STUDY ON EFFECTIVENESS OF PRE-CRASH ACTIVE SEATBELT USING REAL TIME CONTROLLED SIMULATION

Jeong Keun, Lee
Kang Wook, Lee
HYUNDAI MOBIS
Korea
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ABSTRACT

In recent years, products that make use of integrated safety that use the environmental data to optimize occupant restraints have been on the market. Pre-safe system in the integrated safety category is an adaptive and smart protection system that utilizes the occupant information and the monitoring information on the accident prediction. These pre-safe systems need the proper algorithm corresponding to the crash scenario for the crash unavoidable state. Due to the crash scenario categories for the real world accidents is quite various, the development of the algorithm and the occupant protection system to reduce the injury is quite complex and costly. For this reason, a development process for pre-safe related integrated safety systems demands new tools based on the biomechanics to help design and assessment.

The virtual development and assessment process with a viewpoint on the efficiency of the restraint development has been developed. The real time controlled restraint system is adapted for support this process. The virtual development process with real time controlled restraint system offers an optimized guide line in terms of injury reduction over various crash scenarios. With this virtual development process, definition of the proper restraint characteristics and the algorithm for the various crash scenarios can be achieved more easily and fast.

Based on the accident data analysis, there are a large number of crashes where the drivers did not put the brake. For this reason, the active safety technologies like brake assist system are being developed. Brake assist system also can make difference in occupant kinematics and injuries. The frontal impact occupant analysis model with pre-crash brake system was developed. Developed model had the braking stage that produces deceleration of 0.8g for 0.9 seconds. The significant change in the dummy posture was observed during pre-crash braking and this change led the increase of occupant injuries. In order to enhance occupant protection during pre-crash braking, pre-crash seat belt system was applied. The pre-crash seat belt system was modeled with MADYMO-SIMULINK Coupling model in order to control the webbing tension force of the pre-crash seat belt. Numerical simulations were performed with pre-crash seat belt of various tension force limits in the driver side NCAP model.

The increase of seat belt webbing tension force indicates that the occupant injury risk could be reduced due to the initial restraint effect. The chest acceleration, chest deflection and neck injury in the event of crash are basically functions of seat belt webbing tension prior to crash. The results showed the tendency of lower injury level with more retraction in certain dynamic conditions. But excessive retraction of seat belt may cause the upward trend in the chest deflection due to the initial deflection of chest generated by retraction.

Conclusion and Relevance to session submitted

The effectiveness of this process is evaluated and the obtained restraint characteristics will be used as a basis to define the appropriate integrated safety features and the performance criteria.

INTRODUCTION

The integrated safety system (the integration of active safety and passive safety systems) offers the benefit of crash avoidance and reduction of crash severity. The industry developed various ASV products for the driver assistance and safety, for example Lane Departure Warning System (LDWS), Full Range Active Cruise Control (ACC), Pre-Crash Brake Assist (PBA). The monitoring system has the important role that estimates the hazardous object kinematic characteristics like speed, direction and collision time and the object distinction. The monitoring system partitions the driving condition into two zones; collision avoidance zone and collision mitigation zone. The collision mitigation zone is composed of the “pre-crash” and “post-contact” states. Pre-crash technologies activate countermeasures prior to impact to assist in reducing the crash severity. The MSB (Motorized Seat Belt) and the active vehicle control actions (braking, steering) can be employed to enhance passive safety restraint deployments. Collision avoidance zone countermeasures can be applied during the time period ($\approx$TCrash -3s < T < $\approx$ TCrash -0.5s) prior to the potential crash event. Pre-crash state countermeasures can be applied in the time period ($\approx$TCrash -0.5s < T < TCrash) before the coming up crash event [1]. The present study focuses on the active countermeasure to reduce the crash severity in the pre-crash state.

The statistical data of accident analysis in figure 1 show that 43% ~55% drivers put the brake to avoid or mitigate the crash [2]. It can be predicted that this behavior can make difference in occupant kinematics and injuries. On the contrary, there are a large number of crashes where the drivers did not put the brake. For this reason, the active safety technologies like brake assist system are being developed. This brake assist system is a pre-crash zone countermeasure that assists in reducing the crash severity [1]. Brake assist system also can make difference in occupant kinematics and injuries.

