Proceedings of the 13th International Forum of automotive Traffic Safety,2016,pp376-380
No.ATS.2016.418

Numerical Simulations of a Rear-End Crash Pulse Generator

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Abstract. The rear-end crash pulse generator has been considered to be a key device for performing car impact safety research under laboratory conditions. According to the international regulation, ECE R44, the polyurethane (PU) tube was recommended to produce a standard rear-end pulse. However, little literatures on the impact dynamics of PU tube were known. In this study, a numerical model of rear-end crash pulse generator was established under ANSYS/LS-DYNA. With this finite element model, the following conditions to generate the standard rear-end impact pulses were determined: the initial impact velocity of sled was 30km/h, the resultant mass of sled was 680kg, number of PU-tubes was three, and outer diameter of olive knob was 46mm. Compared with the standard deceleration-time curve of actual rear-end crash, this finite element model of rear-end crash pulse generator was preliminarily validated.

Keywords: Rear-end crash, Pulse generator, Polyurethane tube, Finite element model

1 Introduction

Car rear-end impact is a common traffic accident and has a high occurrence rate, 33.82% (272464/805581) in USA (1988-1996, see the NASS Report), and 34% in Korea (2002). In Japan (2004), the deaths from rear-end crashes accounted for 4% of the total traffic deaths, while injuries were up to 51% of the total traffic injuries. In China (2003), the occurrence rate, mortality rate and injury rate of car rear-end impact were 16.77% (129655/773137), 14.19% (15521/109381) and 13.46% (75655/562074), respectively.

The rear-end crash pulse generator has been considered to be a key device for performing car impact safety research under laboratory conditions. According to the international regulation, ECE R44, the polyurethane (PU) tube was recommended to produce a standard rear-end pulse (ECE R44, 2008). However, little literatures on the impact dynamics of PU tube were known (Jayakumari et al., 2011; Patel et al., 2010).

The purpose of this paper is to develop and validate a finite element model of the PU-tube rear-end crash pulse generator.

2 Materials and Methods

Design requirement. Shown in Figure 1, the rear-end crash pulse generator was designed to generate the needed deceleration pulse for simulating the vehicle or car rear-end crash. This device consisted of: impact shaft, olive knob, absorbing tube, sleeve, and sled. The sled was simplified as a cuboid rigid body, and the impact rod bottom was fixed on the surface of impact rigid barrier.

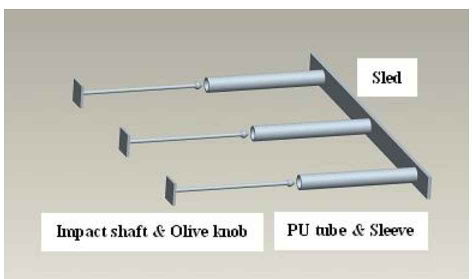

Figure 1 Geometrical model of rear-end crash pulse generator

According to ECE R44, the design requirements of the rear-end crash pulse is that: when the initial impact velocity of sled is 30 km/h, the deceleration-time curve should be in the limit range shown as Figure 2 and Table 1

Design principle. Shown in Figure 1, the polyurethane tube (PU tube) was selected as an absorbing element, and the olive knob was fixed on the impact barrier. During the rear-end crash, PU tubes in the front of sled impact olive knobs at a prescribed initial impact velocity. A finite element analysis was performed to search for the optimal value of outer diameter of olive knob, assuring the corresponding rear-end deceleration-time curve to meet the requirements of ECE R44.

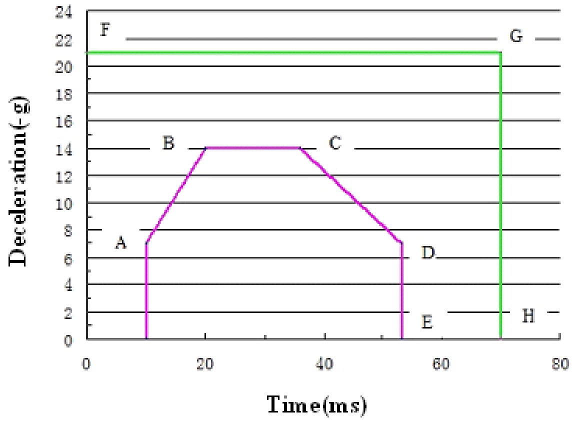

Figure 2 Limit of standard rear-end crash deceleration-time curve
(Upper limit: 'F-G-H'; Lower limit: 'A-B-C-D-E')

Table 1 Limit values of standard rear-end crash deceleration-time curve

	A	B	C	D	E	F	G	H
Time（ms）	10	20	38	52	52	0	70	70
Deceleration（-g）	7	14	14	7	0	21	21	0

3 Finite element modeling.

Geometrical model. The geometrical model of rear-end crash pulse generator shown in Figure 1 was created with a UG 3D software. The geometrical parameters of key components were described below:

① Absorbing tube: Its length and outer diameter were 580mm and 60mm, respectively. Its internal hole was conic and had an inner diameter of 35mm and 27mm separately proximal and distal to the impact end. Two 4mm×500mm symmetrical cracks were chiseled on the surface of absorbing tube (proximal to the impact end). Absorbing tube was made of PU material.

