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Simulation Study on the Thin-walled Tube Structure of a Vehicle Simulator Crash Testing Equipment

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***Abstract*—**A kind of crash energy absorption structure adopted by vehicle simulator crash testing equipment based on mechanical energy storage was studied. Dynamic explicit finite element simulation was achieved for thin-walled tube structure under different conditions of section shape, thickness and inducement groove style. Crash energy absorption property of the structure was obtained. After optimization, a reasonable structure was given which can meet current vehicle crash regulation. And the optimized structure can be adopted in vehicle simulator, which can increase the practicability of the testing equipment.

***Keywords*—**thin-walled tube structure, crash energy absorption, deceleration, finite element simulation

I. Introduction

VEHICLE passivity safety is particularly important now. It is known as vehicle's specific property of protecting both of crew and pedestrians and preventing them from being damaged once inevitable accident happens. Research methods can be divided into experiment testing and computer simulation method. Therein, vehicle crash testing includes real vehicle and vehicle simulator crash testing. Considering reducing cost, convenience and environment applicability, vehicle simulator is adopted widely. Because crash deceleration of real vehicle is quite complex, it is hard for simulator to obtain accurate result. Therefore, crash energy absorption structure is installed between simulator and rigid wall, making deceleration similar to real vehicle crash. Simulation testing started in 1950s [1]. Ford Motor's real vehicle crash system can make frontal and inclined crash testing. MIRA built the earliest full size vehicle crash equipment in Europe [2].

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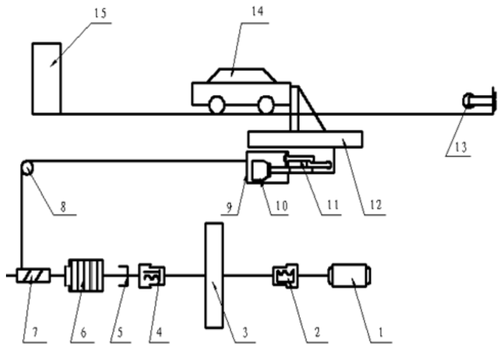
II. Testing Equipment for Vehicle Simulator Crash

Crash regulation requirements are as follows: crash velocity about 55km/h, constant acceleration, horizontal deviation less than 15cm, fixed wall wider than vehicle front, for vehicle simulator, deceleration must be limited in specified range after crash [3].

Structure scheme of vehicle simulator crash testing equipment based on mechanical energy storage is given through deep comparison and analysis of all existing testing equipment, adopting flywheel storage as power supply, steady output traction provided by constant torque mechanism, back-push method adopted for acceleration realization, detachment movement achieved by hook mechanism, this design scheme meets regulation requirements, shown in Fig.1. Flywheel 3 is accelerated by motor 1 through reducer 2, storing kinetic energy. When flywheel 3 speeds high enough, brake 5 is dismissed and controlled by program, at the same time electromagnetic clutch 4 works, then constant torque is transferred to winding drum 7 by constant torque mechanism 6, which ensures steady traction. For vehicle simulator 14, when desired velocity is implemented, the screw mechanism 10 works on release trolley 9. Meanwhile, brake 5 runs, traction ends, hook mechanism 11 starts detachment, then vehicle simulator 14 crashes on fixed wall 15.



1. Motor 2. Reducer 3. Flywheel 4. Electromagnetic clutch 5. Brake 6.Constant torque mechanism 7. Winding drum 8. Pulley 9. Release trolley 10. Screw 11. Hook 12. Pushing trolley 13. Return pulley 14 Vehicle simulator 15. Fixed wall

Fig. 1 Scheme of vehicle simulator crash testing equipment

III. Crash Energy Absorption Structure

Crash energy absorption structure works for simulating real vehicle parameters of velocity, deceleration, as truly as possible. Hydraulic, plastics and mechanical structures are widely used, installing in front of fixed wall, such as steel plate and thin-walled tube structure, sometimes installing in front of vehicle simulator to control deceleration. By plastic deformation, crash energy can be absorbed to realize prescribed deceleration. And deceleration time history of vehicle simulator is quite similar to that of real vehicle [4].

IV. Energy Absorption Property Simulation

When metal thin-walled tube is subjected to axial impact, by virtue of its large displacement buckling, it can absorb energy to ease the strong impact, and because of its low cost and easy manufacturing, thin-walled tube is widely adopted. Thin-walled tube structure has superior energy absorption property[5]. Numerical simulation was implemented to analyze effects of different parameters on deceleration. The crash energy absorption properties of thin-walled tube are relative to its own parameters closely. The followings focus on simulating relating to cross-section shape, thickness and inducement groove.

