THE MECHANISM ANALYSIS OF INTERIOR BALLISTICS OF SERIAL CHAMBER GUN

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OUTLINE

- INTRODUCTION
- LAUNCH MECHANISM OF SERIAL CHAMBER GUN
- LUMPED PARAMETER MODEL
- TWO PHASE FLOW MODEL
- ANALYSIS OF CALCULATION RESULTS
- CONCLUSIONS

INTRODUCTION

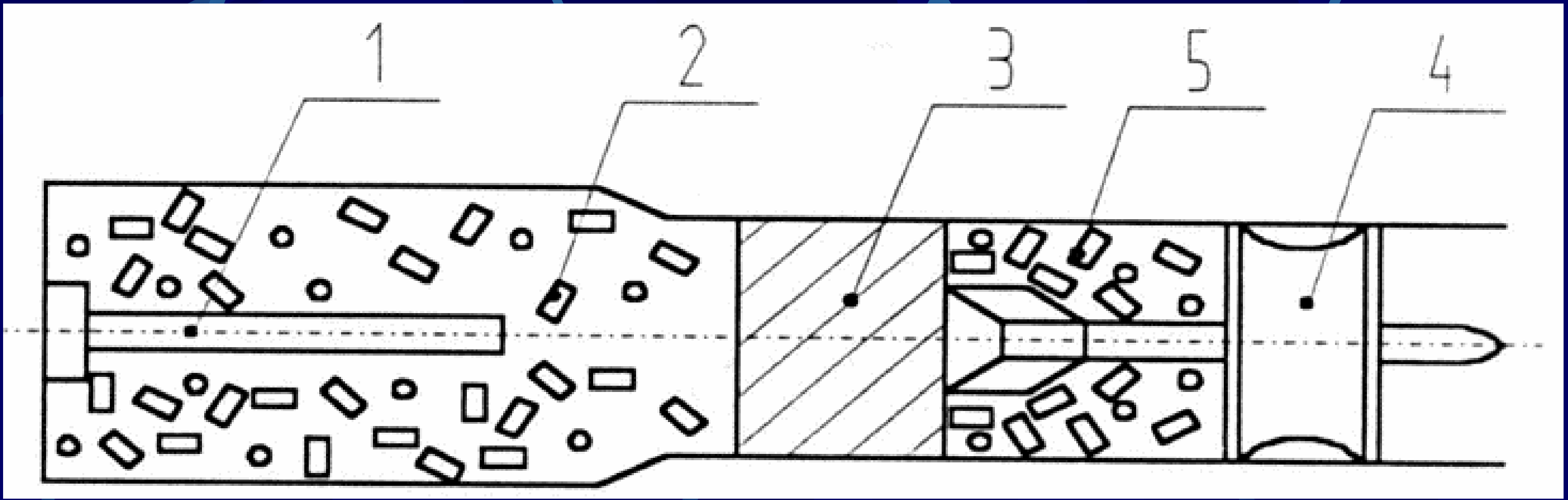
- The requirements for increasing muzzle kinetic energy and muzzle velocity
- Many new launch principles : electrothermal launcher, electromagnetic launcher, regenerative liquid propellant gun, ram accelerator, explosively-driven launcher, and travelling charge gun, and so on
- Serial double chamber gun

INTRODUCTION

Advantages:

- The peak pressure in the main chamber and the subsidiary chamber are lower
- The subsidiary chamber plays an important role in pressure plateau
- When the caliber is enlarged, the breech structure does not need to be changed, only the charge chamber is extended.

LAUNCH MECHANISM



1.center-core igniter 2.main chamber 3.piston
4.projectile and sabot 5.subsidiary chamber
Figure 1. Schematic diagram of serial chamber gun

LAUNCH MECHANISM

Key Problems:

- Propellant web thickness in the subsidiary chamber must be thinner than that of the main chamber.
- Reliable ignition of the subsidiary propellants by a device in the piston
- Ignition and flame-spreading of the propellant in the subsidiary chamber should be very fast and strong

LAUNCH MECHANISM

- Prevent the propellant gases in the main chamber from leaking into the subsidiary chamber, resulting in premature ignition of the propellant in the subsidiary chamber

- The projectile and piston must remain together until sufficient pressure is developed in the subsidiary chamber to promote burning of the propellant.

- How to design the piston, the subsidiary chamber and the projectile is also a key problem

LAUNCH MECHANISM

The whole firing process is divided into three stages.

(1) The main chamber is same as that of common solid propellant gun. When the chamber pressure is larger than the starting pressure, the piston, subsidiary propellant beds and projectile move forward.

(2) The subsidiary propellant beds are ignited by the ignition equipment in the piston. At this moment, the piston, subsidiary propellant beds and projectile move forward together.

(3) When the subsidiary chamber pressure reaches a certain value, the projectile and sabot are separated from the piston and driven forward

$$\frac{sp_1(l_{10}+l_{1\psi})}{\theta}=\frac{f\omega_1\psi_1}{\theta}-\tfrac{1}{2}\varphi(m_H+\omega_2+m_D)v_H^2$$

LUMPED PARAMETER MODEL

Stage One

The mathematical model of the main chamber:

$$\frac{sp_1(l_{10}+l_{1\psi})}{\theta}=\frac{f\omega_1\psi_1}{\theta}-\tfrac{1}{2}\varphi(m_H+\omega_2+m_D)v_H^2$$

$$sp_1=\varphi\ (m_H+m_D+\omega_2)\frac{\mathrm{d}v_H}{\mathrm{d}t}$$

$$l_{10}=W_{10}/s$$

$$l_{1\psi}=l_{10}[1-\frac{\Delta_1}{\delta}-(\alpha-\frac{1}{\delta})\Delta_1\psi_1]$$

