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IMPACT ENERGY ABSORBTION BY ACTIVE BRAKING

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Abstract

Due to urbanization and the significantly increasing number of vehicles, urban roads are becoming more congested day by day, with the result that the rear-end collision has become the third most common type of collision. By developing and integrating active and passive safety systems, car manufacturers are working to prevent accidents and reduce the consequences of an accident. The present study examines a braking procedure and its applicability based on the integration of a passive and active safety system and provides development guidelines for the reduction of personal injuries and property damage in the event of a rear-end accident.

Keywords: *impact energy, brake assistant, rear-end collision, absorption.*

1. Introduction

Owing to the significant development of sensors and control systems, car manufacturers have more and more possibilities to enhance the safety system of vehicles. The sensor-based controlling system which is designed to avoid accidents, can be called an active safety system. In a vehicle, passenger body integrity is provided by the passive safety system. All passive safety systems are responsible for the physical safety of motor vehicle occupants in the event of an accident [1] The development of vehicle safety systems has reached astonishing proportions, as vehicle transport, which has met the need for mobility most widely, has been accompanied by the need for safety from an early age. [2] Although the technologies used today are suited to meet the requirements of transport safety, due to the remarkable increase in the number of vehicles on our roads, accidents numbers are increasing in number day-by-day. Therefore the development of the vehicle safety system is still a very important issue in the vehicle industry. Qualitative and quantitative improvement within the vehicle industry always involves the need for safety. In the case of vehicle safety improvement, it is not only the present requirements that must be considered, but also the demands of the future, such as autonomous transport. Safety and autonomous transport are closely related concepts, since by applying them, inattentive and irresponsible human behaviour–based accidents will be mostly avoided, or reduced. [3] Considering the expansion of autonomous transport, although active safety system fields will be developed, the necessity of the passive safety system cannot be ignored. This study introduces an active and passive element combined integrated safety system, and it deals with the development and application possibilities of this system, focusing on rear-end collision problems.

2. The circumstances of the accidents

According to the NHTSA (National Highway Traffic Safety Administration) report, 30% of road accidents are the result of rear-end collisions, which means the third most common collision types are side and frontal accidents.[4] 80% of these accidents are triggered by the following situations: [5]

– collisions in longitudinal traffic;
– collisions in a traffic jam;

– collisions with a vehicle that is stationary at a traffic light;
– collisions with a vehicle that is just about to turn left.

The statistics of the impact overlap is very important information in researching improvement in the effects of rear-end collisions. In respect of impact research, the overlap can be considered as the distance of the longitudinal axis of the vehicles expressed in per cent form. Figure 1 shows an explanation of this overlap.

Knowledge of the statistical occurrence of the overlap value is important during the development, as it is possible to develop the active and passive safety systems optimally. Consideration of the previously listed traffic situations and recent investigations confirms that 90% of the rear-end collision are an overlap type accident, so the distance of the axis is low or almost zero. [5] A The incidence statistics of rear-end collision overlap can be expressed with a Gauss diagram, where the maximum of the chart indicates the minimum overlap values frequency. (Figure 2)

The effect of rear-end collisions is influenced by the difference in the kinematic energy of each participant vehicle, so the mass and velocity of the vehicles must be known. Accordingly, rear accidents can be divided into two groups. The first can be classified as where both participants are in motion. The other typical impact type is where the velocity of the frontal participant is zero, or almost zero.

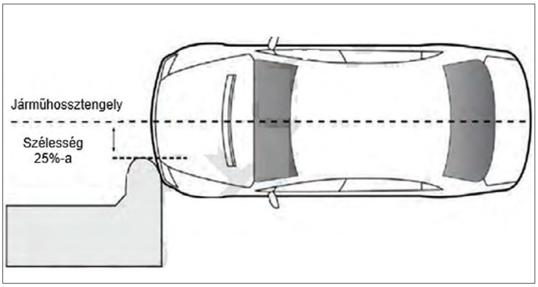

Figure 1. *Explanation of overlap* [6]