A. Finite Element Model

Belyschko-Tsay algorithm, bilinear kinematic hardening model and single point integral were adopted for structure shell element. Fixed pin and impact arm were defined as rigid element. Contact between fixed pin and steel plate and between impact arm and steel plate were defined to avoid penetrating each other. Initial velocity was imposed on impact arm. Vehicle mass was distributed evenly on whole impact arm. Dynamic explicit finite element simulation was implemented on LS-DYNA3D platform.

B. Energy Absorption Properties of Thin-walled Tube Structure versus Section Shape

Simulation was carried out for thin-walled tube structure of square, circular, rectangular section respectively, same boundary conditions and material parameters are defined. Deceleration of simulation is shown in Fig.2, the deformation of three different section shape when 30ms is shown in Fig.3.

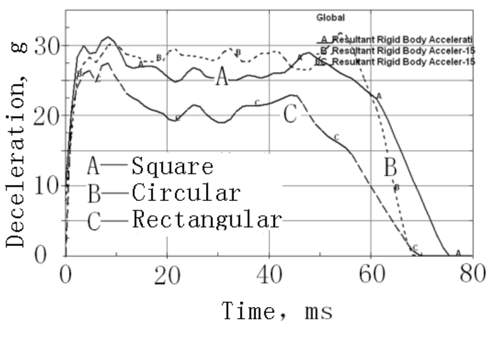
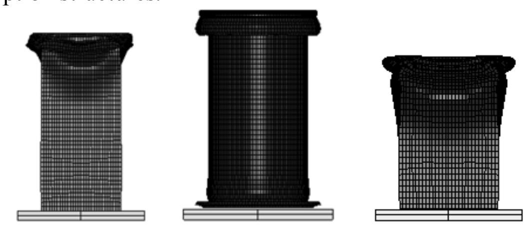


Fig. 2 Deceleration of impact arm vs section shape

Obviously, deceleration difference between square and circular section is not so obvious, deceleration of rectangular section is minimum. The energy absorption time of square section is longer than that of the other two sections. Because there is weak short side in the rectangular section. For that of square and circular section, only when all sides reach to collapse condition, collapse deformation occurs. While for rectangular section, as long as the short side reaches to collapse condition, deformation occurs. So at the same time, the deformation of rectangle section is slightly greater. Considering both deceleration value and energy absorbing time, square section thin-walled tube is more suitable for vehicle crash energy absorption structures.



(a) (b) (c)

Fig. 3 Deformation of different section when 30 *ms*
(a) square (b) circular (c) rectangular

C. Energy Absorption Property of Thin-walled Tube Structure versus Wall Thickness

For square thin-walled steel tubes of wall thickness 1mm, 2mm and 3mm respectively, with same other boundary conditions and materials parameters defined, deceleration of three kinds of impact arm made of thin-walled tubes with different wall thickness is shown in Fig.4. It is shown that deceleration and energy absorption time are all influenced by wall thickness. With the increase of wall thickness, energy absorption time decreases obviously, while deceleration value increases. The thinner wall thickness, the easier and the larger deformation at the same time. This is because the thicker wall thickness, the more difficult and the smaller structure deformation during the same time. Therefore, final determination of wall thickness should be comprehensively considered according to other structure parameters. When energy absorption time of whole structure is short, thin wall thickness should be chosen, otherwise thick wall thickness is chosen.

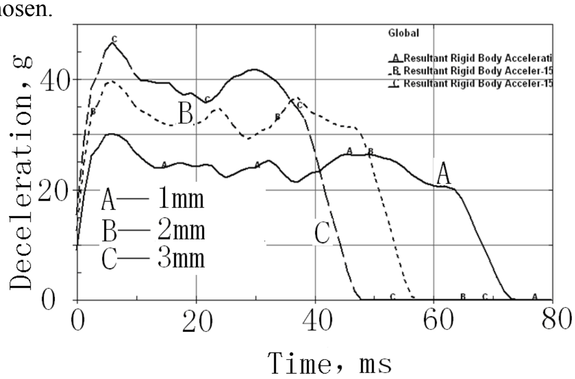
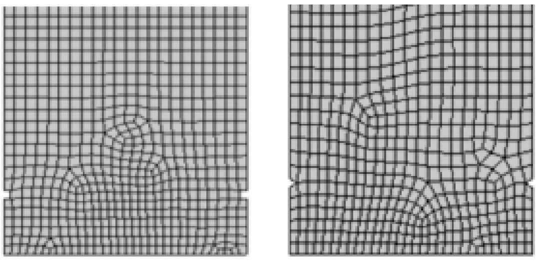


