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THE NUMERICAL SIMULATION OF THE MULTI-POINT IGNITION PROCESS IN A GUN

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ABSTRACT

Applying the two-phase flow internal ballistics theory, through the numerical simulation and experiments, measures to reduce the chamber pressure wave are given to ensure the stability of the internal ballistics performance of the gun, as well as the safety and reliability of the charge.

1 INTRODUCTION

The multi-point ignition technology is the effective method to solve the problems on flame spreading of large caliber guns with high loading density. It improves the simultaneity and uniformity of ignition, so as to improve the safety and stability of gun firing. The technique can also reduce the chamber pressure and enhance the muzzle velocity.

Higher the technologic tactics criterion, higher the projectile's muzzle velocity. Under restriction of the fixed dimensions of chamber, higher loading density and higher propellant energy are required. But this will make the burning procedure more fierce and the ascending gradient of pressure more abrupt. So, once the loading charge was not properly designed, the abnormal incident induced by the abnormal pressure would occur. The procedure of gun firing is a fierce chemical combustion procedure with multi-dimension, high-temperature, high-pressure and high instantaneousness characteristics, Especially in the chamber of large caliber gun with several charge containers, the combustion status are more complicated. Therefore, researching on the multi-point ignition technology by numeric simulations and experiments are very important. This is effective to study the combustion procedure and it is helpful to found the inner regulation of multi-ignition technology.

2 CHARGE DESIGN OF MULTI-POINT IGNITION

Figure 1 shows the structure of an armor-piercing charge structure. There is a gap left between the fore case and the rear case, and the two cases are mounted respectively.

The rear case is fulfilled by granular propellants among which mounted the multi-point ignition tube. On the top of the tube an ignition powder bag is mounted. The fore part of the charge is fulfilled with propellant grains except the tail of the projectile on which bundled some tube-shape propellants. The charge also has other kind of parts, such as the bore erosive paper and the flash reducer. When ignited, gas generated by the primer powder combustion will broken the multi-point ignition tube first, and then ignite the main charge.

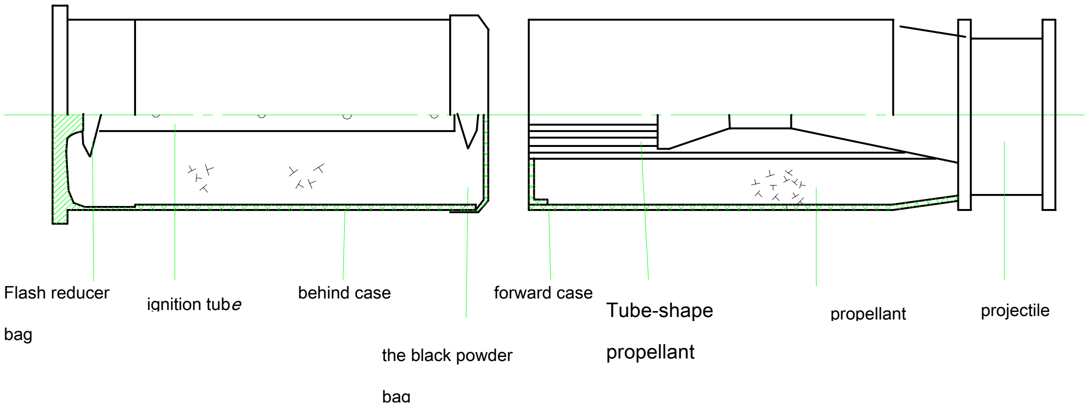

Figure 1 the charge structure

3 MODELS

3.1 Assumptions

The interaction between each parts of the charge is complicated very much, and under the consideration of the flow field characteristics, assumptions are made as follows:

a. The flow in both the barrel and the ignition tube are an one-dimensional two-phase flow.
b. Ignore the influence of the projectile wings .
c. Granular propellants are completely the same, and will burn under the linear combustion laws.
d. The tube-shape propellant is carried by the flow, and will burn like the semi-grooved propellant.
e. The black powder bag and combustion case are looked on the fixed sources, and will release energy locally whose firing status is depending on the local radiation convection and the heat exchange.
f. Regard the multi-point ignition tube as a thread source.
g. Adjust to energy of propellant to compensate the energy absorbed by the barrel.