LUMPED PARAMETER MODEL

Because the propellant in the subsidiary chamber has not burnt, the piston, subsidiary chamber and projectile move forward together

$$v_D = v_H$$

where v_D and vH is the projectile and the piston velocity.

$$\frac{sp_1(l_{10}+l_{1\psi})}{\theta}=\frac{f\omega_1\psi_1}{\theta}-\tfrac{1}{2}\varphi(m_H+\omega_2+m_D)v_H^2$$

LUMPED PARAMETER MODEL

Stage Two

In this stage, the mathematical model of the main chamber is same as that of stage One.

$$\frac{sp_1(l_{10}+l_{1\psi})}{\theta}=\frac{f\omega_1\psi_1}{\theta}-\tfrac{1}{2}\varphi(m_H+\omega_2+m_D)v_H^2$$

$$sp_1=\varphi\ (m_H+m_D+\omega_2)\frac{\mathrm{d}v_H}{\mathrm{d}t}$$

$$\frac{sp_1(l_{10}+l_{1\psi})}{\theta} = \frac{f\omega_1\psi_1}{\theta} - \frac{1}{2}\varphi(m_H+\omega_2+m_D)v_H^2$$

LUMPED PARAMETER MODEL

In stage two, the propellant of the subsidiary chamber is ignited and burns at isovolumetric state.

$$v_D = v_H$$

$$sp_2 l_{20} = \frac{f\omega_2\psi_2}{\theta}$$

$$\frac{sp_1(l_{10}+l_{1\psi})}{\theta}=\frac{f\omega_1\psi_1}{\theta}-\frac{1}{2}\varphi(m_H+\omega_2+m_D)v_H^2$$

LUMPED PARAMETER MODEL

Stage Three

In stage three, the projectile is separated from the piston and each part continues to move forward but at different velocities. The fundamental equations of the main chamber are as following.

$$\frac{sp_1(l_{10}+l_{1\psi})}{\theta}=\frac{f\omega_1\psi_1}{\theta}-\frac{1}{2}\varphi\, m_H v_H^2-\int sp\,\mathrm{d}l-W$$

$$s(p_1-p_2)=\varphi\, m_H\frac{\mathrm{d}v_H}{\mathrm{d}t}$$

$$\frac{sp_1(l_{10}+l_{1\psi})}{\theta}=\frac{f\omega_1\psi_1}{\theta}-\tfrac{1}{2}\varphi(m_H+\omega_2+m_D)v_H^2$$

LUMPED PARAMETER MODEL

The conservation equations of the subsidiary chamber are as following.

$$\frac{sp_2(l_{20}+l_{2\psi})}{\theta}=\frac{f\omega_2\psi_2}{\theta}-\tfrac{1}{2}\varphi\, m_D v_D^2+\int sp\mathrm{d}l+W$$

$$sp_2=\varphi\, m_D\frac{\mathrm{d}v_D}{\mathrm{d}t}$$

LUMPED PARAMETER MODEL

TABLE I CALCULATION INPUT DATA

dm^3	ballistic chamber volume(m^3)	0.0235
	loading weight of the main chamber(kg)	10.9
	loading weight of the subsidiary chamber(kg)	4.88
	projectile weight(kg)	11.12
	projectile travel(m)	6.0
	ignition delay of subsidiary chamber(ms)	1.5
	specific heat ratio	1.23
	propellant force(J/kg)	1050000
	piston weight(kg)	12.5

