Defence Science Journal, Vol. 66, No. 5, September 2016, pp.504-508, DOI : 10.14429/dsj.66.9815

Low Acceleration Overload Catapult Technique for Throwing the Small Scout Robot

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ABSTRACT

The small scout robot is generally thrown into the war zone by soldier. The short thrown distance and the danger of soldier exposed to the enemy limit the application of the small scout robot. So this paper presents a type of low acceleration overload catapult device of no flash, no smoke and no sound. It can throw the small scout robot covertly to long distances with low acceleration overload, and avoid the danger that soldier be exposed to the enemy when artificial throwing. The high and low pressure chambers of the catapult device achieve the low acceleration overload launching, and eliminate the risk of robot damaged by huge acceleration overload. The covert launching of no flash, no smoke and no sound is achieved by the piston to seal the gun propellant gas in barrel. Based on the interior ballistic model, the interior ballistic performance is calculated. The experiment for measuring the acceleration overload of the projectile is achieved by using the catapult device prototype and the measurement system developed by authors. The simulation and test results show that this catapult device can meet the requirement to throw the small scout robot into the war zone.

Keywords: catapult device, acceleration overload, high and low pressure chamber, interior ballistics, robot

1. INTRODUCTION

The small scout robots such as BIT scoutbot, Throwbot XT and Recon scout IR[1-6] shown in Fig. 1 are generally thrown into the war zone by soldier. The thrown distance only reaches several meters to tens of meters, and the soldier is exposed to the enemy, so the applications of small scout robots is restricted. As a kind of precise electronic equip0ment, the small scout robot cannot bear the huge acceleration overload. If using the rifle grenade or grenade launcher to carry out the launching, the robot will be damaged because of the huge acceleration overload, and the launching process will generate the smoke and flash in muzzle and noise, so the position of the device will easily be exposed. The energy storage launcher can achieve the low acceleration overload, and it can launch hundreds of kilograms torpedo or missile, but the launch and energy storage equipment is complicated and huge.

To throw the small scout robot covertly to long distances with low acceleration overload, a catapult device of no flash, no smoke and no sound is designed, and its interior ballistic performance is researched and verified by experiment.

2. CATAPULT DEVICE

The low acceleration overload catapult device of no flash, no smoke and no sound is shown in Fig. 2. The primer ignites the gun propellant to produce the gas of high temperature and high pressure in the high pressure chamber. When pressure in the high pressure chamber rises to the pressure which can break through the lining of nozzle, the gas in the high pressure chamber will enter the low pressure chamber through the nozzle. When the pressure in the low pressure chamber achieves the starting pressure of projectile with putter, the piston pushes the projectile with putter to do the accelerated motion. The peak of pressure in the low pressure chamber is efficiently weakened, and the interior ballistic acceleration overload of projectile is reduced. The pressure in the low pressure chamber and the muzzle velocity of projectile are controlled by structure parameters of the catapult device, gun propellant parameters, and loading parameters.

Figure 1. The small scout robots: (a) BIT scout robot, (b) Throwbot XT, and (c) Recon scout IR.

Received : 03 March 2016, Revised : 27 June 2016
Accepted : 01 July 2016, Online published : 30 September 2016

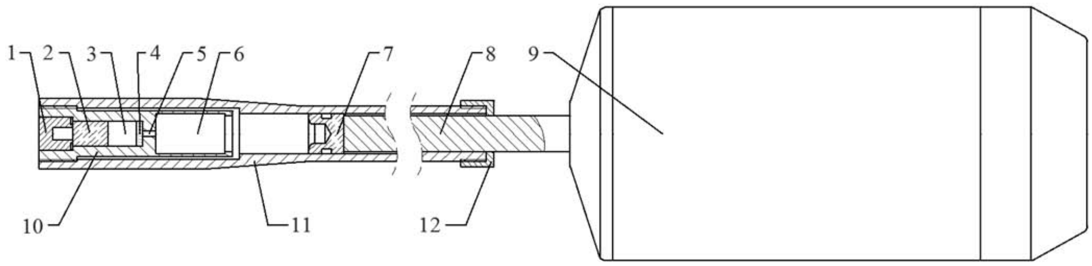

Figure 2. The engineering drawing of the catapult device: 1-primer; 2-gun propellant; 3-high pressure chamber; 4-lining; 5-nozzle; 6-low pressure chamber; 7-piston; 8-putter; 9-projectile; 10-integration box; 11-barrel; 12-brake equipment.

