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Innovative active head restraint system in car: Virtual prototyping and safety assessment

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The risk of a fatal or serious injury of an occupant occurring in a side impact is higher than with other types of impact. Whereas the front and rear parts of a vehicle provide deformation zones that absorb part of an impact, the lateral parts of a car have minimal space for the absorption of energy during impact. Traumatic brain injuries incurred in lateral impact are more severe than those resulting from non-lateral impact [1]. Most currently used head restraints are unable to protect the head and cervical spine during oblique and lateral collisions or during vehicle rotation or rollover. Therefore, we describe the development and testing of a new active head restraint system. Its size is comparable to commonly used head restraints. The expanding frame has an arched shape and is equipped with a failsafe that activates the head restraint during a collision. It should absorb the abrupt movement of the occupant by deploying a padded element on each side of the occupant's head, see Fig. 1.

The finite element (FE) model of the head restraint system is developed including all relevant parts and containing more than 24,000 elements in total. The head restraint model is implemented within an FE model of a passenger vehicle. We consider a fully deformable model of a small car, including its interior. Side windows are not considered in these impact scenarios, though the vehicle model is equipped with a side airbag. The model is evaluated with regard to the injury assessment of the driver and is composed of more than 470,000 elements. It is fully validated for the impact scenarios.

The occupant is represented via the Virthuman model. Its basic skeleton is formed from of a "multi-body structure" (MBS). The surface of the model, on the other hand, is divided into a set of segments that are connected to the skeleton via nonlinear springs and dampers, which represent deformations of soft tissues. The model is formed from 263 rigid bodies in total. It is easy to position and enables fast calculations. Its biofidelity is confirmed e.g. in [3]. Virthuman models are scaled to account for diverse anthropometry of occupants from the 1st percentile female up to 99th percentile male. Namely, 18 different anthropometric types are considered. Standard seating position is considered with respect to the EuroNCAP procedure [2]. The head restraint is adjusted for each Virthuman model to obtain the correct position. The occupant is belted with a standard 3-point belt without pre-tensioning. Moreover, four different out-of-positions (OOP) are considered to assess potential risk from the deployment of the paddings itself. It includes leaning of the head towards the window and the passenger as well as rotations of whole body to both left and right sides.

Five collision scenarios are considered based on EuroNCAP protocols. Pole side impact

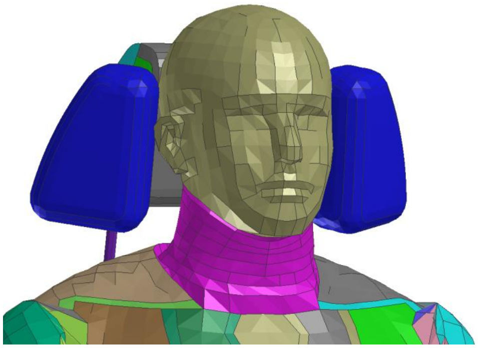

Fig. 1. Numerical model of an occupant (35-year-old male of the 99th percentile) with the restraint system at the active state

is a perpendicular impact of the vehicle to the rigid pole with the diameter of 254 mm at the velocity of 29 km/h. In the oblique pole side impact, the impact angle is 75 degrees and the impact velocity is 32 km/h, see [2]. These impact are considered at both driver and passenger side of the vehicle. Finally, the far-side impact as defined by the EuroNCAP is considered.

Safety assessment of the head restraint system and its virtual prototyping is done in three steps [4]. The results are evaluated with regards to the head and neck injury criteria. Standard injury criteria are considered as defined by the EuroNCAP testing protocols [2]. In the first step, 50th percentile male driver in a standard seating position is considered in four impact scenarios. Including of both inactive and activated state of the head restraint system leads to the total number of 8 simulations. The results suggest increase of occupant safety especially for the pole side impact. Based on the results, first steps of virtual prototyping are made in terms of deployment time as well as increasing the deployment angle.

Second step includes testing with various anthropometric types with improved head restraint system. All 18 representatives are considered in standard seating positions. Consideration of both side and oblique pole impact for all anthropometric types together with the impact at the passenger side for selected representatives leads to the total number of 96 simulations. The results suggest increase of the overall safety for variety of anthropometric types. However, some design changes are favourable in order to increase safety for particular extreme cases (such as 1st percentile female). Namely, additional foam and fabric are proved to be sufficient.

Finally, OOP are tested in all five impact scenarios leading to the total number of 17 simulations. Here, 50th percentile male is considered as an occupant. The model of head restraint is improved as described in two previous steps. Results of these simulations suggest that no injury of the occupant is caused by the deployment of the head restraint system itself.

Safety assessment and the process of virtual prototyping suggest potential benefit of the active head restraint system in terms of reducing occupant injury risk. It may represent a cheaper alternative to airbags. Also, this system might be a solution for passive safety in future mobility (autonomous vehicles) where the application of standard passive safety elements might be problematic.

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