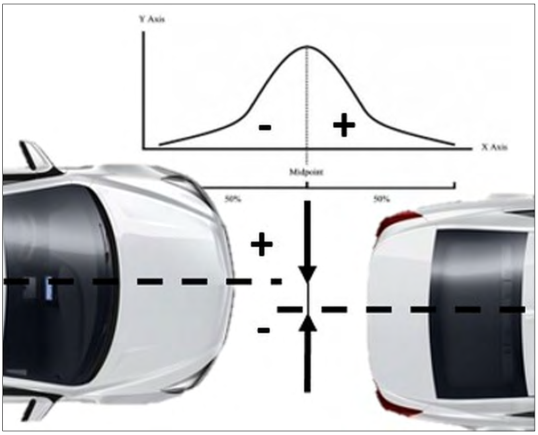

Figure 2. *Frequency of overlap.*

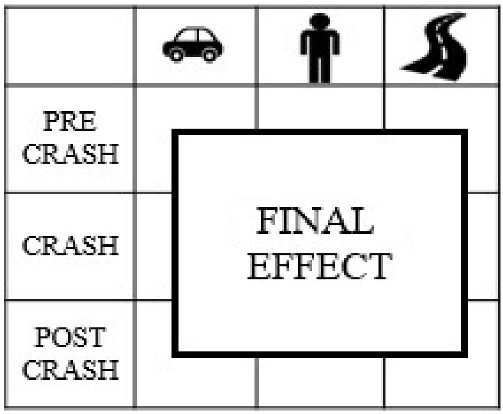

Figure 3. *Haddon-matrix.*

3. Dilemma of the active and passive safety system

The ESP (Electronic Stability Program), the Active Brake Assistant and the ACC (Adaptive Cruise Control) active safety systems are working in synergy cooperation to avoid the rear-end collision. Collision is avoided by autonomous braking of the vehicle coming from behind so that these systems intervene by overriding the driver for safety reasons. Thanks to this reflex-based safety system, a remarkable proportion of the rear accidents can be avoided, or the impact energy can be reduced significantly. In the case of impact, the real consequences of these accidents are not only influenced by the reflex-based system of the rear vehicle but the frontal (frequently innocent) vehicle's safety system also. This context can be expressed by the Haddon matrix. (Figure 3) According to this the final outcome of the accident is not only influenced by the pre- but the actual- and the post-parameters of the car, driver and environment. This means that from the moment of the impact the passive safety system of the participants plays a notable role in the effects of the collision.

This system aims to prepare the innocent frontal vehicle for the accident before the moment of impact, and actuate the necessary safety system for the safety of the passengers. However, unfortunately, the previously listed sensor-based systems integration is not enough to prepare the vehicle itself for the impact. Figure 4 also confirms, very frequently the accidents, where the frontal participant is stationary, so the ESP can not provide information.

The vehicle coming from behind can not be detected by the ACC detector, since that is mounted on the front of the vehicle, and it has sensing angle limitations. The blind spot detector which is mounted behind the rear bummer shell is not suited for reliable detection of the fact and the velocity of the objects arriving from the back. Therefore, the optimization of the safety system to reduce the consequences of a rear-end accident always requires the installation of an additional radar integrated into the rear bumper. The installation position of the radar is helped by the statistics of the overlap, according to which the middle longitudinal axis of the vehicle is the most optimal position for the sensor.

4. Limitation of the radar

The installation position is supported by the overlap statistics, however, it mustn't be neglected that the radar has operational and reliability limitations. The reliability of the radar's detection of different materials and shaped objects must be taken into consideration. The reliability of the system when considering the weather can not be guaranteed however; snow and ice on the bumper can cover the sensing surface of the sensor. An important aspect is also the precise calibration of the radar sensitivity and the range. Radar calibrating for short-range can reduce the number of unnecessary alarms, nevertheless, there would not be enough time to prepare the vehicle for the impact. The over-calibrated radar would give a frequent unnecessary alarm for the driver, and it would be actuated also when it is not justified. Intersections and the junctions have also an important role in terms of the calibration since false detection of the situations gives a needless alarm (Figure 5). The frequent alarm results in inconvenience for the driver, and no sympathy for the system. The previously mentioned shape recognition could also have reliability problems. Namely, sometimes the size of the subject approaching from behind frequently does not corresponding with its real mass. Let's think of a truck, the radar can recognize and handle the size of the truck, however, there is no information about its loaded state. So the radar can not provide exact information about the kinetic energy of the vehicle approaching from behind.