LUMPED PARAMETER MODEL

dm³

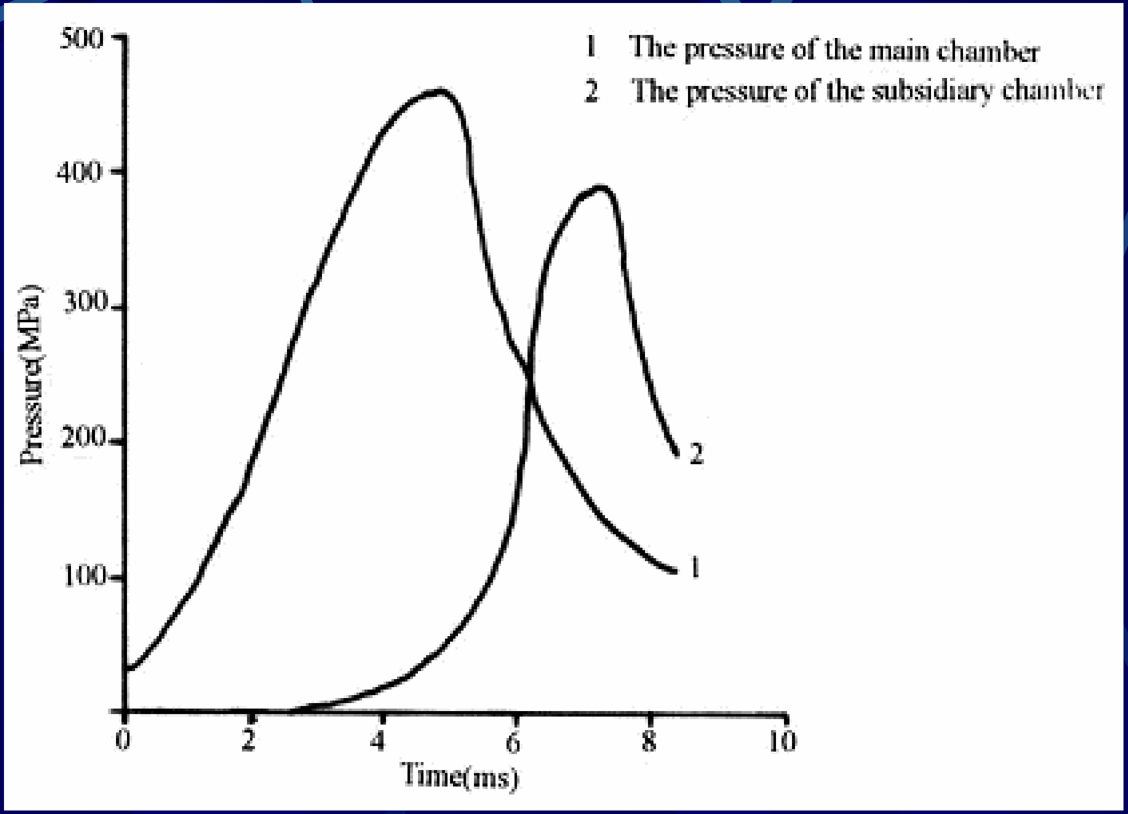


Figure The pressure curves of main and subsidiary chamber

LUMPED PARAMETER MODEL

dm³

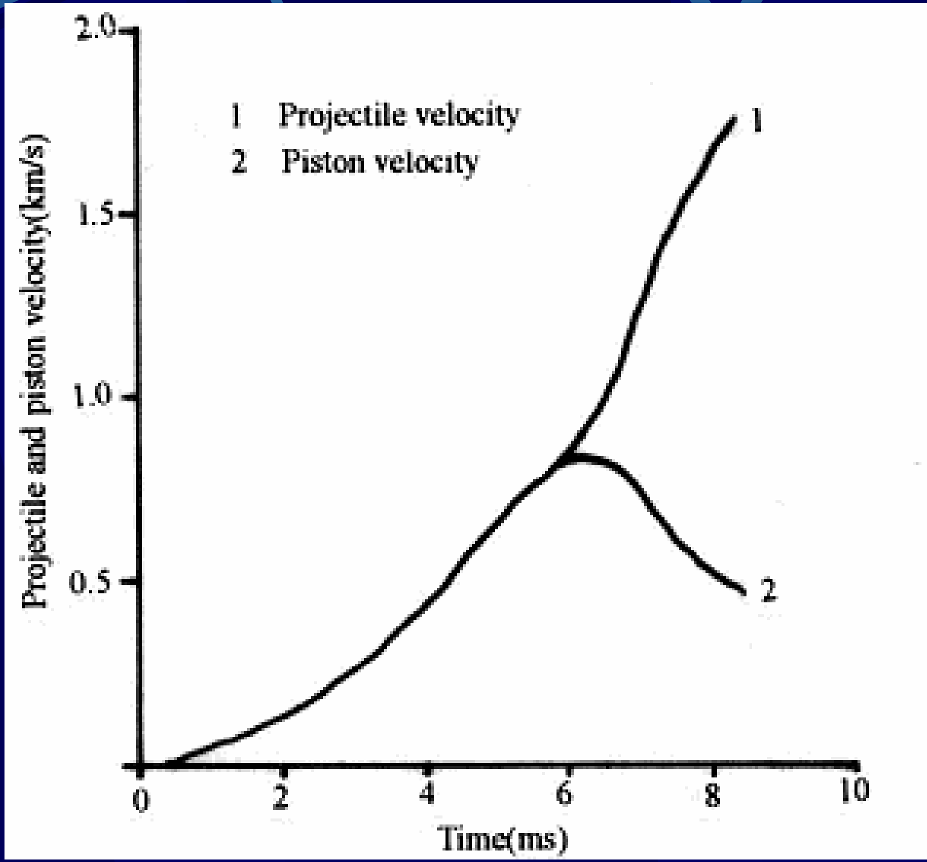


Figure The velocity curves of projectile and piston

TWO PHASE FLOW MODEL

A two phase flow model of the main chamber is also established.

$$\frac{\partial(\varphi_z \hat{\rho}_{gz} A_z)}{\partial t} + \frac{\partial(\varphi_z \hat{\rho}_{gz} u_{gz} A_z)}{\partial x} = \dot{m}_{cz} A_z + \dot{m}_{ignz} A_z$$

dm³

$$\frac{\partial(\varphi_z \hat{\rho}_{gz} u_{gz} A_z)}{\partial t} + \frac{\partial(\varphi_z \hat{\rho}_{zg} u_{gz}{}^2 A_z)}{\partial x} + (A_z \varphi_z)\frac{\partial p_z}{\partial x} = -f_{sz} A_z + \dot{m}_{cz} u_{pz} A_z + \dot{m}_{ignz} u_{ignz} A_z$$

$$\frac{\partial[\varphi_z \hat{\rho}_{zg} A_z (e_{gz} + \frac{u_{gz}{}^2}{2})]}{\partial t} + \frac{\partial[\varphi_z \hat{\rho}_{zg} u_{gz} A_z (e_{gz} + \frac{p_z}{\hat{\rho}_{zg}} + \frac{u_{gz}{}^2}{2})]}{\partial x} + p_z \frac{\partial(A_z \varphi_z)}{\partial t} = -Q_{pz} A_z - f_{sz} u_{pz} A_z + \dot{m}_{cz} A_z (E_{pz} + p_z / \hat{\rho}_{pz} + \frac{u_{pz}{}^2}{2}) + \dot{m}_{ignz} H_{ignz} A_z$$

$$\frac{\partial[(1-\varphi_z)\hat{\rho}_{zp} A_z]}{\partial t} + \frac{\partial[(1-\varphi_z)\hat{\rho}_{zp} u_{pz} A_z]}{\partial x} = -A_z \dot{m}_{cz}$$

$$\frac{\partial[(1-\varphi_z)\hat{\rho}_{zp} u_{pz} A_z]}{\partial t} + \frac{\partial[(1-\varphi_z)\hat{\rho}_{zp} u_{pz}{}^2 A_z]}{\partial x} + A_z(1-\varphi_z)\frac{\partial p_z}{\partial x} + \frac{\partial[(1-\varphi_z) R_z A_z]}{\partial x} = f_{sz} A_z - \dot{m}_{cz} u_{pz} A_z$$

