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Characteristic of Intelligent Air Bag Venting Structure Actuating by Electrostrictive Stack Actuator*

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Abstract: In this paper the conception of smart materials and structures is firstly combined with research of air bag, and the main theory of self-adapting cushioning of intelligent air bag is expatiated. The intelligent venting structure is the main part affecting the cushioning result. Electrostrictive material was found having big force, high response speed and wide linearity, and it is fit to utilize in intelligent venting structure. The characteristic of the dynamic response and cushioning actuating of an electrostrictive stack actuator is analyzed, and the result of the computer simulation of the fuzzy control to intelligent venting structure is given. It is concluded that intelligent venting structure has good actuating characteristic and can satisfy the need of intelligent air bag.

Key words: intelligent air bag; electrostrictive stack actuator; venting structure

1 Intelligent Air Bag

Intelligent air bag is the result of combining intelligent structure materials and traditional air bag for research[1]. It has the ability of absorbing impact energy when shocking, and the ability of collecting information, dealing and controlling, performing by its sensing cell, controlling cell and actuating cell. It can modify its parameters according to the change of cushioning condition to acquire the best cushioning curve. Then intelligent air bag has self-adapted cushioning ability, which can be used for the impacting protection of passengers in helicopters and astronautic returning cabins, and the unmanned aircraft vehicles' recovery. Its advantage is occupying less weight and volume of the vehicle, while it cushions more efficiently.

Intelligent air bag is the application and advance of the intelligent structure materials technology. Generally traditional air bag is a fabric enclosure with a constant vent opening, whose aera is fixed. Before working, its fixed vent opening is sealed and filled with gas. When impacting it compresses and at a pointed time the bleeding vent opens to release shocking energy and decrease G forces. The cushioning efficience is low due to the unchanged aera of bleeding vent, though the impact acceleration is restricted, see Fig.1(a)[2]. Traditional air bag needs more volume and height to limit the same shocking acceleration while intelligent air bag does not. Intelligent air bag can adjust its vent aera timely according to the need of compression stroke. Then the air bag performance can be improved because the payload will be decelerated at the allowable deceleration all the time, see Fig.1(b).

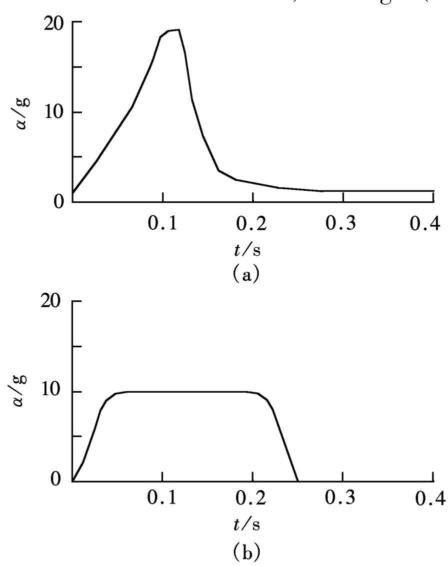

Fig.1 Cushioning characteristic curves of traditional and intelligent air bag. (a) Traditional air bag; (b) Intelligent air bag

When an air bag is working, the relationship among acceleration of payload, gas pressure in bag and bleeding vent aera can be expressed as[2]

$$\rho_v A_v q C_D = -\frac{d}{dt}(\rho h A) \tag{1}$$

$$M\frac{d^2 h}{dt^2} = (P - P_0)A - Mg \tag{2}$$

where ρ_v, A_v and q represent the gas density in vent,

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vent aera and flow velocity in vent; ρ, P, and P_0 represent the gas density in bag, gas pressure in bag, and atmospheric pressure; h, A and M represent the air bag height, bottom aera and payload mass.

It is shown that $A_v(t)q(t)$ must be changed at a special rule to maintain the impact G forces(or bag pressure). For it is difficult to control the vent bleeding velocity $q(t)$, the vent aera $A_v(t)$ can only be controlled to satisfy the need of active impact control.