3.2 Basic equations

The basic equations are as follows. Some subsidiary equations are given bellow, and others could be found in the references listed at the end of the paper.

a. Equation of mass for the charge gas phase as

$$\frac{\partial F\phi\rho_1}{\partial t}+\frac{\partial F\phi\rho_1 u}{\partial x}=FI_1+F_1\dot{m}_1+F\dot{m}_{\mathrm{ign2}} \tag{1}$$

$$\frac{\partial F\phi\rho_2}{\partial t}+\frac{\partial F\phi\rho_2 u}{\partial x}=FI_2 \tag{2}$$

Where is I_1、 I_2、 $\dot{m}_{\mathrm{ign2}}$ *—the generation rate of gaseous mass by the combustion of granular propellant, tube-shape, igniter powder；* F *— Cross-sectional area of barrel；* F_1 *—Cross-sectional area of multi-point ignition tube；* $\dot{m}_1$ *—mass flow rate of combustion gas from multi-point igniter through side holes into case in unit volume ；* ϕ *—porosity；* u *— velocity of gas;* ρ_1 *—gas Density generated by granular propellants;* ρ_2 *—gas density generated by the tube-shape propellants.*

b. Equation of mass for gas phase combustion case

$$\frac{\partial F\phi\rho_3}{\partial t}+\frac{\partial F\phi\rho_3 u}{\partial x}=FI_3 \tag{3}$$

where ρ_3 *—gas density of granular propellant;* I_3 *—mass generation rate by the combustion case in unit volume.*

$$\rho=\rho_1+\rho_2+\rho_3$$

$$R=\frac{\sum\limits_{\mathrm{i}=1}\rho_{\mathrm{i}}R_{\mathrm{i}}}{\sum\limits_{\mathrm{i}=1}\rho_{\mathrm{i}}} \qquad \alpha=\frac{\sum\limits_{\mathrm{i}=1}\rho_{\mathrm{i}}\alpha_{\mathrm{i}}}{\sum\limits_{\mathrm{i}=1}\rho_{\mathrm{i}}} \qquad (\ \mathrm{i}=1,2,3\ )$$

c. Equation of momentum for the gas-phase

$$\frac{\partial F\phi\rho u}{\partial t}+\frac{\partial F\phi\rho u^2}{\partial x}+F\phi\frac{\partial P}{\partial x}=FI_1u_{p1}+FI_2u_{p2}-FD_1-FD_2+F_1\dot{m}_1u_{\mathrm{ign1}} \tag{4}$$

where u_{ign1} *—velocity of gas at holes from which the gas expelled from multi-point ignition tube into barrel ；* D_1 、 D_2 *—the pressure declination caused by the resistance of the gas and the granular propellant, tube-shape propellants；* u_{p1} 、 u_{p2} *—velocity of granular propellant and single-perforated。*

d. Equation of energy for the gas phase as

$$\frac{\partial F\phi\rho(e+u^2/2)}{\partial t}+\frac{\partial F\phi\rho\, u(e+u^2/2)}{\partial x}+\frac{\partial F\phi uP}{\partial x}+FP\frac{\partial\phi}{\partial t}$$
$$=\sum_{i=`1}^{3} FI_i H_{\mathrm{p}i}+F_1\dot{m}_1 H_{\mathrm{g1}}+F\dot{m}_{\mathrm{ign2}}H_{\mathrm{g2}}-F\dot{q}-\sum_{i=1}^{2} Fu_{\mathrm{p}i}D_i \tag{5}$$

where H_{p1} 、 H_{p2} 、 H_{p3} 、 H_{g1} 、 H_{g2} *- enthalpy of gas generated by granular propellants, single-perforated propellants, combustion case, igniter tube and black powder bag; ,* $\dot{q}$ *—interphase heat exchangement.*