5. Impact without pre-braking

Driving courses often tell drivers to keep an eye on the movement of the vehicle behind them in the event of an unexpected breaking event, so they can be prepared for a collision if necessary. In the case of vehicles with automatic transmission, in almost 100% of cases, (and also in the case of manual transmission vehicles), very often the driver depresses the brake pedal while waiting at an obstacle or a lamp. This pre-braked mode strongly influences the course and the effects of the accident. Figure 6. shows the impact situation, where the service brakes in the front vehicle

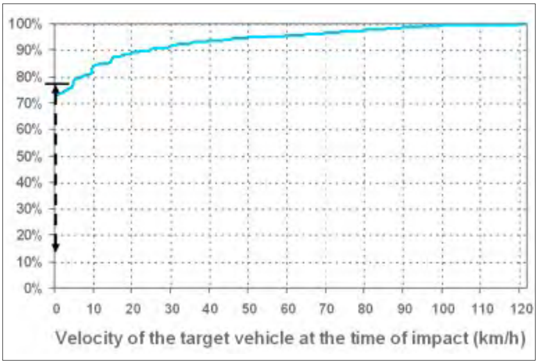

Figure 4. *Statistical data of the frontal vehicle's velocity at the moment of rear impact.* [5]

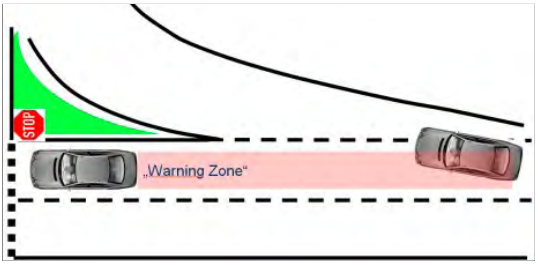

Figure 5. *Over-calibrated radar.* [5]

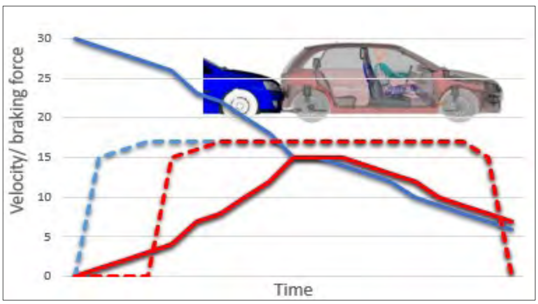

Figure 6. *Collision without pre-braking.*

(coloured red) are not actuated at the moment of impact. The front vehicle at the moment of impact experiences a shock-like, sudden acceleration which results in steep-increased velocity characteristics. The speed of the rear (blue) vehicle sudden reduces to zero, so the deceleration steeply rises and results in a huge impact force on the passengers.

The sudden acceleration of the frontal vehicle can result in whiplash injury in the case of the passengers. If, at the moment of impact, the head is not supported by the head restraint, the head will tilt backwards due to its inertia and, depending on the distance between the head restraints, may suffer even a maximum negative state of so-called hyper-extension. (**Figure 7**)

As **figure 6** also confirms, the participant vehicles decelerate to a common speed point, and then reach zero. This means that passengers in the vehicle in front are burdened with a sudden acceleration at the moment of the collision and then a sudden deceleration from braking due to a defensive or panic reflex. From the state of hyper-extension, the head tilts forward due to the inertia of the head, but depending on the amount of deceleration caused by the sudden stop, even the state of hyperflexion can be reached. This means that the cervical vertebrae and the neck stiffening muscles can suffer from the two anatomical border states in an extremely short time.

