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Study on Multi-objective Optimization of Airbag Landing Attenuation System for Heavy Airdrop

Hong-yan WANG*, Huang-jie HONG, Jian-yang LI, Qiang RUI

Academy of Armored Force Engineering, Beijing 100072, China

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Abstract

A finite element model of vehicle and its airbag landing attenuation system is established and verified experimentally. Two design cases are selected to constrain the airbag design for extreme landing conditions, while the height and width of airbag and the area of vent hole are chosen as design variables. The optimization is forced to compromise the design variables between the conflicting requirements of the two extremes. In order to optimize the parameters of airbag, the multi-dimensional response surfaces based on extended Latin hypercube design and radial basis function are employed instead of the complex finite element model. Pareto optimal solution sets based on response surfaces are then obtained by multi-objective genetic algorithm. The results show the optimization method presented in this paper is a practical tool for the optimization of airbag landing attenuation system for heavy airdrop.

Keywords: Airbag; Multi-objective optimization; Finite element analysis; Response surface

1. Introduction

The airbag landing attenuation system is one of the most important technologies for the landing impact attenuation for heavy airdrop. There are many landing cushion technologies, such as honeycomb and retro, which normally have complicated structures and thus are very expensive. Airbag landing attenuation system is comparatively simple, convenient, efficient and cheap. It can absorb most of landing impact energy to reduce the impact force by exhausting the inflation gas through vents.

Drop tests are credible to research airbag landing attenuation system but too expensive. The safety and time are the other two key problems. Thus it is practically impossible to optimize the parameters of airbag landing attenuation system for heavy airdrop only by experimental methods. Development of simulation technology makes the problems overcome. Several simulation models of airbag were established [1−3]. It's feasible to optimize the parameters of airbag landing attenuation system for heavy airdrop using simulation technology.

In this paper, a finite element model of vehicle with airbag landing attenuation system was established based on control volume model and finite element method. The established model was validated by drop test. Furthermore, the multi-dimensional response surfaces were employed instead of the complex finite element model. Pareto optimal solution sets based on response surfaces were then obtained by multi-objective genetic algorithm.

2. Modeling and verification

2.1. FE Model of airbags

Airbag landing attenuation system consists of eight independent and identical airbags, as shown in Fig. 1. It's connected to the bottom of vehicle. Each airbag has a main

* Corresponding author. Tel.: +86 13811431852.
E-mail address: why_cvt@263.net (H.-Y. WANG).
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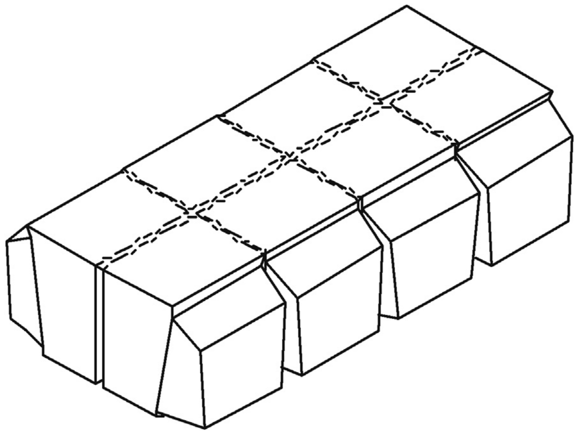

Fig. 1. Airbag landing attenuation system.

chamber and an assistant chamber connected with main chamber through communication holes. The injection holes are located in the bottom of the main chamber in order to implement air inflation when vehicle descends. When the bottoms of airbags are in contact with the ground, the injection holes are closed. The vent holes are located at the sides of airbags for exhaust. These holes are closed initially and are opened when the pressure difference between the inside and outside airbags exceeds venting pressure Fig. 1.