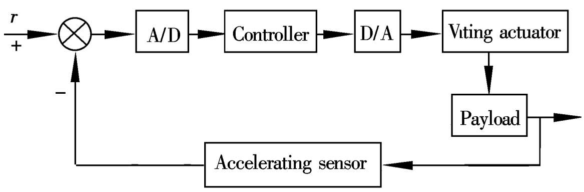


Fig.2 Active impact control graph of intelligent air bag

The whole cushioning course of intelligent air bag occupys about 100 ms, and the stroke of the blocking plate is approximately 30 mm. If the vent aera $A_v(t)$ should change according to the cushioning in a cutty time, the essential requirements to the actuator are: ① Fast response, no lag; ② Wide frequency response and linearity range, and well appropriate driving force.

In this paper, an electrostrictive stack actuator is utilized as the executing cell to design a venting device of the intelligent air bag, and its actuating characteristics are investigated to meet the appeal of the intelligent air bag.

2 Characteristics Analysis of Electrostrictive Stack Actuator

The whole working course of intelligent air bag is as short as 100 ms, and the control system must make correct dealing and decide how actuator should do immediately on the timely G force and pressure information. That is the basic ability of intelligent structures. Thus the response speed of the sensor, controller and actuator is rather important to the whole system, which should be several milliseconds, or the active impact control ability of intelligent air bag will not be acquired.

Now sensor and controller technology, can satisfy the needs of intelligent air bag, but the actuator can not. There are some functional materials developed for various intelligent structures, such as piezoelectric ceramic(PZT), shape memory alloys(SMA), electrostrictive material, electrorheological fluids(ERF) and magnetorheological fluids(MRF). PZT and electrostrictive material are all appropriate due to the properties of intelligent air bag and response speed, and the latter is chosen in this paper.

2.1 Theoretical analysis of force-voltage relationship of electrostrictive stack actuator

$Pb(Mg_{1/3}Nb_{2/3})O_3$ (PMN for short) is a kind of ferroelectric ceramics with high dielectric coefficient, which can become the base of duality system $Pb(Mg_{1/3}Nb_{2/3})O_3$-$PbTiO_3$ (PMN-PT for short). They all have properties of striking electrostrictive effect, big actuating force, high response speed and good stability, and can be used to make for electrostrictive stack actuator with adhesive layers to fit the actuating demand. The structure of stack actuator is shown in Fig.3. Its shape is long cuboid, 125 mm long, and its section is square with the side 9 mm long. It is made of multi-layer stack structure composed of PMN-PT layer and adhesive layer, while electrode layer coats about them.

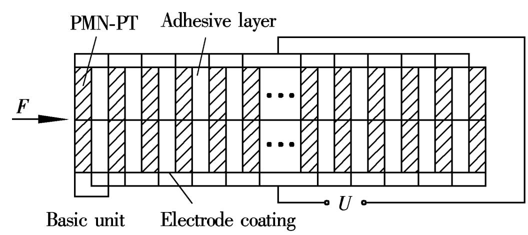


Fig.3 Structure of stack actuator

Without taking the boundary effect and current leak into account, displacement occurs to the stack actuator under electric field in the direction of thickness (polarization). Since the electrode coating is so thin in thickness that it can be neglected in analysis. Every basic unit is composed of two parts: the electrostrictive layer and the adhesive layer. The whole actuator is a serial system made up of many identical basic units.

The electrostrictive material has non-linear mechanical electrical coupling relationship, and there is a linear piezoelectric term and a second order of electrostrictive term in the constitutive equation. Under the combined action of force and electric field, its mechanical and electrical coupling relationship can be expressed as[4]

$$S_3 = s_{3i}^E T_i + (g_{mi} + Q_{mr3} D_r)/D_m \quad (3)$$

where S_3, T_i, D_m and D_r are strain in Z direction, stress, electric potential and electric displacement, respectively; s_{ij}^E, g_{mi} and Q_{mr3} are flexibility coefficient, piezoelectric voltage constant and electrostrictive coefficient of the ferroelectric material.

Neglecting the attenuation effect, the relationship between force and voltage of electrostrictive stack actuator can be expressed as[4]

$$F(U) = g_{33}\varepsilon_{33}\frac{U_3}{ls_{33}^E} + \frac{\varepsilon_{33}^2 Q_{333} A_P U_3^2}{l^2 s_{33}^E} + F_1 \qquad (4)$$

where ε_{33} represents the dielectric coefficient of PMN-PT layer; l is thickness of electrostrictive layer; F_1 is pre-stress; A_P is the cross-sectional area of the actuator; U_3 is the voltage of the actuator.

