Study on the Solid Propellant Burning Rate Enhanced by Plasma in the Closed Bomb

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INTRODUCTION

In the electrothermal-chemical (ETC) launch, a plasma generator (PG) is used to replace the conventional ignition. The ignition and combustion process of the propellant with the plasma is quite different from that with the conventional ignition. The process of the interior ballistics can be improved and the projectile muzzle can be increased in the ETC launch .

Closed bomb experiments are taken to analyze the ignition and combustion phenomena of the propellant with or without plasma. In the closed bomb experiments, the influence of the charging structure and the temperature of the propellant is analyzed. The physical and chemical analysis of the propellant ignited in the interrupted closed bomb experiments is carried out by the scanning electron microscopy (SEM) and X-Ray fluorescence (XRF) spectroscopy. In order to analyze the ignition characteristics of the propellant in the chamber, low electric energy is used in the ETC launch and gun simulator.

In this paper, a closed bomb experimental system is established. Different kinds of solid propellants (4/7 high-nitrogen solid propellant, 5/7 high-graphite solid propellant and 5/7 low temperature sensitivity coated propellant) are ignited by the conventional ignition or the capillary plasma generator (CPG). In the closed bomb experiments, the input electric energy of the CPG and the distance between the solid propellant and the CPG are changed. The ignition delay time, the time of the maximum of the pressure and the pressure in the closed bomb are measured. The burning time of the propellant and the pressure changing rate are calculated. Depending on the experimental results, the influence on the ignition and combustion of the propellant with the plasma is analyzed.

EXPERIMENTAL SYSTEM OF THE CLOSED BOMB

The structure diagram of the closed bomb experimental system is shown in Figure 1. It is contained by the pulse forming network (PFN), the closed bomb and the measuring & controlling system. The PFN contains four modules which can be used independently as a system circuit . Each module contains a 1220μF capacitor, a 40μH inductance, a high power switch, a crowbar circuit and a surge protection resistor. The closed bomb is a high-pressure thick-walled cylinder, the volume is 145 cm^3, and the maximum of the allowed pressure is 500MPa. The igniter mounted at the left side of the closed bomb can be changed. The electric primer is used as the conventional ignition in the closed bomb experiment. The length of the CPG used in the closed bomb is 60mm, and the inner diameter is 6mm. The solid propellant sample is placed in the closed bomb, and the distance between the CPG and solid propellant can be changed.

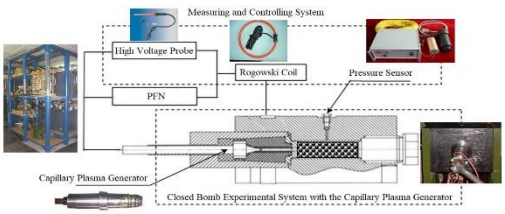

Figure 1 Structure diagram of the closed bomb experimental system

The experimental measuring system is composed of sensors and a data acquisition equipment. Gas pressure is measured by a Kistler 6215 pressure sensor. High voltage probe and Rogowski coil are used to measure the voltage and current of the CPG. JV5200 transient recorder is used to record the experimental data. There are 8 channels for the collection in the transient recorder, and the sampling frequency is 20MHz.

CONCLUSIONS

A closed bomb experimental system with the CPG is built to study the ignition and combustion of the solid propellant with the plasma. 4/7 high-nitrogen solid propellant, 5/7 high-graphite solid propellant and 5/7 low temperature sensitivity coated propellant are ignited by the conventional ignition and the CPG in the closed bomb. The ignition delay time is reduced by the plasma. Compared with the pressure changing rate curves with different igniters, the enhanced gas generation rate during electrical discharge (EGGRDED) is proved. Compared with the maximum of the pressure changing rate with different igniters, the enhanced gas generation rate post electrical discharge (EGGRPED) appears when 4/7 high-nitrogen solid propellant and 5/7 low temperature sensitivity coated propellant is ignited by the CPG. The EGGRPED is influenced by the composition of the propellant.

The influence of the electric power and the distance between the CPG and the propellant is studied by the closed bomb experiments with 4/7 high-nitrogen solid propellant. The EGGRDED increases with the increasing of the electric power or the decreasing of the distance between the CPG and the propellant, while the EGGRPED is not influenced by the electric power and the distance between the CPG and the propellant.

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RESULTS AND DISCUSSIONS

4/7 high-nitrogen solid propellant, 5/7 high-graphite solid propellant and 5/7 low temperature sensitivity coated propellant are used in the closed bomb experiments. In the experiments, the discharge voltage of the capacitor and the distance between the CPG and the propellant are changed.