The model of airbag landing attenuation system can be modeled on the basis of the following assumptions [4]:

1) Perfect gas law and adiabatic condition are valid for the gas in airbag during landing process.
2) The aerodynamic resistance is negligible in the process of landing cushion.
3) The air in airbag is exhausted only through the vent holes.
4) The pressure in airbag is uniform.

The equations of the air in airbag are

$$\begin{cases} PV = mRT \\ P = (\gamma - 1)\rho E \\ \frac{\mathrm{d}E}{E} = (1-\gamma)\frac{\mathrm{d}V}{V} \end{cases} \tag{1}$$

where P is the gas pressure in airbag; V is the gas volume; m is the gas mass; T is the gas temperature; R is the gas constant; ρ is the gas density; E is the energy in airbag; and γ is the ratio of specific heat.

Airbag is regarded as expanding control volume [5]. For each time step, the gas pressure in airbag is calculated based on the thermodynamics equations. When the gas pressure acts on the elements of airbags, the shape of airbags can be then obtained. Control volume is given as

$$V = \int\int\int \mathrm{d}x\mathrm{d}y\mathrm{d}z = \oint x n_x \mathrm{d}\Gamma \approx \sum_{i=1}^{N} \overline{x}_i n_{ix} A_i \tag{2}$$

where $\overline{x}_i$ is the mean value of x coordinate values of element I; n_{ix} is the direction cosine between normal of element and x direction; and A_i is the surface area of element i.

The mass flow rate in control volume is given by the mass flow of gas injected into airbag and the mass flow of gas expulsed out of airbag.

$$\dot{m} = \dot{m}_{\mathrm{in}} - \dot{m}_{\mathrm{out}} \tag{3}$$

where $\dot{m}_{\mathrm{in}}$ is the mass flow of gas injected into airbag; and $\dot{m}_{\mathrm{out}}$ is the mass flow of gas expulsed out of airbag.

2.2. Contact model between vehicle, airbag and ground

The transformations of shape and position of airbags are very complex in the process of landing cushion. The airbags may contact with each other because of large compression deformation. Here, penalty method is adopted to describe self-contact of airbags [6]. Every side of airbags is slave surface as well as master surface. For each time step, it's checked whether the slave nodes penetrate the master surfaces first. If a slave node does not penetrate through master surface, no treatment is required. Otherwise, an interface force vector is introduced at the position between slave node and master surface. It can be modeled as a normal spring between the slave node and the master surface. The absolute magnitude of force is proportional to penetration l and master surface stiffness k_i.

$$f_s = -l k_i n_i \tag{4}$$

where f_s is the contact force vector between slave node and master node; and n_i is the normal unit vector in contact point of master surface S_i.

The contact between airbag landing attenuation system and vehicle is described by tied contact model. The bottom of simplified vehicle model is defined as master surface, while the top of airbag landing attenuation system is defined as slave surface. With a tied contact model, it is possible to connect rigidly the slave surface nodes with a master surface. This kinetic constraint is applied on all slave nodes. They remain at the same position on their master surfaces. The acceleration and velocity of each master node are calculated from the force and mass applied by the slave nodes.

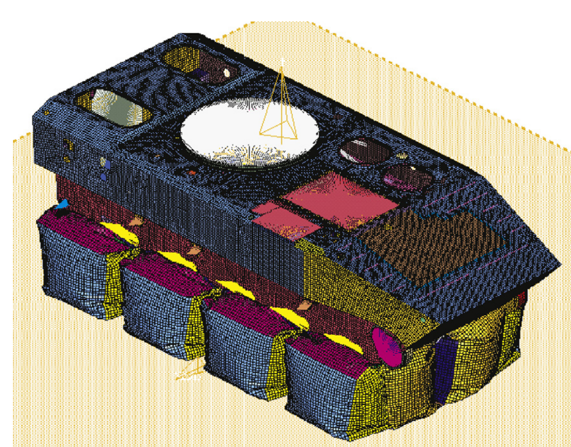

Fig. 2. Finite element model.