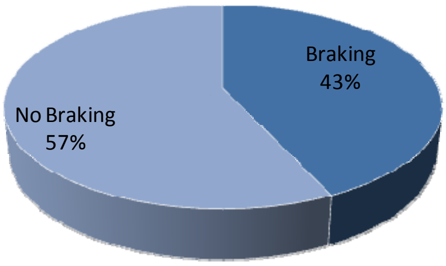

Figure1. Brake Operation in Frontal Crash (from Tobata et al. [2], Fujita et al. [4])

Figure 2 shows the operation procedure of the brake assist system. If the vehicle approaches the obstacle, pre-crash safety system activates the warning system that cautions a driver against collision. The pre-crash safety system predicts a high probability of crash, the pre-crash brake assist system is put on standby for assist driver's braking force. If the driver put the brake pedal, the pre-crash brake assist system increases the braking force in accordance with the driver's braking force. If the driver's braking response is late or the braking force is low and the monitoring system decides that a collision is unavoidable, the pre-crash seat belt system is activated.

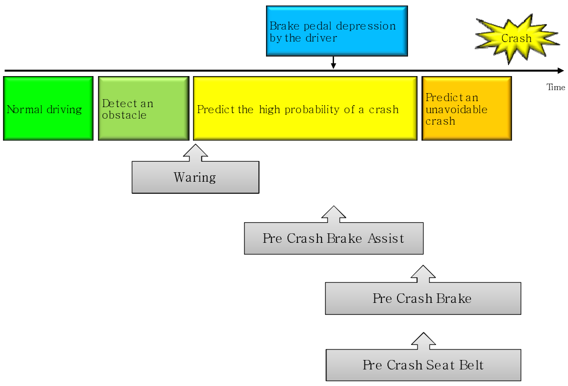

Figure2. Operation Procedure of the brake assist system (from Tsuchida et al. [3])

The pre-crash seat belt system retracts the seatbelt webbing in order to improve the effectiveness of occupant restraint just before the collision. Increase of initial restraint for occupant can help to enhance the occupant protection during the collision. If the driver does not apply the brakes as shown in figure 1, the pre-crash brake applies the brakes automatically for helping to reduce the vehicle speed and the crash severity [3].

Figure 3 shows the vehicle speed reduction due to brake operation prior to impact. The driver applied the brake 0.8seconds prior to the crash. Results of vehicle speed reduction were reported for three different braking forces and brake operation speeds of driver. Results indicate that a speed reduction effect of 10km/h or higher can be achieved when the braking force is 100N from an initial vehicle speed of 50km/h [4]. In other study, the braking system produced decelerations of 0.8g for 0.9 seconds. The 0.8g level was reached in 0.5 seconds and remaining stable at that level for the next 0.4 seconds. This deceleration reduced the vehicle velocity of 19km/h from the initial running speed of 67km/h [5]. Under these braking prior to impact, the occupant in real world or the dummy in the crash test inclined forward due to the braking deceleration. Therefore it is difficult to keep a normal position just before the collision. This change of occupant posture and the forward movement can increase the occupant injuries. In addition, the decrease of distance between occupant and airbag can lead the head or neck injury due to the direct impact of airbag (bag slap).

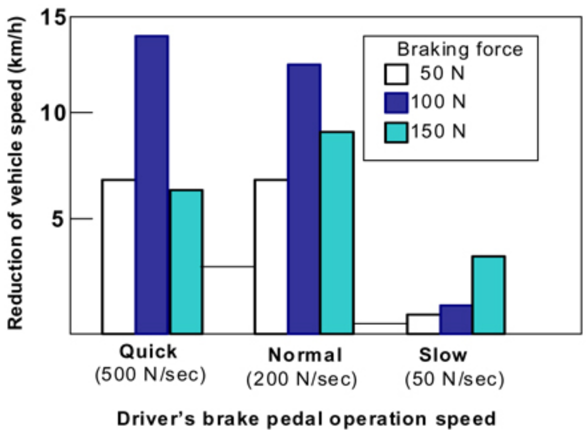

Figure3. Pre-crash braking effect (from Fujita et al. [4])

This paper introduces the numerical simulation model for the braking stage prior to collision and the posture change and forward movement are observed. The real time controlled pre-crash seat belt model is developed to control the webbing retraction with tension force. The configuration, function, and effects of the developed real time controlled pre-crash seat belt model in the occupant analysis model are investigated.