6. Reduce whiplash damage with an active headrest

Many recent investigations confirm that the severity of whiplash injury is strongly influenced by the head-headrest distance. According to the proportional nexus, the higher distance results in higher neck and spine injury. **[8–11]**

In accordance with the listed studies in the headrest-supported head case, the severity of the neck injury can be significantly reduced due to the lack of tilting of the head. Based on this, it could be a good solution if the driver adjusts the headrest exactly, as close as possible to his/her head. However, this could cause an uncomfortable driving position and result in further concentration problems. This problem can be reduced by an active headrest. At the moment of rear impact, the headrest moves forward automatically by a spring mechanism and prevents the tilting of the head. (**Figure 8**) With this, the safety and comfort requirements are completed simultaneously.

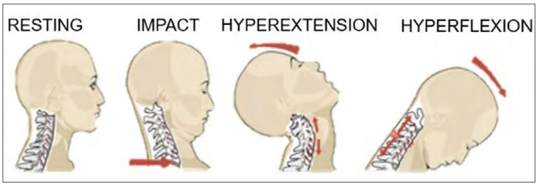

Figure 7. *Movements due to the inertia of the head from the moment of impact.* **[7]**

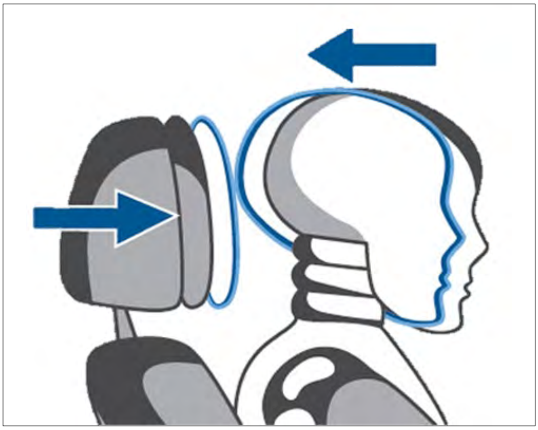

Figure 8. *The function of the active headrest.* **[12]**

7. Impact energy absorption with braking

An object in motion has kinetic energy depending on its mass and speed. In the case of a moving vehicle, the kinetic energy can be converted into thermal energy by braking, so that the speed is reduced to zero. In the event of a collision, this kinetic energy is converted into collision energy. The force generated at the moment of collision works on the displacement projected to deform the crumple zone of the vehicle and is expressed as impact energy. This energy can be absorbed through passive safety elements, thus reducing the amount of impact force on the occupants of the vehicle. During the investigation, we recognized the possibility of applying brake-assistants as an impact energy absorber. It means that we would like to solve passive safety tasks with active safety technologies.

In a panic situation, the drivers actuate the brake pedal fast enough, but not as effectively. This pedal-control crisis is even more complicated if the accident is a rear-end collision, and the passive acceleration is to be be controlled. Furthermore, investigations confirm the fact, the legs of the drivers are displaced from the pedals at the moment of the rear-end impact. (**Figure 9**).

So the driver can not constantly control the braking force to cushion the acceleraion caused by the impact. Furthermore, the lack of a constant brake force could result in a third collision with the previous object. Therefore the in-vehicle applied brake assistant has an important role in terms of active and passive safety also.

7.1. Short review about the brake assistant

The most important parameter for the operation of the brake assist is the operating speed of the brake pedal. The internal structural displacement of the brake assist can be measured with a linear potentiometer. The pedal velocity can be expressed by the time derivation of its displacement. The brake pressure value thus obtained is compared by the electronics of the brake assist with a threshold value currently assigned to the motion parameters of the vehicle (**Figure 10**). The logical operation of the system is accompanied by a self-learning algorithm that determines the deceleration associated with the movement of the brake pedal for each brake application. If the brake assists control electronics detect emergency braking, it immediately activates the brake assist actuator and creates a higher braking force than the current brake pedal depression position. Thus, with the use of the brake assist, deceleration with the same dynamic time as with a strong brake pedal can be achieved, even in the event of an inadequate reaction time or under-braking. With the electrically controlled brake assist the brake effect freely could be modified independently from the driver. Over this control the active brake assist can be utilized in more subsystem operation:

- on an incline, the start can be made free of rolling back,
- suitable for ASR, EDS and ESP control to create pressure when braking,
- allows tracking distance with cruise control or radar sensor control system from the driver implementation of independent deceleration,
- immobilizer in case of theft.