TWO PHASE FLOW MODEL

A two phase flow model of the subsidiary chamber is established.

$$\frac{\partial(\varphi_f \hat{\rho}_{fg} A_f)}{\partial t} + \frac{\partial(\varphi_f \hat{\rho}_{fg} u_{gf} A_f)}{\partial x} = \dot{m}_{cf} A_f$$

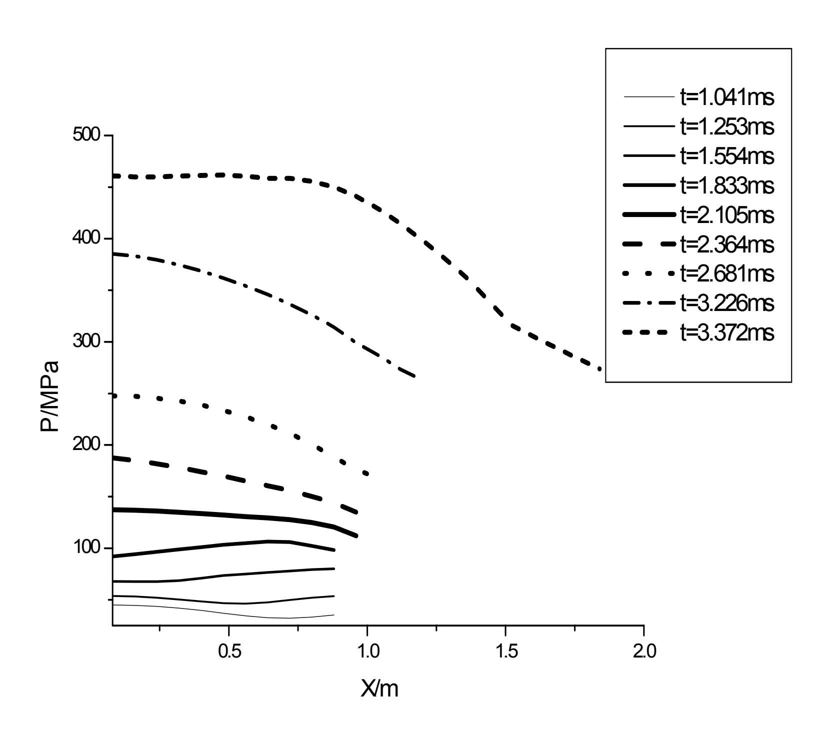
$$\frac{\partial(\varphi_f \hat{\rho}_{fg} u_{gf} A_f)}{\partial t} + \frac{\partial(\varphi_f \hat{\rho}_{fg} u_{gf}{}^2 A_f)}{\partial x} + (A_f \varphi_f)\frac{\partial p_f}{\partial x} = -f_{sf} A_f + \dot{m}_{cf} u_{pf} A_f$$

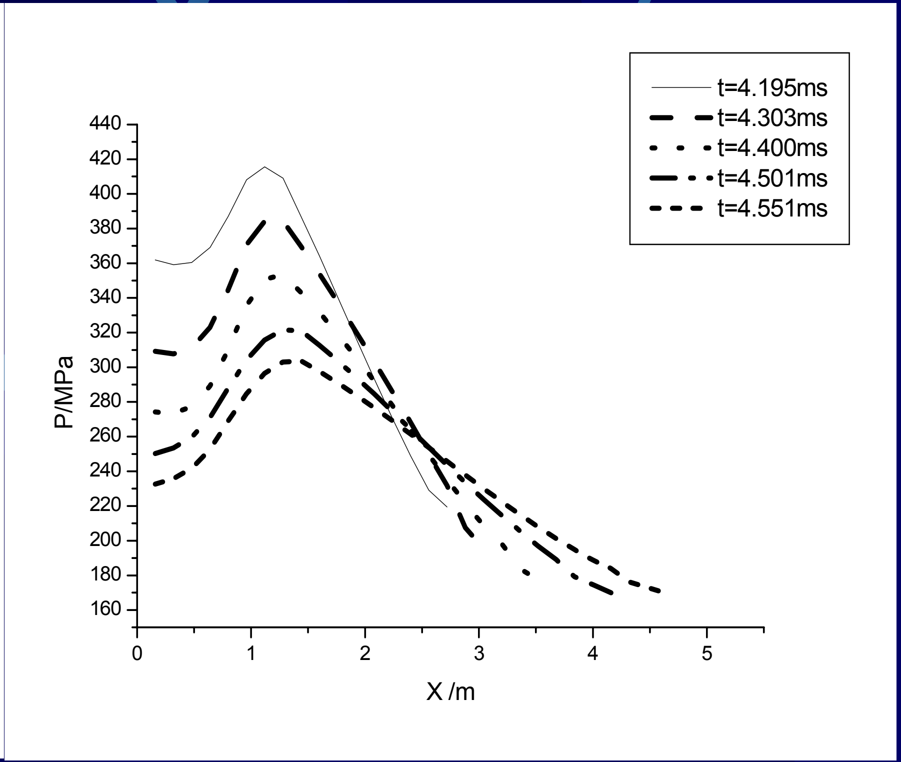
$$\frac{\partial[\varphi_f \hat{\rho}_{fg} A_f (e_{gf} + \frac{u_{gf}{}^2}{2})]}{\partial t} + \frac{\partial[\varphi_f \hat{\rho}_{fg} u_{gf} A_f (e_{gf} + \frac{p_f}{\hat{\rho}_{fg}} + \frac{u_{gf}{}^2}{2})]}{\partial x} + p_f \frac{\partial(A_f \varphi_f)}{\partial t} = -Q_{pf} A_f - f_{sf} u_{pf} A_f + \dot{m}_{cf} A_f (E_{pf} + p_f / \hat{\rho}_{pf} + \frac{u_{pf}{}^2}{2})$$

