Multi-Body Integrated Vehicle-Occupant Models for Collision Mitigation and Vehicle Safety using Dynamics Control Systems

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ABSTRACT

The aim of this paper is to investigate the effect of vehicle dynamics control systems (VDCS) on both the collision of the vehicle body and the kinematic behaviour of the vehicle’s occupant in case of offset frontal vehicle-to-vehicle collision. A unique 6-Degree-of-Freedom (6-DOF) vehicle dynamics/crash mathematical model and a simplified lumped mass occupant model are developed. The first model is used to define the vehicle body crash parameters and it integrates a vehicle dynamics model with a vehicle front-end structure model. The second model aims to predict the effect of VDCS on the kinematics of the occupant. It is shown from the numerical simulations that the vehicle dynamics/crash response and occupant behaviour can be captured and analysed quickly and accurately. Furthermore, it is shown that the VDCS can affect the crash characteristics positively and the occupant behaviour is improved.

KEYWORDS

Collision Mitigation, Mathematical Modelling, Occupant Kinematics, Vehicle Dynamics and Control, Vehicle Transportation Safety

1. INTRODUCTION

Vehicle dynamics control systems (VDCS) exist on the most modern vehicles and play important roles in vehicle ride, stability, and safety. For example, Anti-lock brake system (ABS) is used to allow the vehicle to follow the desired steering angle while intense braking is applied (Yu et al., 2002; Morteza, et al, 2015). In addition, the ABS helps reducing the stopping distance of a vehicle compared to the conventional braking system. The Active suspension control system (ASC) is used to improve the quality of the vehicle ride and reduce the vertical acceleration (Yue et al., 1988; Alleyne and Hedrick, 1995; Jongsang, et al., 2015). From the view of vehicle transportation safety, nowadays, occupant safety becomes one of the most important research areas and the automotive industry increased their efforts to enhance the safety of vehicles. Seat belts, airbags, and advanced driver assistant systems (ADAS) are used to prevent a vehicle crash or mitigate vehicle collision when a crash occurs.

To evaluate the crashworthiness, real crash tests or vehicle modelling are carried out. Due to the complexity and the high cost of crash tests, vehicle modelling is commonly used in the first stage
of development. Vehicle modelling can be mainly classified as finite element and mathematical modelling. Finite element models of vehicles are increasingly used in preliminary design analysis, component design, and roadside hardware design (Belytschko, 1992). However, finite element modelling is also costly and slow in its simulation analysis. Mathematical modelling produces very quick results and it can be accurately used for unlimited numbers of different types of vehicles in case of vehicle-to-barrier crash tests (Kamal, 1970).

Using mathematical models in crash simulation is useful at the first design concept because rapid analysis is required at this stage. In addition, the well-known advantage of mathematical modelling provides a quick simulation analysis compared with FE models. Vehicle crash structures are designed to be able to absorb the crash energy and control vehicle deformations, therefore simple mathematical models are used to represent the vehicle front structure (Emori, 1968). In this model, the vehicle mass is represented as a lumped mass and the vehicle structure is represented as a spring in a simple model to simulate a frontal and rear-end vehicle collision processes. Also, other analyses and simulations of vehicle-to-barrier impact using a simple mass spring model were established by Kamal (1970) and widely extended by Elmarakbi and Zu (2005, 2007) to include smart-front structures. To achieve enhanced occupant safety, the crash energy management system was explored by Khattab (2010). This study, using a simple lumped-parameter model, discussed the applicability of providing variable energy-absorbing properties as a function of the impact speed.

In terms of the enhancing crash energy absorption and minimizing deformation of the vehicle’s structure, a frontal structure consisting of two special longitudinal members was designed (Witteman and Kriens, 1998; Witteman, 1999). This longitudinal member system was divided to two separate systems: the first, called the crushing part, guarantees the desired stable and efficient energy absorption; the other, called the supporting part, guarantees the desired stiffness in the transverse direction. For high crash energy absorption and weight efficiency, new multi-cell profiles were developed (Kim, 2002). Various design aspects of the new multi-cell members were investigated and the optimization was carried out as an exemplary design guide.

The vehicle body pitch and drop at frontal impact is the main reason for the unbelted driver neck and head injury (Chang et al., 2006). Vehicle pitch and drop are normally experienced at frontal crash tests. They used a finite element (FE) method to investigate the frame deformation at full frontal impact and discussed the cause and countermeasures design for the issue of vehicle body pitch and drop. It found that the bending down of frame rails caused by the geometry offsets of the frame rails in vertical direction during a crash is the key feature of the pitching of the vehicle body.

1.1. Related Work

The most well-known pre-collision method is the advance driver assistant systems (ADAS). The aim of ADAS is to mitigate and avoid vehicle frontal collisions. The main idea of ADAS is to collect data from the road (i.e. traffic lights, other cars distances and velocities, obstacles, etc.) and transfer this information to the driver, warn the driver in danger situations (Fanxing, et al., 2015) and aide the driver actively in imminent collision. There are different actions may be taken when these systems detect that the collision is unavoidable. For example, the brake assistant system (BAS) (Tamura et al., 2001), the collision mitigation brake system (CMBS) (Sugimoto and Sauer, 2005) and electric steering activation system (Jitendra et al., 2015) were used to activate the braking instantly based on the behaviour characteristics of the driver, and relative position from the most dangerous other object for the moment.

The effect of vehicle braking on the crash and the possibility of using vehicle dynamics control systems to reduce the risk of incompatibility and improve the crash performance in frontal vehicle-
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