Naturally, these require additional units to supply the system **[13]** We aim to use this braking assistant to overcome this driving behaviour for safety purposes in our development.

7.2. Brake assistant optimization for passive safety

It is very important that in case of a rear accident the vehicle is able to control automatically the brake force during the whole accident event.

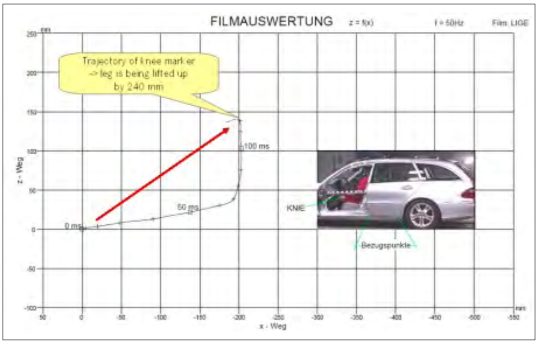

Figure 9. *The displacement of the leg at the moment of rear impact.* **[5]**

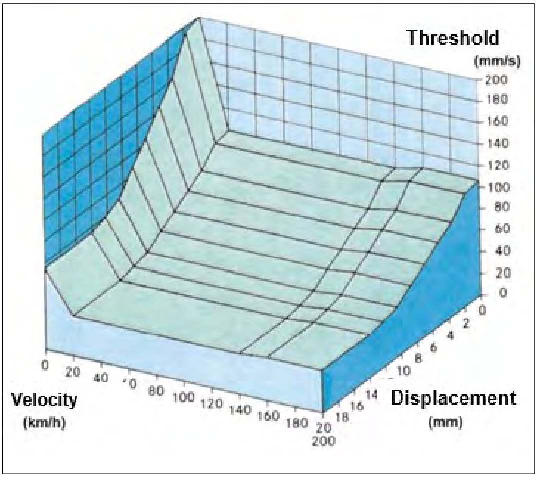

Figure 10. *Operation threshold.* **[13]**

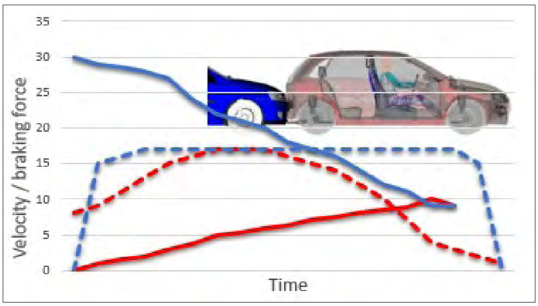

Figure 11. *Moderately pre-braked impact.*

The optimized brake chart for the passive safety is introduced in **Figure 11.** The continuous lines indicate the acceleration and deceleration of the participant vehicle, while the dashed lines present the actuated braking force limit. The colours of the chart lines correspond to the colours of the vehicles shown in the figure.