2.2 Experiment result

In experiments, the stable and dynamical forcevoltage response characteristics of electrostrictive stack actuator are measured, shown in Fig.4. The displacement of actuator is limited to measure and search the relationship between force and voltage only. In Fig.4(a), the mark "+" represents loading course while "*" represents the reverse course. In Fig.4(b), the lower curve is input signal whose frequency is 600 Hz and the voltage value ranges from 50 to 300 V, mainly investigating the force's response delay.

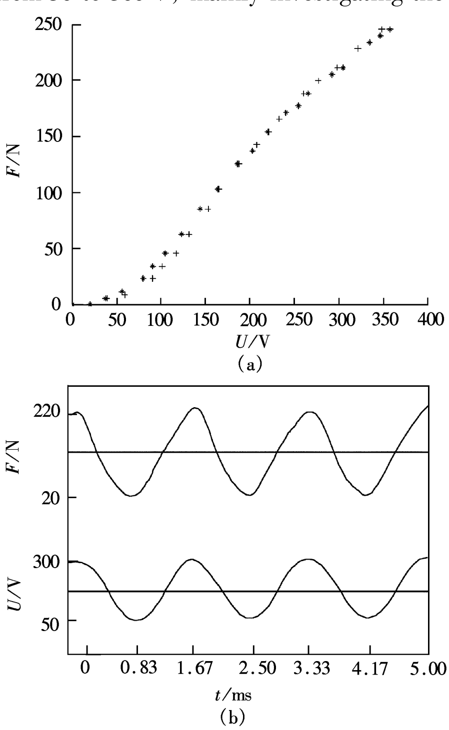


Fig.4 Force-voltage characteristic curves of stack actuator. (a) Static characteristics; (b) Dynamical characteristics

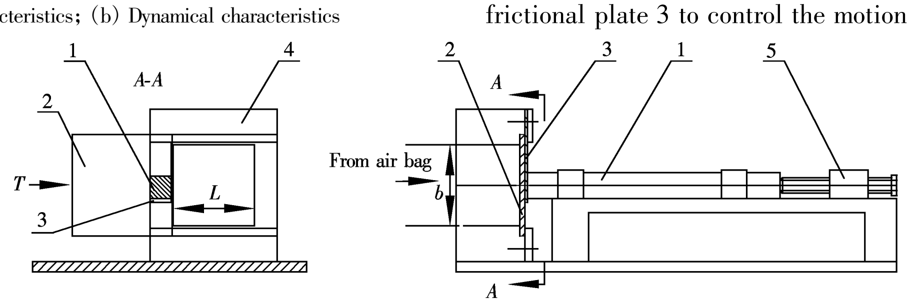
It is found that when stable input voltage value changes from 50 to 300 V, the force's response is approximately linear. When the voltage value is less than 50 V, there is much more non-linearity[5]. Though there is no delay found in dynamical response curve, one cannot say there is no. Perhaps the delay appears just as one period that covers up the fact. This depends on later experiments to verify.

3 Design of Venting Device of Intelligent Air Bag

3.1 Structure and analysis

Fig.5 shows the venting device structure of intelligent air bag. When cushioning, the gas in air bag flows out through a bleeding vent whose size is $L \times b$. One end of the venting device connects with air bag, the other mounts blocking plate 2 which can slide in slide groove 4. One side of the venting device has a frictional plate 3, who has two surfaces: one contacts blocking plates 2 and they can move relatively; the other contacts electrostrictive stack actuator 1 and they have no relative movement. One end of electrostrictive stack actuator 1 contacts frictional plate 3, the other contacts tighten bolt 5. The whole implement keeps motionless except blocking plate 2, which can be moved by outer force T.