CONFIGURATION OF PRE-CRASH SEAT BELT MODEL

A pre-crash seat belt has an electric motor, reduction gear and clutch mechanism for retracting the seat belt webbing. A conventional seat belt retractor as like pretensioner and force limiter mechanism also equipped in the pre-crash seat belt. The pre-crash seat belt is operated by an electric motor, it can be used repeatedly. The seat belt is retracted by rotation of the shaft in the inlet direction. When an unavoidable crash is determined, a current is supplied to the motor. The motor rotates in the inlet direction and the rotation activates the clutch mechanism and then retracts the seat belt webbing. To release the seat belt webbing, the motor is rotated in reverse direction to disengage the clutch mechanism. Once the clutch mechanism is disengaged, the shaft becomes free and the seat belt returns to its original state. In general, the pre-crash seat belt is activated in the collision unavoidable state that is determined by the monitoring system. The seat belt returns to its original state once the crash is avoided. The pre-crash seat belt is also activated, when an emergency brake is executed by the driver [4].
Because the pre-crash seat belt is operated by an electric motor, there is a relation between the motor torque (seat belt webbing tension force) and the webbing retraction. Figure 4 shows the retraction performance of motor retractor. This linear upward monotonic increase of shoulder belt tension with the increase of retraction length clearly indicates that upper limit of the seat belt tension should be set or adjusted in accordance with the occupants' tolerance limit [2].

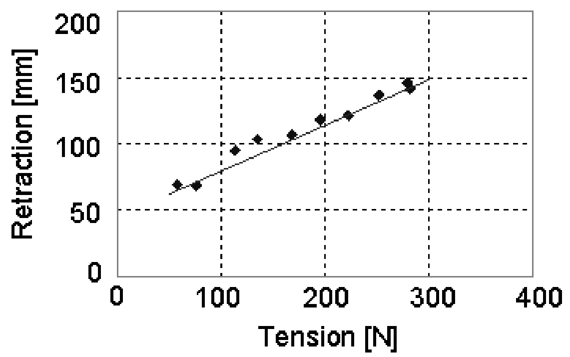

Figure4. Retraction performance of motor retractor (from Tobata et al. [2])

The retraction handling is relatively simple for the pre-crash seat belt model, but it is difficult to reflect the interaction between the tension force and the occupant, and the tension force limit of motorized seat belt. In this study, the real time controlled restraint system (MADYMO-SIMULINK Coupling) is adapted for the tension force control of the pre-crash motorized seat belt in the occupant analysis model. This simulation model can be used for getting insight of the different control aspects and setting the conceptual specifications for the seat belt actuator. Figure 5 shows a developed MADYMO-SIMULINK Coupling model for the pre-crash seat belt. The green boxes are the matlab-simulink, the red boxes are MADYMO and the yellow boxes mean the data exchange between MADYMO and the matlab-simulink. This real time controlled pre-crash seat belt model helps to prevent the unrealistic retraction exceeding the torque capability of the motorized seat belt. This means the webbing retraction length can be controlled based on the webbing tension force of pre-crash belt during braking stage. Numerical simulation was conducted to find an optimal webbing tension force level of pre-crash seat belt.

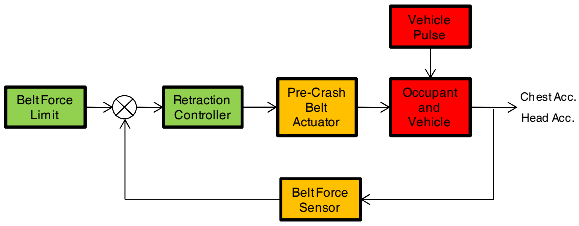

Figure5. Concept of controlled numerical model

NUMERICAL SIMULATION

Numerical simulation was conducted on the assumption that the brake was activated prior to collision. This indicates a situation of applying 0.8g brake during 0.9seconds (The 0.8g level was reached in 0.5 seconds and remaining stable at that level for the next 0.4 seconds) with an initial velocity of 75 km/h before it crashes at 56 km/h full frontal rigid barrier test conditions. Without pre-crash seat belt case, this braking deceleration leads dummy posture changes and body movement as shown in Figure 6. The dummy posture changes during the braking stage are following; the head forward displacement is 105mm, the chest forward displacement is 80mm, the pelvis forward displacement is 35mm. Numerical simulations were performed with pre-crash seat belt of various tension forces in order to investigate the effectiveness of the pre-crash seat belt and the trend of the injuries according to the belt tension force. The simulation model has an air bag in standard AM50 HYBIII-MADYMO dummy model.
Figure 7 shows the retraction performance with respect to the tension force during the pre-defined braking situation. The retraction length is linearly proportional to the shoulder belt tension.