$$\frac{\partial[(1-\varphi_f)\hat{\rho}_{fp} A_f]}{\partial t} + \frac{\partial[(1-\varphi_f)\hat{\rho}_{fp} u_{pf} A_f]}{\partial x} = -A_f \dot{m}_{cf}$$

$$\frac{\partial[(1-\varphi_f)\hat{\rho}_{fp} u_{pf} A_f]}{\partial t} + \frac{\partial[(1-\varphi_f)\hat{\rho}_{fp} u_{pf}{}^2 A_f]}{\partial x} + A_f(1-\varphi_f)\frac{\partial p_f}{\partial x} + \frac{\partial[(1-\varphi_f) R_f A_f]}{\partial x} = f_{sf} A_f - \dot{m}_{cf} u_{pf} A_f$$

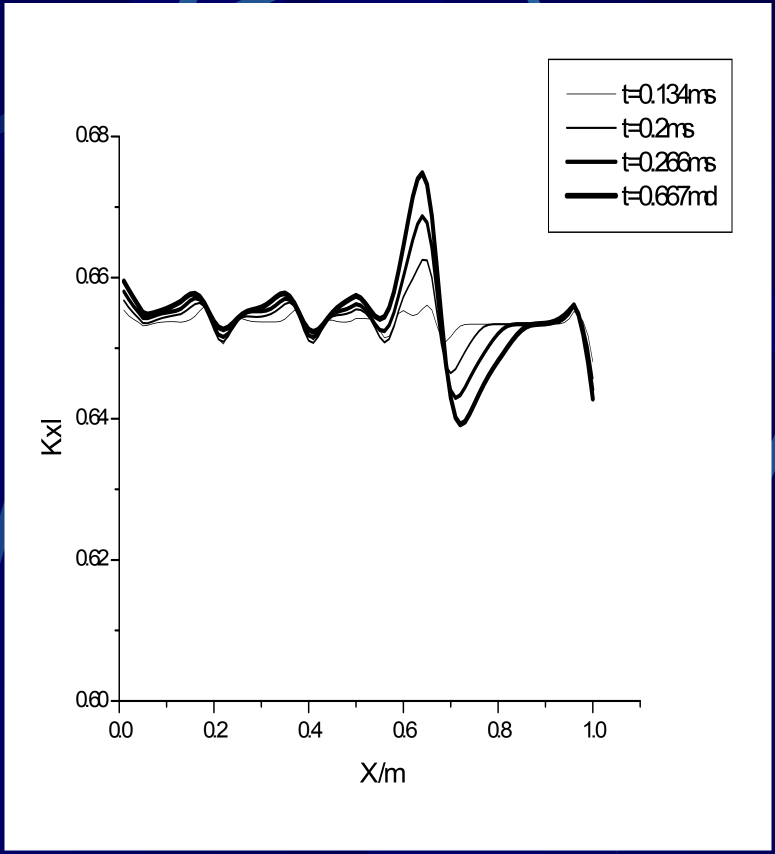
TWO PHASE FLOW MODEL

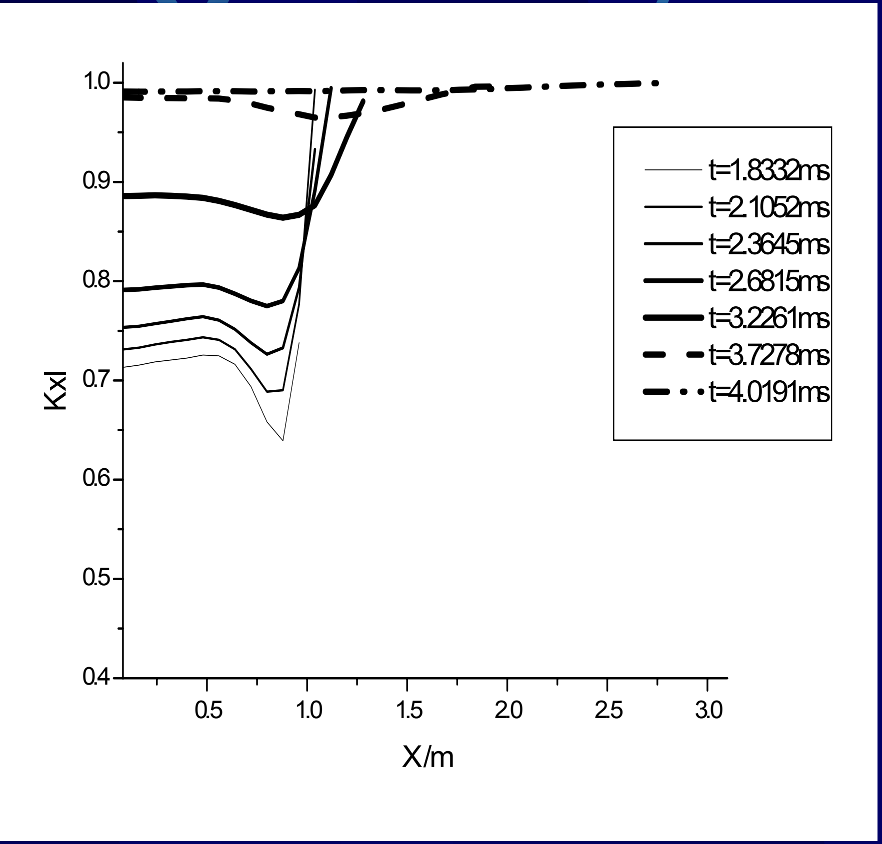




The pressure distribution of the main chamber.