② Impact shaft and olive knob: The outer diameter of olive knob was 40-49mm, and its optimal value was determined by simulation calculation. The length and diameter of impact shaft were 630mm and 28mm, respectively. On the bottom of impact shaft was a 120×120×15mm cuboid, which was fixed on the impact rigid barrier. Olive knob was made of high-quality stainless steel, and other parts were made of C45 steel.

③ Sleeve: Its inner and outer diameters were 64mm and 80mm, respectively. It was fixed on the sled and made of C45 steel.

④ Sled: It was simplified to a cuboid with a surface of 1600mm×20mm. Its mass was 680kg. It was made of C45 steel.

Definition of element type. The solid element 'SOLID164' was used for impact shaft, olive knob, bushing and sled, as well as PU tube. A crushing phenomenon might occur during meshing and thus lead to calculation termination, if shell element was used for PU tube with thicker wall (32mm).

Meshing. As there were two symmetrical cracks on the surface of absorbing tube, 'the free meshing method', other than 'the mapped meshing method', was adopted for the geometrical model of rear-end crash pulse generator (Figure 3).

Definition of interface surface. There exist three pairs of interface: the "olive head-absorbing tube inner wall", "absorbing tube outer wall-sleeve inner wall" and "absorbing tube bottom-sleeve bottom". Their definitions are as follows:

① Interface type: All interfaces were defined as the surface-surface interface;

② Interface solid: The inner wall of absorbing tube was defined as a 'Contact' surface, while the surface of olive head as a 'Target' surface.

③ Friction coefficient: The dynamic friction coefficient is 0.3.

④ Interface time: The 'Birth' time is 0 ms, while the 'Death' time is 120 ms.

Restrict and loading. The impact shaft-olive knob complex and sleeve were defined as "the complete restrict" since the olive knob-absorbing tube impact could be allowed to occur only along the X-direction and both the rotation and displacement should be limited. The mass and initial impact velocity of the cuboid rigid body (Figure 1) replace that of the rear-end crash sled.

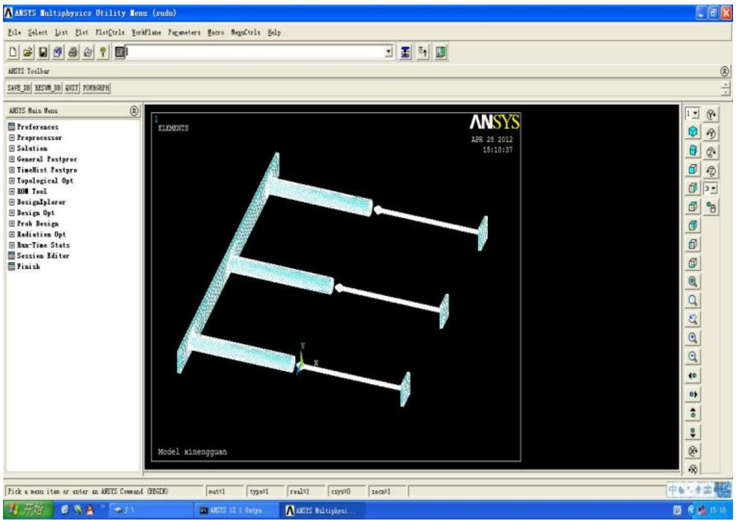

Figure 3 Finite element meshing of rear-end crash pulse generator

Material property. All the olive knob, impact shaft, sleeve and sled are made of C45 steel, modeled as the linear material (Table 2), while the absorbing tube is made of polyurethane, modeled as the elastic plastic material (Table 3).