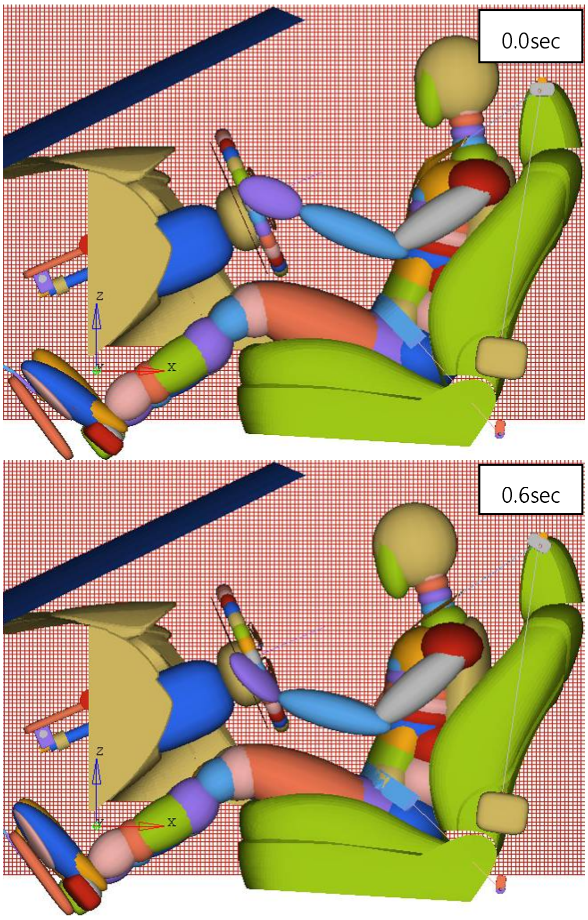

Figure6. Posture change and movement due to braking

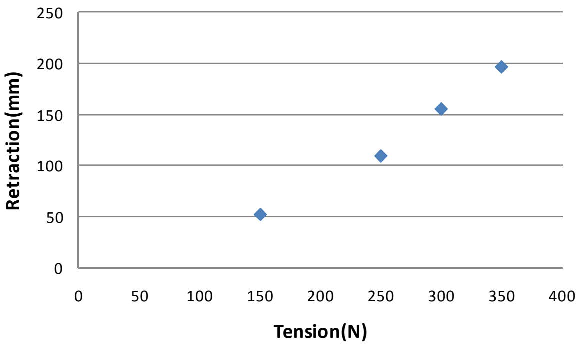

Figure7. Retraction performance in braking stage

Figure 8 shows the improvement of the chest acceleration (CG3ms) and chest deflection. The decrease in CG3ms can be observed except for the about 50mm retraction. The result shows the more belt retraction, the lower the chest acceleration over 50mm retraction. The reduction trend of the chest deflection is observed up to 109mm retraction, the chest deflection is showing an upward trend over the 109mm retraction. The upward trend in the chest deflection may caused by the initial deflection of chest generated by retraction of seat belt. The improvement of the neck injury is observed due to less neck tension force and the flexion moment. The increase of seat belt webbing retraction indicates that the occupant injury risk could be reduced due to the initial restraint effect.

