symposium AAET, 2010, Braunschweig.

[6] U. Merz, R. Bachmann, R. Bogenrieder, A. Wagner: „PRE-SENSE - Bindeglied zwischen Umfeldsensorik und akutem Insassenschutz“, DaimlerChrysler AG, VDI Tagung Fahrzeugsicherheit, 2007.