Table 2 Material property of C45 steel

Density (kg/m3)	Elastic modulus (GPa)	Poisson ratio	Yield stress (MPa)	Tensile stress (MPa)	Friction coefficient
7850	210	0.3	235	335	0.3

Table 3 Material property of polyurethane

Density (kg/m3)	Elastic modulus (GPa)	Poisson ratio	Yield stress (MPa)	Tensile stress (MPa)	Friction coefficient
0.0368	44	0.3	0.323	0.414	0.3

Numerical solution. Numerical solution aimed to continuously modify the outer diameter of olive knob until the optimal value was figured out and the deceleration-time curve meeting the requirements of ECE R44 was established. Under LS-DNYA, numerical solution was composed of the following procedures: Firstly, the 3D geometrical model in a format of ‘iges’ was imported into ANSYS and then PREP, the pre-processor of ANSYS, created an executable “K file”; Secondly, LS-DYNA solver created a ‘d3plot’file; Finally, LS-PREPOST displayed and analyzed the computation results.

Model validation. The deceleration-time curve of actual rear-end crash under the similar test conditions to “Section Generation conditions of standard rear-end crash pulse” was applied to validate the above finite element model (Lin et al., 2009).

4 Results

Simulation results of standard rear-end crash pulse. The deceleration-time curve (Figure 4) and velocity-time curve (Figure 5) met the requirement of ECE R44, which are numerically simulated as a standard rear-end crash pulse.

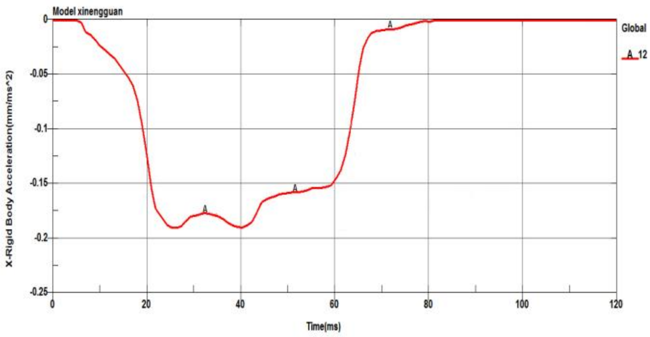

Figure 4 Numerical simulation of deceleration-time curve for standard rear-end crash

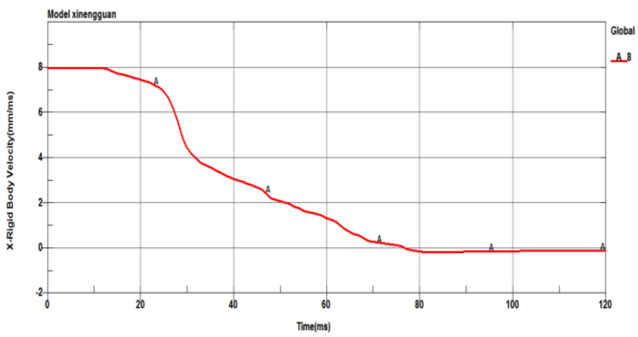

Figure 5 Numerical simulation of velocity-time curve for standard rear-end crash

Generation conditions of standard rear-end crash pulse. The following conditions to generate the standard rear-end impact pulses were determined: the initial impact velocity of sled was 30km/h, the resultant mass of sled was 680kg, number of PU-tubes was three, and outer diameter of olive knob was 46mm.

Validation results. Figure 6 showed the deceleration-time curve of actual rear-end crash under the test conditions similar to “Section Generation conditions of standard rear-end crash pulse”(Lin et al., 2009). The pulse curves shown in Figure 6 and Figure 4 were comparable, indicating the finite element model of rear-end crash pulse generator presented in this study is reasonable.

5 Discussions and conclusions

In this study, the rear-end crash pulse generator was designed to generate the needed deceleration pulse for simulating the car rear-end crash. This device consisted of: impact shaft, olive knob, absorbing tube, sleeve, and sled. Correspondingly, a finite element model of rear-end crash pulse generator was established under ANSYS/LS-DYNA. Compared with the standard deceleration-time curve of actual rear-end crash, its reasonability was preliminarily validated.

With this finite element model, the following conditions to generate the standard rear-end impact pulses were determined: the initial impact velocity of sled was 30km/h, the resultant mass of sled was 680kg, number of PU-tubes was three, and outer diameter of olive knob was 46mm.

During the finite element modeling, the rear-end crash pulse generator was simplified to be an impact between PU tube and olive knob, and sled was simplified to a cuboid. Our consideration did not include the effects of the posture and inertial moment of experimental objects (e.g., human surrogate, experimental animal, etc.) on the rear-end impact pulse. This will be taken into account in the subsequent study.

6 Acknowledgements

The work reported in this paper was supported in part by the National Natural Science Foundation of China (NSFC) (No. 30928005), the Chongqing Natural Science Foundation of China (No. CSTC2009BB5013) and the Project Sponsored by the Scientific Research Foundation for the Returned Overseas Chinese Scholars of China State Education Ministry.

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