When the projectile with the putter flies away from barrel, the piston is stopped at the muzzle by the brake equipment and the buffer gasket in brake equipment absorbs the kinetic energy of piston. The gas in the barrel is sealed by the piston and integration box. The low acceleration overload, no flash, no smoke and no sound are realised. When completing the launching mission, the brake equipment and piston can be removed from the barrel and the gas in the barrel is discharged. The catapult device can be reused by replacing the primer and gun propellant.

The main target levels of low acceleration overload catapult device include two parts. One is a maximum acceleration overload in interior ballistics not more than 200 g for a 2.0 kg projectile. The other is a maximum projection range no less than 50 m.

3. INTERIOR BALLISTIC MODEL

The interior ballistic model is the equation set that consist of nozzle state equation, form function and burning rate equation of gun propellant, pressure equation of high pressure chamber and low pressure chamber, and motion equation of projectile[7].

The gas transfer process in high and low pressure chamber can be shown as Fig. 3, where N_1 - relative gas mass of high pressure chamber, N_2 - relative gas mass of low pressure chamber, f - propellant force, β_1 - correction coefficient of propellant force, ω - mass of gun propellant, ψ - burning percentage of gun propellant, k - specific heat ratio, R - molar gas constant, T_2 - gas temperature, G - flow rate of nozzle, φ - coefficient of secondary work, χ_h - heat loss correction coefficient, m - mass of projectile, v - velocity of projectile.

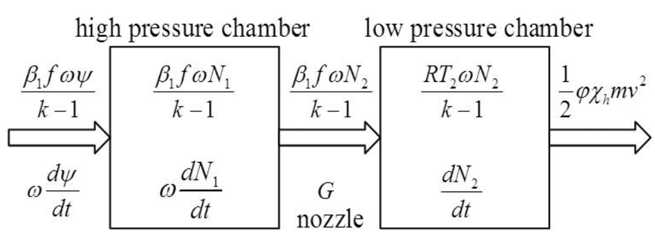

Figure 3. The interior ballistic model.

The interior ballistic process can be divided into four stages, and the interior ballistic model of each stage is discussed as follows[8].

3.1 Interior Ballistic Model of Early Stage

The early stage is defined as the period from firing primer to breaking through the lining of nozzle. The gun propellant burns in constant volume high pressure chamber within this stage, and the gun propellant form function based on geometric burning rule can be expressed as

$$\psi = \chi z(1+\lambda z+\mu z^2)=\frac{V_1/\omega-1/\delta}{\beta_1 f/p_{11}+\alpha-1/\delta} \tag{1}$$

where z - relative thickness of gun propellant, χ, λ and μ - form coefficient, α - covolume, δ - gun propellant density, V_1 - volume of high pressure chamber, p_{11} - pressure which can break through the lining of nozzle.

3.2 Interior Ballistic Model of First Stage

The first stage is defined as the period from breaking through the lining of nozzle to projectile starting motion. Within this stage, the interior ballistic model can be expressed as

$$\begin{cases} \dfrac{dz}{dt}=\dfrac{a}{e_1}p_1^n \\ \psi=\chi z(1+\lambda z+\mu z^2) \\ N_1=\psi-\dfrac{1}{\omega}\displaystyle\int_{t_1}^{t}Gdt \\ p_1=\dfrac{\beta_1 f\omega N_1}{V_1-\omega(1-\psi)/\delta-\omega N_1\alpha} \\ N_2=\dfrac{1}{\omega}\displaystyle\int_{t_1}^{t}Gdt \\ p_2=\dfrac{\beta_1 f\omega N_2}{V_2-\alpha\omega N_2} \end{cases} \tag{2}$$

where a - burning rate coefficient, e_1 - thickness of gun propellant, n - pressure factor, V_2 - initial volume of low pressure chamber, p_1 - pressure in high pressure chamber, p_2 - pressure in low pressure chamber.