e. Equation of mass for solid-phase

$$\frac{\partial F\rho_{\mathrm{p1}}\sigma_1}{\partial t}+\frac{\partial F\rho_{\mathrm{p1}}\sigma_1 u_{\mathrm{p1}}}{\partial x}=-FI_1 \tag{6}$$

$$\frac{\partial F\rho_{\mathrm{p2}}\sigma_2}{\partial t}+\frac{\partial F\rho_{\mathrm{p2}}\sigma_2 u_{\mathrm{p2}}}{\partial x}=-FI_2 \tag{7}$$

where σ_1, σ_2 *—porosity of granular propellants and tube-shape propellant.*

f. Equation of mass for combustion case

$$\frac{\partial F\sigma_3}{\partial t}+\frac{\partial F\sigma_3 u_{\mathrm{p3}}}{\partial x}=-FI_3/\rho_{\mathrm{p3}} \tag{8}$$

$$u_{\mathrm{p3}}=0\ ,\quad \frac{d\sigma_3}{dt}=-I_3/\rho_{\mathrm{p3}}$$

σ_3 — *porosity of* *burnable case.*

g. Equation of momentum for solid-phase

$$\frac{\partial F\sigma_1 u_{\mathrm{p1}}}{\partial t}+\frac{\partial F\sigma_1 u_{\mathrm{p1}}^2}{\partial x}+F(1-\phi)\frac{\partial p}{\partial x}=-FI_1 u_{\mathrm{p1}}/\rho_{\mathrm{p1}}+FD_1/\rho_{\mathrm{p1}} \tag{9}$$

$$\frac{\mathrm{d}}{\mathrm{d}t}\left[\int F(1-\phi)\rho_{\mathrm{p2}}\,u_{\mathrm{p2}}dx\right]=\int FD_2\mathrm{d}x+F(1-\phi)p\,|_{\mathrm{te}}-F(1-\phi)\,|_{\mathrm{tf}}-\int FI_2 u_{\mathrm{p2}}\mathrm{d}x \tag{10}$$

te—*breech parameter of BL*， **tf**—*top parameter of BL*

3.3 Subsidiary Equations

3.3.1 Equation of state

$$p\cdot\left(\frac{1}{\rho}-\alpha\right)=RT$$

3.3.2 Porosity

$$\phi=1-\sigma_1-\sigma_2-\sigma_3$$

3.4 Boundary conditions

3.4.1 Initialization conditions

At $t=0, 0\le x\le l_m$, l_m :Length of chamber

$$p=p_0,\quad T=T_0, T_{ps}=T_0, \rho=\rho_1=1/(RT_0/p_0), e=RT_0$$

$$u=u_{p1}=u_{p2}=u_{p3}=0\ ,\ \phi=\phi_0=1-\sigma_{01}-\sigma_{02}-\sigma_{03}$$

3.4.2 Boundary conditions

At $t\ge 0, x=0$

breech： $u=0$ ， $u_{pj}=0$, (j=1 ，2 ，3), and other parameters are dealt with the mirror reflection method.

Projectile base： $\mathrm{d}x/\mathrm{d}t=u_J$.

$$m\frac{\mathrm{d}}{\mathrm{d}t}u_J=\int_F p_J\mathrm{d}F-F_r$$

where m *—projectile mass；* u_J *—projectile velocity ;* p_J *—pressure at the bottom of the projectile；* F_r *—total resistance of projectile*

4 NUMERICAL SIMULATIONS AND EXPERIMENT RESULTS ANALYSIS

4.1 Numerical simulation results

Based on the equations above, simulations are carried out with ‘Mac mark’ method. Numerical simulation result such as ballistics parameters and pressure curves shows well consistency with that of the **e**xperiments, and it manifests that the model and the simulation are reasonable.

With detailed numerical simulation, the pressure distribution in different periods, Regulations of ignition, burning status and grains motion in the chamber are obtained. Simulations show that if the multi-point ignition tube is designed incompatibly, only part of the bed of grains burn fiercely, and would lead to the strong pressure wave (showed in fig. 2).