IGNITION WITH DIFFERENT SOLID PROPELLANTS

Three different propellants are ignited by the conventional ignition and the CPG. The weight of the propellant is 36.1g, and the propellant is placed in the middle of the closed bomb. The discharge voltage of the capacitor is 10kV.

No.	Propellant	E_{pl}(kJ)	t_{ig}(ms)	t_{end}(ms)	p_m(MPa)
1	4/7 high-nitrogen	0	1.673	4.95	300
2		71.4	0.197	2.44	319
3	5/7 high-graphite	0	1.79	5.9	303
4		69.7	0.275	3	326
5	5/7 low temperature sensitivity coated	0	10.52	17.52	262
6		68.2	0.386	4.538	287

With the plasma, the ignition delay time and the burning time are reduced, and the burning process is enhanced. With the conventional ignition, the pressure changing rate curve has only one spike, which appears near the end of the combustion. It increases with the increasing of the pressure. The pressure changing rate curve with the CPG has another spike during the discharge of the CPG. The enhanced gas generation rate during electrical discharge (EGGRDED) is proved. The enhanced gas generation rate post electrical discharge (EGGRPED) appears, when 4/7 high-nitrogen solid propellant and 5/7 low temperature sensitivity coated propellant is ignited by the CPG. It is influenced by the composition of the propellant.

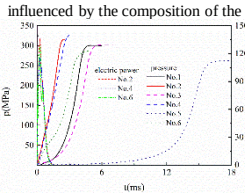

Figure 2 Pressure and electric power

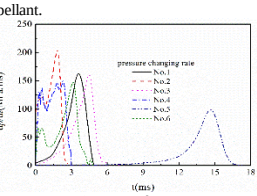

Figure 3 Pressure changing rate

IGNITION WITH DIFFERENT ELECTRICAL PARAMETERS

In order to analyze the influence of the electrical parameters of the CPG, only the discharge voltage of the capacitor is changed.

No.	U_c(kV)	E_{pl}(kJ)	t_{ig}(ms)	t_{end}(ms)	p_m(MPa)
7	4	15.6	0.64	3.56	305
8	8.3	48.2	0.261	2.93	318
2	10	71.4	0.197	2.44	319

At the same distance between the CPG and the propellant, the ignition and enhanced burning process of the propellant is proportional to the electric power. During the electrical discharge, the pressure changing rate increases with the increasing of the electric power. It is proved that the EGGRDED is influenced by the electric power. The maximum of the pressure changing rate stays at 205MPa/ms. It is proved that the EGGRPED is not influenced by the electric power of the CPG.

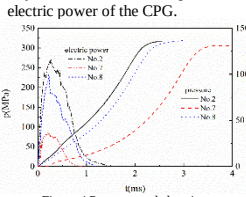

Figure 4 Pressure and electric power

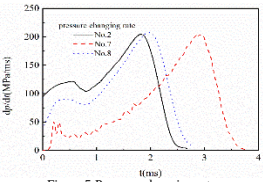

Figure 5 Pressure changing rate

IGNITION WITH DIFFERENT DISTANCES

The CPG is mounted at the left side of the closed bomb. In the experiments, the place of the propellant in the closed bomb is changed.

No.	U_c(kV)	Place	E_{pl}(kJ)	t_{ig}(ms)	t_{end}(ms)	p_m(MPa)
8	8.3	middle	48.2	0.261	2.93	318
9	8.3	right	46	0.33	3.15	310
2	10	middle	71.43	0.197	2.44	319
10	10	left	71.51	0.167	2.16	329

With the similar electric power, the ignition and enhanced burning process of the propellant is inversely proportional to the distance between the CPG and the propellant. During electrical discharge, the pressure changing rate increases with the decreasing of the distance. The EGGRDED with the similar electrical parameters is inversely proportional to the distance between the CPG and the propellant, while the EGGRPED is not influenced by the distance.

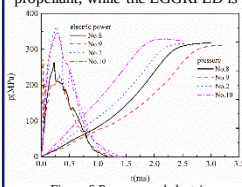

Figure 6 Pressure and electric power

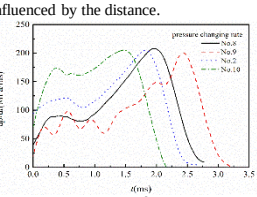

Figure 7 Pressure changing rate