The basis of the operation is a middle-limited radar, which is mounted behind the rear bumper shell. When the vehicle is stationary at an intersection or a traffic light, the radar examines the danger zone to the rear. When the radar detects an object arriving at high speed from behind, it actuates the safety system and prepares the vehicles for the impact with the help of the control unit. The control unit calculates the necessary pre-braking force for the wheels considering more sensor-supported information. Such data include the presence and distance of an obstacle in front of the vehicle. Since this distance limits the energy absorbed by pre-braked cushioning. In addition, the amount of braking force currently applied by the brake pedal is also important information. The current brake pedal force and the mode of the gearbox are also important information to the proper operation of the safety system. The system could work even more precisely if the rear radar would be able to recognise the size of the arriving vehicle from behind. Since with this information the kinetic energy of the rear vehicle could be calculated before the moment of impact. So from the calculated kinetic energy, the amount of the impact energy can be determined. The brake assistant actuates the proportional braking force with the amount of the kinetic energy according to the control unit calculation. On the wheels, actuated braking force prevents the impact caused by sudden passive acceleration, so the negative, hyper-extension period of the whiplash effect can be reduced. The acceleration of the front vehicle and the deceleration of the rear vehicle can be influenced by the amount of the pre-braking force. So the time of the accident can be expanded, which involves the reduction of the acceleration and deceleration caused by impact force suffered by the passengers. The brake assist must remain operational throughout the impact. The onset of a whiplash injury is positive, so the hyper-extension phase is caused by a sudden stop due to panic braking. In contrast, the safety system based on the brake assist we imagine reduces the increased braking force in the initial phase of the accident, so that the inertia of the head movement can be controlled. The aim is therefore to absorb a significant part of the kinetic energy of the vehicle coming from behind and thus of the impact energy with controlled braking, in addition to the energy absorption caused by the deformation of the creased zones. As shown in **figure 10** at the moment before the collision, the wheels of the vehicle in front are subjected to a moderate braking force by the brake assistant (dashed red line) This moderate braking force allows the vehicle to roll forward due to the collision, but the extent and acceleration of this forward rolling is limited, while at the same time damping the kinetic energy of the rear vehicle. Compared to a fully blocked pre-brake, this solution also reduces the deceleration of the rear vehicle, thereby reducing the risk of personal injury

7.3. Auxiliary safety devices

In addition on the pre-braking, the pretension of the seat belts could be occurred in response to the signal of the seat occupancy sensor. With this method the body displacement due to inertia could be reduced or prevented. With the possibility of using active headrests, the head can be under-set as early as the moment of impact, thus preventing the head from tilting backwards

7.4. Limitations of a brake assist system optimized for passive safety

Of course, there can be limits to the application of impact energy absorption by braking. Such a barrier may be the detection of an obstacle in front of the vehicle or its proximity. After all, the impact energy absorption is based on the controlled displacement of the vehicle, which requires a displacement phase. The ACC radar already mentioned in the previous chapter provides information on the extent of the available displacement distance. The distance it perceives must be taken into account since a nearby obstacle can partially or even completely sabotage the possibility of displacement, while a distant or unobstructed path allows greater displacement. If an obstacle is detected too close, the solution may be to brake the wheels completely and thus avoid further indirect collisions. Another limitation of the impact energy absorption based on the operation of the brake assist may be the movement of the innocent vehicle. After all, in the case of a small speed deviation, the braking of the vehicle in front to absorb the impact energy can have the exact opposite effect and a collision can occur. In this respect, the application of the safety system described by us is limited primarily to the situation of a collision with a stationary vehicle

8. Conclusions

The focus of our research is on enhancing the collision safety of motor vehicles by applying an active and passive safety system simultaneously. Our study focuses on the absorption of impact energy from braking by a brake assist. The most common type of crash is that the damage to the whiplash can be traced back to the extraordinary acceleration and abrupt stop caused by the collision. The severity of the injuries can be reduced if the time of the collision can be increased. Based on the vehicle's radar technology, the wheels are braked with a moderate braking force at the moment before the collision. Due to this, the movement of the vehicle in front is allowed, but it is controlled if we want to absorb some of the impact energy with the help of the braking system and prolong the time course of the collision. Nowadays, car manufacturers apply similar solutions to reduce the effect of the rear accident. They use the active brake-based safety system for rear-end collisions, however, they apply the total blocked wheel method at the moment of the accident. Thanks to this, the displacement and the acceleration of the frontal vehicle are almost zero. However owing to the energy conversation law, the impact energy will be handed over to the rear vehicle. This implies more personal and technical injuries at the rear vehicle. According to this scenario, the impact results in serious personal injury and technical damaged by the deceleration force. With belt tensioners and an active head restraint activated at the same time, the extent of injuries can be further reduced.

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