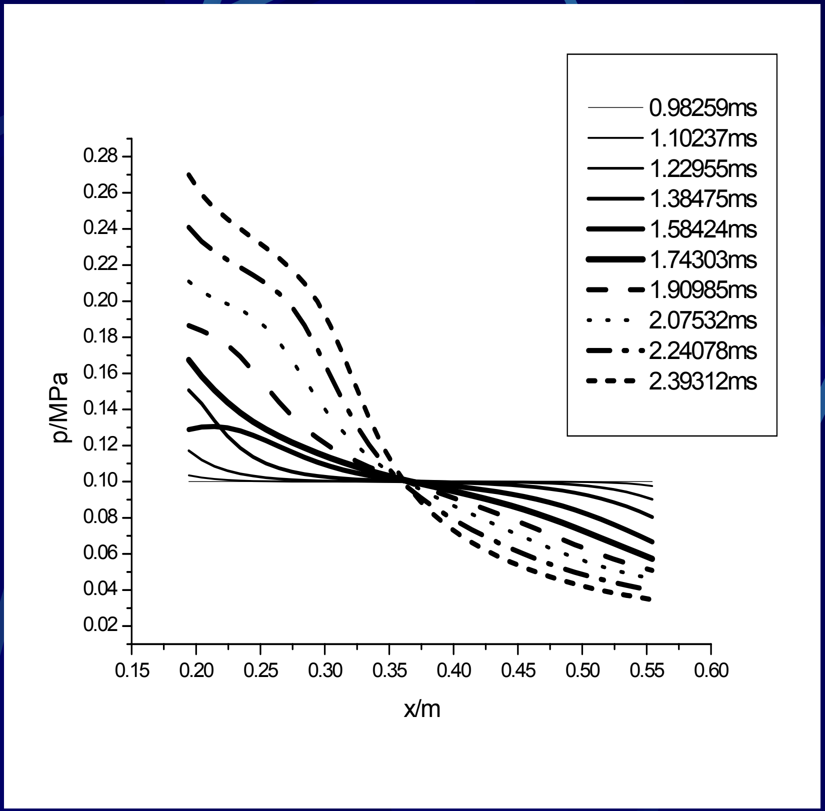
TWO PHASE FLOW MODEL

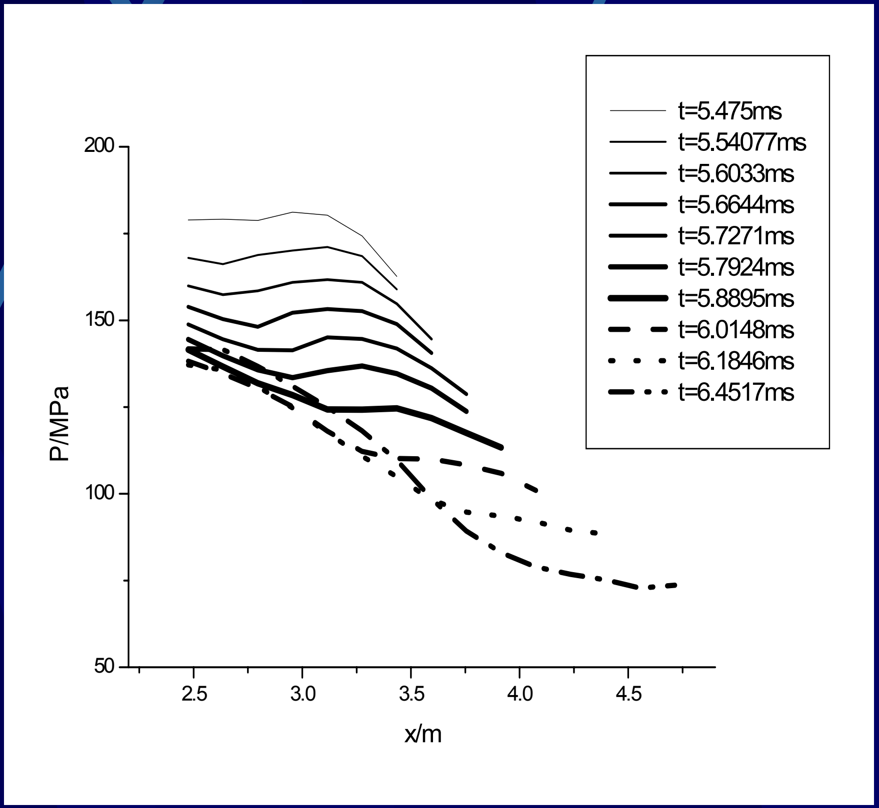




The porosity distribution of the main chamber.