The gas flow in the nozzle appears to have three kinds of state such as critical state, non-critical state and balance state. When the pressure in the high and low pressure chamber can meet the equation as

$$\frac{p_2}{p_1}\le\left(\frac{2}{k+1}\right)^{\frac{k}{k-1}}$$

the gas flow in the nozzle is in a critical state, and the flow rate of nozzle can be computed by

$$G = \phi C_{cs} A p_1 \tag{3}$$

where ϕ - discharge correction coefficient, A - nozzle area

$$C_{cs} = \Gamma / \sqrt{RT} = \Gamma / \sqrt{\beta_1 f}\ ,\ \Gamma = \sqrt{k}\left(\frac{2}{k+1}\right)^{\frac{k+1}{2(k-1)}}.$$

When the pressure in the high and low pressure chamber can meet the equation as

$$1 > \frac{p_2}{p_1} > \left(\frac{2}{k+1}\right)^{\frac{k}{k-1}}$$

the gas flow in the nozzle is in a non-critical state. The flow rate of the nozzle can be computed by

$$G = \phi C_{ncs} A p_1 \tag{4}$$

where

$$C_{ncs} = \sqrt{\frac{2k}{(k-1)\beta_1 f}} \cdot \sqrt{\left(\frac{p_2}{p_1}\right)^{\frac{2}{k}} - \left(\frac{p_2}{p_1}\right)^{\frac{(k+1)}{k}}}$$

When the pressure in the high and low pressure chamber can meet the equation as

$$\frac{p_2}{p_1} = 1$$

the gas flow in the nozzle is in a balance state, and flow rate of the nozzle is zero.

3.3 Interior Ballistic Model of Second Stage

The second stage is defined as the period from projectile starting motion to gun propellant burning finishing. Within this stage, the interior ballistic model can be expressed as

$$\begin{cases} \dfrac{dz}{dt} = \dfrac{a}{e_1} p_1^n \\ \psi = \chi z(1 + \lambda z + \mu z^2) \\ N_1 = \psi - \dfrac{1}{\omega}\displaystyle\int_{t_1}^{t} G dt \\ p_1 = \dfrac{\beta_1 f \omega N_1}{V_1 - \omega(1-\psi)/\delta - \omega N_1 \alpha} \\ N_2 = \dfrac{1}{\omega}\displaystyle\int_{t_1}^{t} G dt \\ p_2 = \dfrac{\beta_1 f \omega N_2 - (k-1)\varphi \chi_h m v^2 / 2}{V_2 - \alpha\omega N_2 + Sx} \\ dv/dx = S p_2 / \varphi m v \end{cases} \tag{5}$$

where S- barrel caliber area, x- projectile movement distance in interior ballistic.

3.4. Interior Ballistic Model of Third Stage

The third stage is defined as the period from the finish of gun propellant burning to projectile flying away from barrel. Within this stage, the interior ballistic model can be expressed as

$$\begin{cases} p_1 = p_b\left[1 + \dfrac{(k-1)\phi\Gamma A\sqrt{\beta_1 f}}{2V_1}(t - t_b)\right]^{\frac{k-1}{2k}} \\ N_1 = N_{1b}\left[1 + \dfrac{(k-1)\phi\Gamma A\sqrt{\beta_1 f}}{2V_1}(t - t_b)\right]^{\frac{k-1}{2k}} \\ p_2 = \dfrac{\beta_1 f \omega N_2 - \frac{1}{2}(k-1)\varphi\chi_h m v^2}{V_2 - \alpha\omega N_2 + Sx} \\ dv/dx = S p_2 / \varphi m v \end{cases} \tag{6}$$

4. INTERIOR BALLISTICS SIMULATION AND EXPERIMENT

4.1 Initial Parameters

The structure parameters of the catapult device, gun propellant parameters, loading parameters and constants calculated are listed in Table 1.