The position shown in Fig.5 is the starting position of the venting device of intelligent air bag. The outer force T has been put on blocking plate 2, and the bleeding vent is sealed by an elastic plug that prevents blocking plate 2 from moving. When the air bag compresses, its air pressure increases to a pointed allowable value, then the elastic plug is burst open and gas in bag bleeds out. At the same time, the blocking plate 2 begins to move due to the escape of elastic plug, and the bleeding vent is gradually being closed. Operated by control system, the stack actuator adjusts friction of blocking plate 2 through changing pressure of frictional plate 3 to control the motion of blocking plate



1—Stack actuator; 2—Blocking plate; 3—Frictional plate; 4—Slide groove; 5—Tighten bolt

Fig.5 Structure of intelligent air bag venting device

2. Thus, the motion equation of blocking plate 2 is

$$\frac{d^2 L}{dt^2} = T - \mu F(U) \tag{5}$$

where L is stroke of blocking plate 2; μ is frictional coefficient between frictional plate 3 and blocking plate 2. Stroke L decides bleeding vent aera A_v, expressed as $A_v = Lb$. When cushioning, the relationship of bag pressure P and bleeding vent aera A_v is confirmed by[6]

$$A_v = \frac{W'}{q}\left(\frac{P}{P_0}\right)^{0.717} \tag{6}$$

where W' represents volume decrease rate of air bag.

Then, active impact control model of intelligent air bag can be established from formulae (1), (2), (4), (5) and (6).

$$a = f(U) \tag{7}$$

where a is impact G force, and U is actuating voltage.

3.2 Simulation of control system of venting device

The MATLAB software is used for control system simulation according to active impact control graph in Fig.2, and the result is shown in Fig.6. Because of the

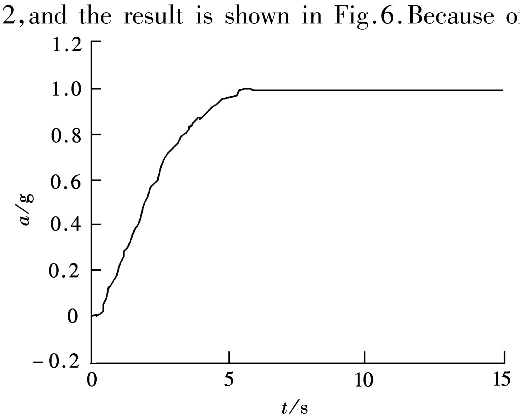


Fig.6 Simulation result

non-linearity of the whole system, the fuzzy control approach is utilized in simulation to decrease calculation and shorten response time. It seems that control system has attained the predicted objective, though response delay still exists. This implies that control system is not satisfied enough, and the fuzzy controller should be improved in control tactics.

4 Conclusions

1) It is realizable to use stack actuator as the venting device cell of intelligent air bag. The stack actuator have properties of wide linearity, big actuating force and low response delay, and it may satisfy the need of intelligent air bag.

2) The venting device of intelligent air bag using stack actuator as performing cell to design has perfect dynamical response characteristics. It can be utilized for active impact control investigating from simulation result.

3) There are some problems in venting device such as larger volume and response delay. More work is needed in actuator structure to decrease the volume, and control system should be improved respectively in order to put the technology to application.

References

[1] Tao Baoqi. *Intelligent materials and structures* [M]. Beijing: National Defense Press, 1997.3 - 21. (in Chinese)

[2] Lee Calvin, Rosato Nick, Lai Francis. *An investigation of improved airbag performance by vent control and gas injection* [R]. AIAA-91-0892-CP, 1991.

[3] Liu Yinmei, Wen Baosong. Studies on the microstructure, dielectric and electrostrictive properties of PMN-PT ceramics [J]. *Journal of Inorganic Materials*, 1994, **9**(1): 117 - 121.

[4] Chen Yong, Gao Wei, Gu Zhongquan, Tao Baoqi. Analysis of electrostrictive stack actuator for active trailing edge flaps [J]. *Chinese Journal of Aeronautics*, 2000, **13**(4): 198 - 203.

[5] Tang Feng, Huang Shanglian. Electromechanical behaviours of PZT, SMA and electrostrictive material as an actuator [J]. *Piezoelectrics & Acoustooptics*, 1996, **18**(1): 50 - 53.

[6] Ewing E G, Knacke T W, Bixby H W. *Direction of recovery system design*. Beijing: Astronautic Industry Press, 1988.376 - 381.

致电伸缩材料驱动智能气囊排气装置特征

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摘　要　本文利用层叠电致伸缩驱动器设计了智能气囊排气装置,分析了其动态响应特性与缓冲驱动特性,并结合应用的需要进行了控制特性仿真.研究结果表明,该排气装置具有良好的驱动性能,可以满足智能气囊的排气控制要求.

关键词　智能气囊, 层叠电致伸缩驱动器, 排气装置

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