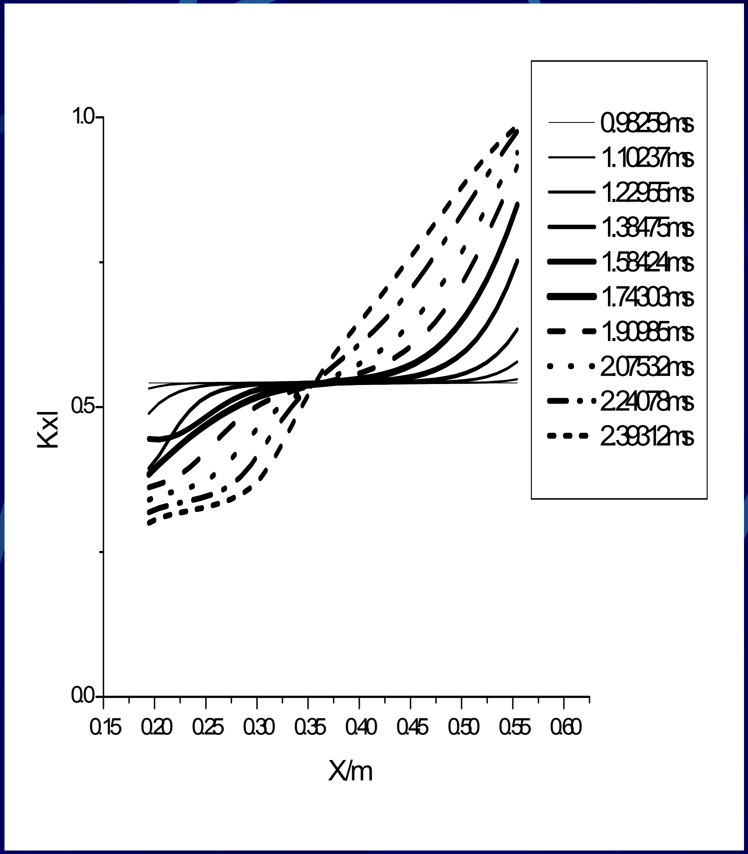
TWO PHASE FLOW MODEL

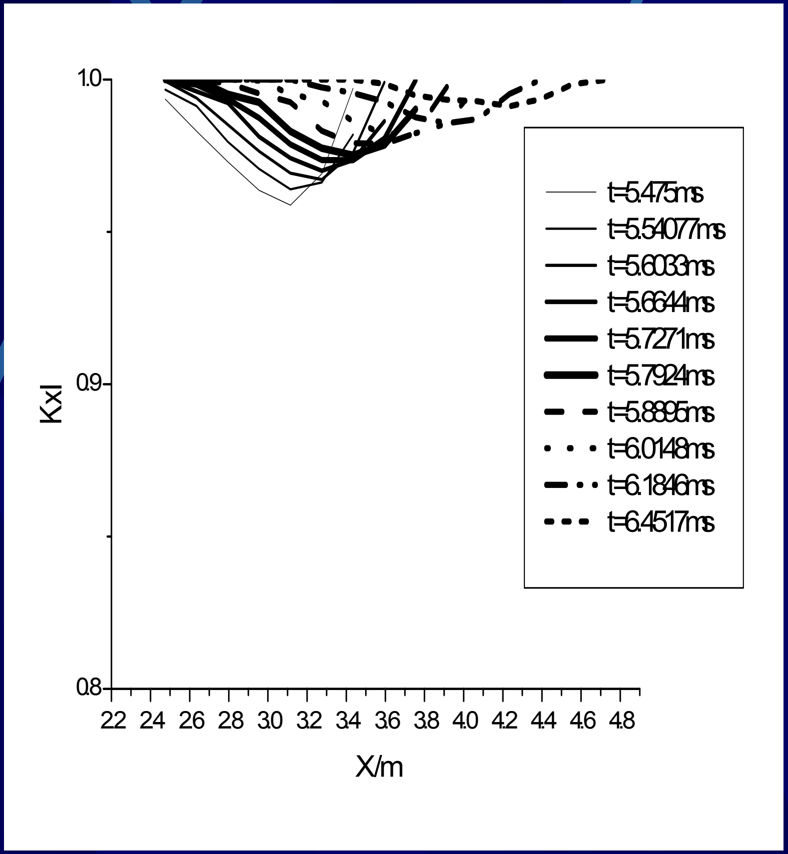




The pressure distribution of the subsidiary chamber.

TWO PHASE FLOW MODEL

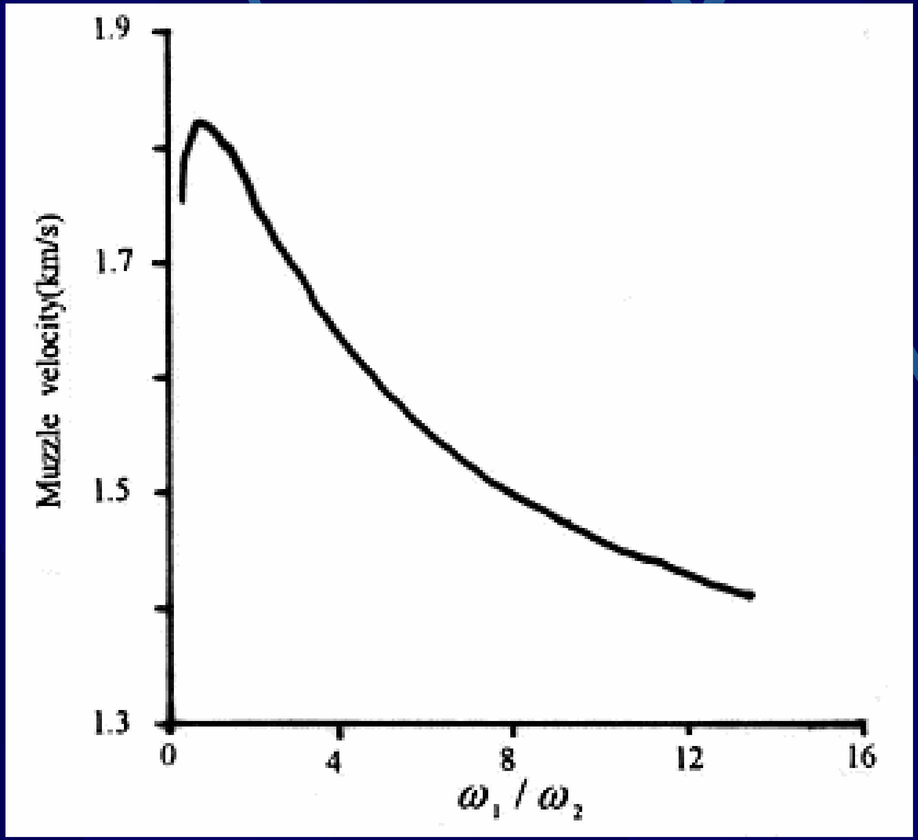




The porosity distribution of the subsidiary chamber.