4.2 Multi-point ignition influence on pressure wave

Applying this model to several multi-point ignition charge structures, the primary regulations of the multi-point ignition are acquired. Some methods to alleviate the pressure wave are obtained, showed as bellow:

a. reduce the ignition powder in the ignition tube, and increase the primer powder in front of the ignition tube appropriately.

b. adjust the charge distribution may decline the first negatives pressure difference.

c. adjust the ignition location in the tube.

4.3 Multi-point ignition influence on the internal ballistics performance of a gun

Calculation results show that using the multi-point ignition tube can better the co-instantaneousness comparing to using a common ignition tube in a same charge structure, and can enhance the muzzle velocity and the peak pressure, and therefore, enhance the utilization rate of the charge.

5. CONCLUSIONS

In this paper, the two-phase flow model of multi-point ignition is established, simulations are carried out, and factors impacting on the pressure wave and the internal ballistics performance are obtained. With mass simulations and analysis, the followed conclusions are found:

A . Making the charge structure and the multi-point ignition system to match each other can decline pressure waves.

B. The charge utilization can be slightly enhanced when using multi-point ignition than using the common methods.

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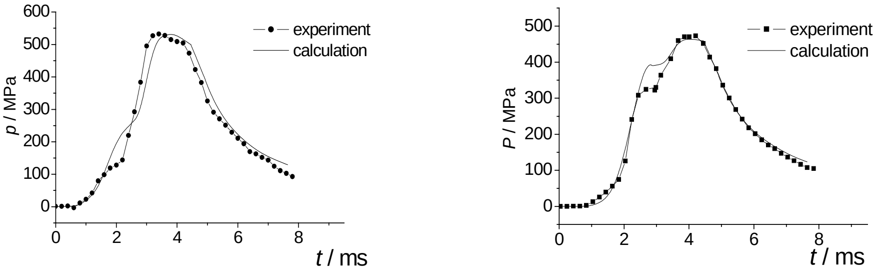
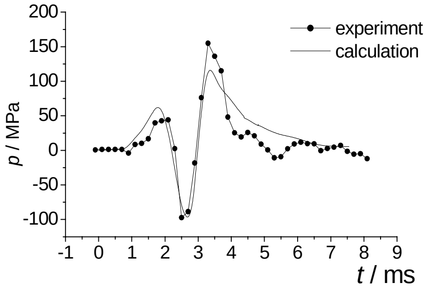


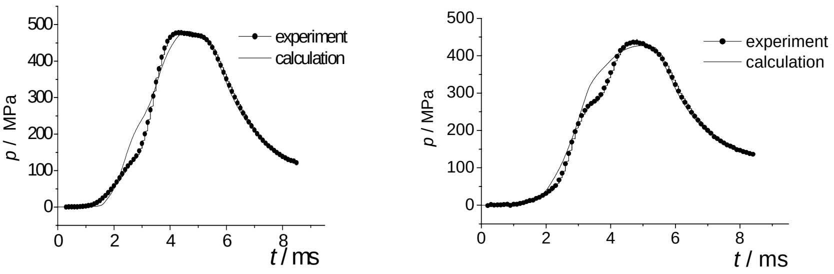
a. *P-t* Curve of breech

b. *p-t* curve of mouth of case

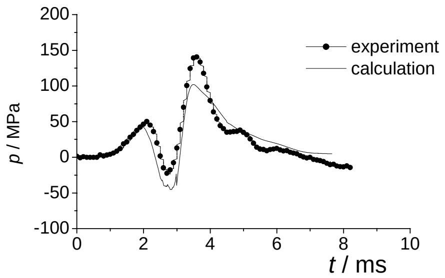


c. Δ*p-t* curve of pressure difference between breech and mouth of case.

Figure 2 .pressure-time curves p-t,Δp-t curve



a. *P-t* Curve of breech b. *p-t* curve of mouth of case



c. Δ*p-t* curve of pressure difference between breech and mouth of case.

Figure 3. *Improved pressure-time curves p-t,Δp-t curve*