Fig. 4 Deceleration of impact arm vs thickness

D. Energy Absorption Property of Thin-walled Tube Structure versus Inducement Groove

Vehicle crash energy absorption structure is often designed with inducement groove, which plays a part in perfect inducement of energy absorption, to make the structure have a better energy absorption property[6]. In the simulation study, deformation process should be as smooth as possible. Therefore the simulation of thin-walled tube structure with rectangular and triangular inducement groove has been conducted, as shown in Fig.5. In Fig.6, the deceleration of different thin-walled tube structures with none-inducement groove, rectangular inducement groove and triangular inducement groove is given. It is shown that inducement groove has little influences on deceleration value. Inducement groove induces the structure to deform better for absorbing energy, so deceleration of structure with inducement groove is smoother. Although the energy absorption time of rectangular inducement groove is slightly shorter than triangular inducement groove, deceleration is not as smooth as triangular inducement groove. This is because rectangular gap is wider than triangular gap, so crash deformation occurs easier, which reduces the capacity of energy absorption. The triangular inducement groove can be adopted as an vehicle crash energy absorption structure to obtain relatively smoother deceleration.



(a) (b)

Fig. 5 Inducement groove
(a) square section (b) triangular section

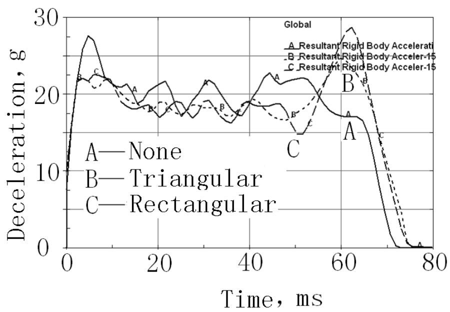


Fig. 6 Deceleration of impact arm vs inducement groove

V. Energy Absorption Property Optimization of Thin-walled Tube

According to the analysis of deceleration under different conditions of section shape, thickness and inducement groove form, it is shown that square section has the best effect of energy absorption and inducement groove induces the structure to deform better for easy energy absorption for obtaining smooth deceleration. Thick wall thickness will lead to difficult deformation, not achieving the desired effect of energy absorption. Thin wall thickness makes deformation too easy to absorb energy. Considering all factors, decision is made as follows: square section, triangular inducement and 3 mm thickness. After establishing the optimization model, the simulation result of deceleration is given in Fig.7. It is shown that the structure meets basic requirements of vehicle simulator crash testing. Only in the beginning, the fluctuation of mutations is great. When plastic deformation occurs, thin-walled tube deforms successively as plastic hinge, and deceleration is relatively smooth. But comparing with composite steel tube structure, the fluctuation of mutations is relatively smooth and the energy absorption time increases slightly. So in accurate vehicle crash testing, thin-walled tube structure can be adopted as crash energy absorption structure.

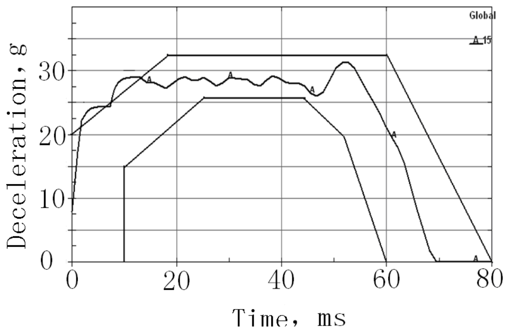


Fig. 7 Deceleration of impact arm after optimization

VI. Conclusion

Finite element simulation of metal thin-walled structure was achieved for crash energy absorption structure adopted by vehicle simulator testing equipment based on mechanical energy storage. The method of dynamic explicit finite element simulation is feasible, which is helpful for the design of crash energy absorption structure in vehicle simulator testing equipment. For metal thin-walled tube structure, square section thin-walled tube is more suitable for crash energy absorption by taking into consideration deceleration value and absorption time. Inducement groove can induce structure to obtain satisfied deformation and energy absorption, making deceleration process more stable. With the increase of wall thickness, energy absorption time obviously decreases, however, deceleration value increases.

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References

[1] O. Dai Xiaojing: Energy absorption method study for a novel vehicle simulator. (Hunan University master dissertation, China 2007).

[2] Marc Fredette, Lema Sikoti Mambu: Accid Anal Prev Vol 40 (2008) , p.1987.
[3] Yang. J. K, H. Land: The 15th International Technical Conference of the Enhanced Safety of Vehicles. 1996.
[4] G. M. Nagel, D.P. Thambiratnam: Int J Mech Sci Vol.46 (2004), p.201.
[5] Gene H. Numerical Modeling of Tube Crash with Experimental Comparison. SAE Passenger Car Meeting and Exposition. 1988: 937-948.
[6] Kim C H. Development of Simplified Models for Design and Optimization Automotive Structures for Crashworthiness. Structural and Multidisciplinary Optimization. 2001: 22