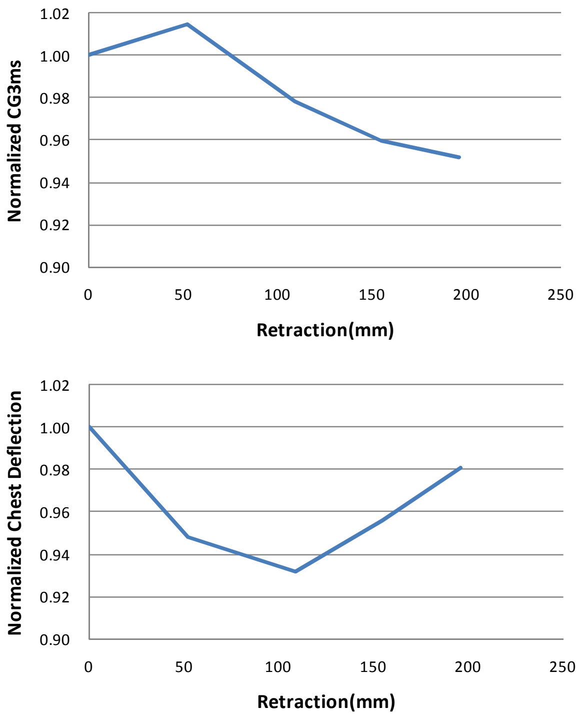

Figure8. Improved chest injuries by seat belt retraction

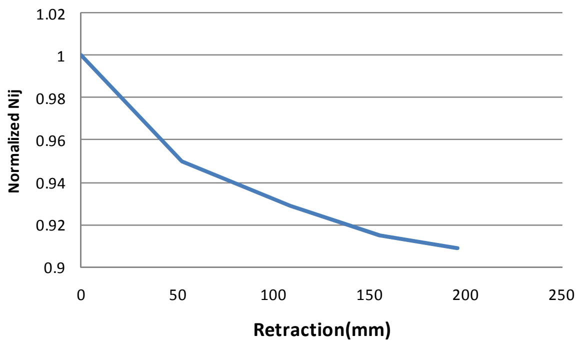

Figure9. Improved neck injury by seat belt retraction

Figure 10 shows the effectiveness of the pre-cash seat belt in the NCAP relative risk score and there is optimal retraction amount in the NCAP relative risk score. Excessive retraction length or tension force of seat belt cause the upward trend in the chest deflection due to the initial deflection of chest generated by retraction, so NCAP relative risk score is increased in spite of reduction of neck injuries. Figure 10 shows the optimal retraction length is 150mm and it corresponds to the 300N in webbing tension force in figure 7. This value can be used as an upper limit for torque control of motorized seat belt.

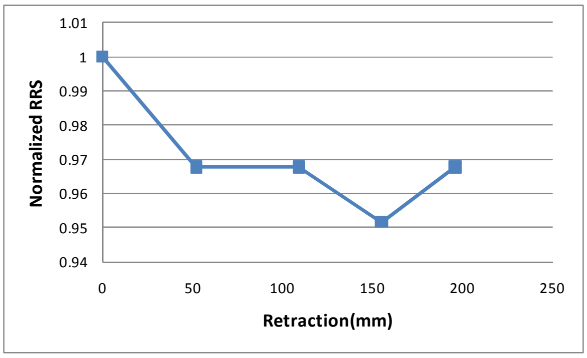

Figure10. Improved Relative Risk Score by seat belt retraction

CONCLUSIONS

Based on the accident data analysis, there are a large number of crashes where the drivers did not put the brake. For this reason, the active safety technologies like brake assist system are being developed. Brake assist system also can make difference in occupant kinematics and injuries. The frontal impact occupant analysis model with pre-crash brake system was developed. Developed model had the braking stage that produces deceleration of 0.8g for 0.9 seconds. The significant change in the dummy posture was observed during pre-crash braking and this change led the increase of occupant injuries. In order to enhance occupant protection during pre-crash braking, pre-crash seat belt system was applied. The pre-crash seat belt system was modeled with MADYMO-SIMULINK Coupling model in order to control the webbing tension force of the pre-crash seat belt, because it is difficult to model the Motorized Seat Belt having torque capacity. Numerical simulations were performed with pre-crash seat belt of various tension force limits in the driver side NCAP model. The increase of seat belt webbing tension force indicates that the occupant injury risk could be reduced due to the initial restraint effect. The chest acceleration (CG3ms), chest deflection and neck injury in the event of crash are basically functions of seat belt webbing tension prior to crash. The results showed the tendency of lower injury level with more retraction in certain dynamic conditions. But excessive retraction of seat belt may cause the upward trend in the chest deflection due to the initial deflection of chest generated by retraction. The optimal webbing tension force based on the webbing retraction length of pre-crash belt was found by using the motorized seat belt model utilizing MADYMO-SIMULINK Coupling.

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