ANALYSIS OF CALCULATION RESULTS

dm³



Effects of Loading Weight Ratio of Two Charge Chambers on Muzzle Velocity

ANALYSIS OF CALCULATION RESULTS

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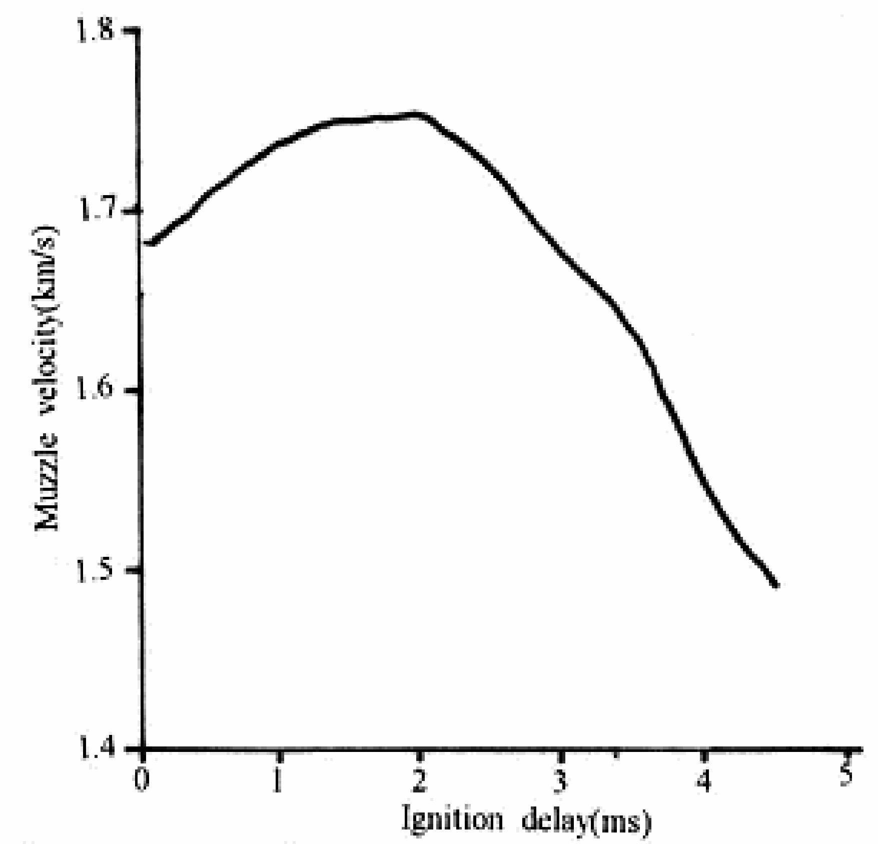

The effects of ignition delay on muzzle velocity

ANALYSIS OF CALCULATION RESULTS

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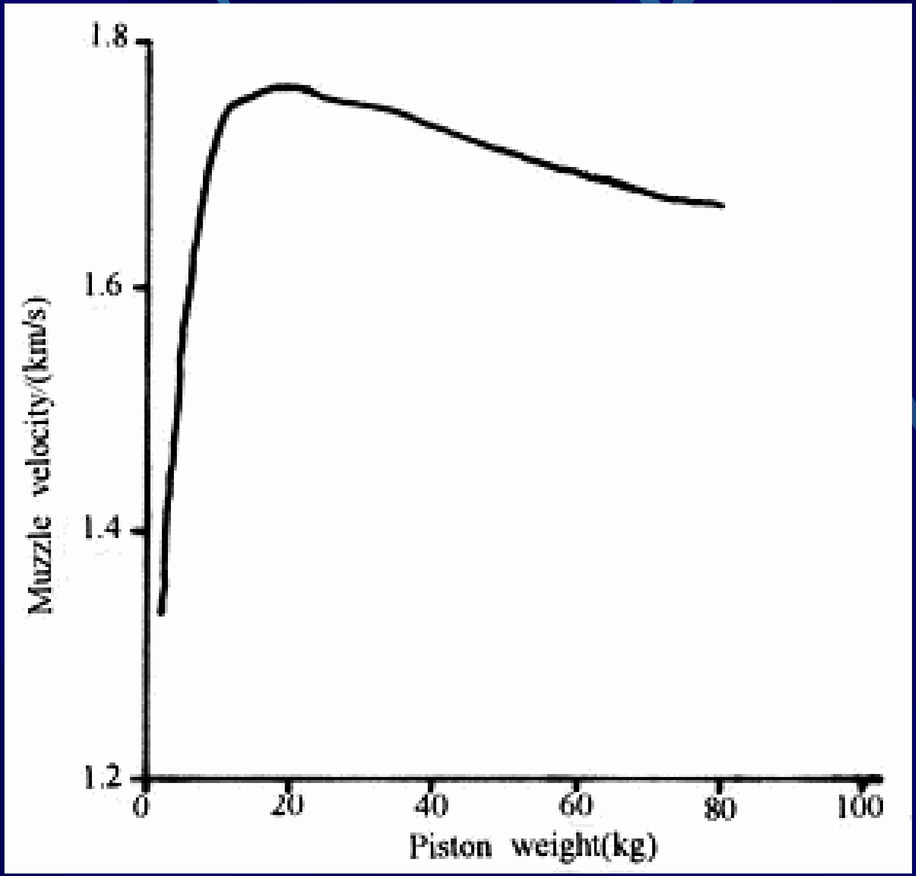

The effects of piston weight on muzzle velocity

CONCLUSIONS

- The mechanism of serial double chamber is presented and some key problems are discussed.

dm^3

- By theoretical analysis, it can be found that the loading weight ratio, the piston weight, the ignition delay and the propellant web thickness are main factors influencing the ballistic performance of the serial chamber gun.

- Only when these factors are reasonably matched, can the optimum performances be obtained.