4.2 Simulation

Based on the interior ballistic model and initial parameters, the pressure of the high and low pressure chamber is simulating calculated[9,10], and the simulation results are shown in Fig. 4. The maximum pressure in the high pressure chamber is

Table 1. Initial parameters

Symbol	Parameter	Unit	Value
D	caliber	m	0.016
m	mass of projectile	kg	2.0
L	length of interior ballistic	m	0.309
V_1	volume of high pressure chamber	m^3	1.259×10^{-6}
V_2	initial volume of low pressure chamber	m^3	5.035×10^{-6}
b	lining thickness (brass A62)	m	0.1×10^{-3}
d	nozzle diameter	m	0.001
p_1	which can break through the lining of nozzle	MPa	141.1
n_1	nozzle number		1
BZD-1	reference signs of gun propellant		
ω	mass of gun propellant	kg	0.62×10^{-3}
f	propellant force	kJ/kg	1142.19
α	covolume	m^3/kg	9.16×10^{-4}
δ	gun propellant density	kg/m^3	1.59×10^3
k	specific heat ratio		1.234
a	burning rate coefficient	ms^{-1}/Pa	7.65×10^{-10}
e_1	thickness of gun propellant	m	1.75×10^{-4}
β_1	correction coefficient of propellant force		0.95
ϕ	discharge correction coefficient		0.75
φ	coefficient of secondary work		1.21
χ_h	heat loss correction coefficient		1.75

218.8MPa. 3 ms after the primer is activated, the nozzle starts to work, and the gas enters the low pressure chamber. The maximum pressure in the low pressure chamber is 14.47 MPa. The muzzle velocity of projectile is 23.3 m/s. To compare with the experimental results, the pressure curve of the low pressure chamber can be converted into the acceleration curve of projectile shown as the dashed line in Fig. 5. The maximum acceleration overload of the projectile in interior ballistics is 150.5 g (gravitational acceleration).

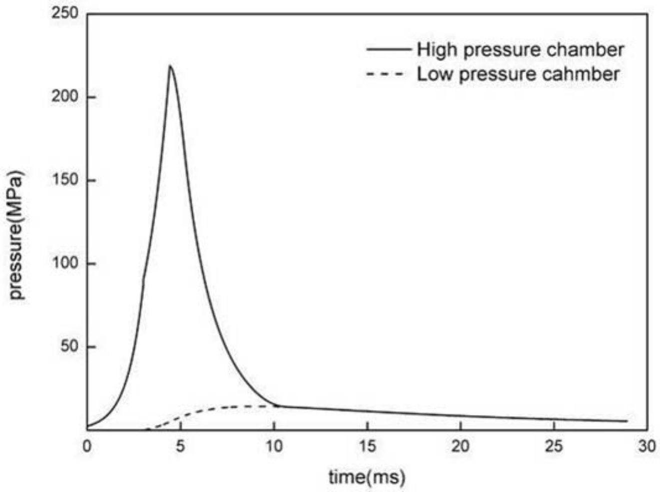

Figure 4. The simulation curve of pressure in high and low pressure chamber.

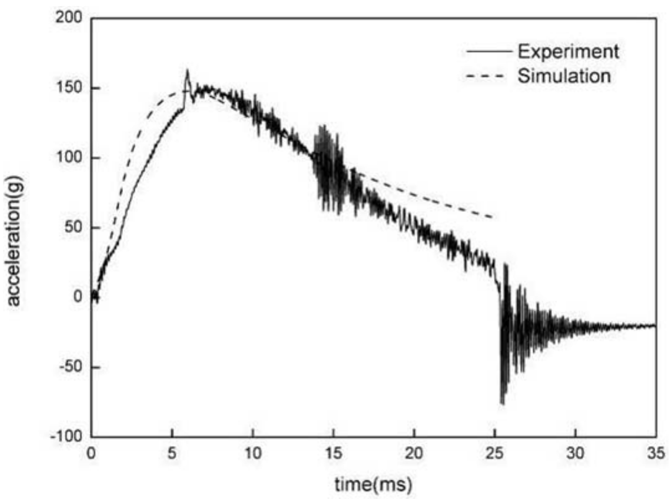

Figure 5. The acceleration curve of projectile in interior ballistics.

Figure 6. The catapult device.

4.3 Experiment

The authors designed the catapult device prototype, as shown in Fig. 6. To measure the acceleration overload of the projectile in interior ballistics, the measurement system is designed shown in Fig. 7. In this measurement system, the acceleration sensor is installed in the interior of projectile, and the acceleration overload of projectile in launching process is directly measured[11]. Figure 8 presents the experiment scene. The test result is shown as the solid line in Fig. 5.

The test result shows that the maximum acceleration overload of the projectile in interior ballistics is 148.7 g, and is at excellent consistency with the simulation result. The interior ballistic time is 25 ms. The maximum projection range of projectile is 52.4 m when the projection angle is 45 degrees.

In experimental measurement shown in Fig. 5, the reason of the acceleration oscillation located in approximately 15 ms is uncertain, possibly due to problems in the installation of the

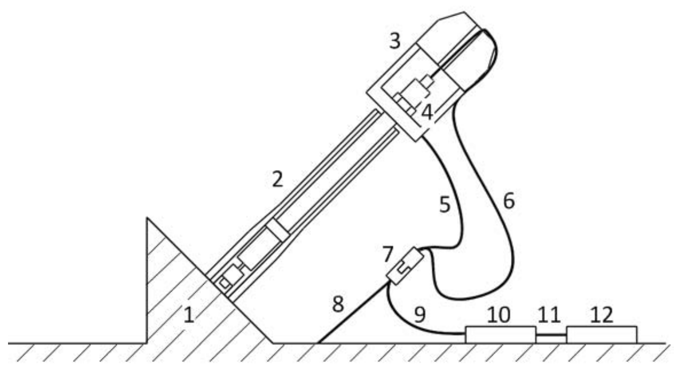

Figure 7. The measurement system: 1-fixed plate; 2-catapult device; 3-projectile; 4-acceleration sensor; 5-connector wire; 6,9,11-data cable; 7-pluggable connector; 8-fixed line of pluggable connector; 10-data acquisition board; 11-data storage and computer.

Figure 8. The experiment scene.

sensor. The acceleration oscillation located in approximately 25 ms is a result of the pulling out process of the pluggable connector when the projectile with the putter flies away from barrel.

5. CONCLUSIONS

In this paper, a type of low acceleration overload catapult device of no flash, no smoke and no sound is presented. It can throw the small scout robot covertly to long distances with low acceleration overload, and avoid the danger that soldier be exposed to the enemy when artificial throwing. The low acceleration overload launching is achieved by the high and low pressure chamber of the catapult device, and eliminates the risk of robot damaged by huge acceleration overload. The covert launching of no flash, no smoke and no sound is achieved by the piston to seal the gun propellant gas in barrel.

Based on the interior ballistic model, the interior ballistic performance is calculated. The experiment for measuring the acceleration overload of the projectile in interior ballistics is achieved by using the catapult device prototype and the measurement system developed by authors. The simulation and test results show that the maximum acceleration overload in interior ballistics for a 2.0 kg projectile is 148.7 g. The maximum projection range of the projectile is 52.4 m when the projection angle is 45 degrees, and the interior ballistic time is 25 ms correspondingly. The results indicate that this device can meet its ideal target levels.

Improvements still need to be made for further increase in the maximum projection range of the projectile.

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ACKNOWLEDGMENTS

This work has been supported by Program for Changjiang Scholars and Innovative Research Team in University under Grant IRT1208.

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