MEASUREMENT OF DELAY TIME FROM PROPELLANT IGNITION TO PROJECTILE LAUNCH IN TWO-STAGE LIGHT GAS GUN USING ELECTROTHERMAL-CHEMICAL GUN TECHNOLOGY

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ABSTRACT

The hypervelocity impact experiments on the ground are indispensable in order to develop the defense structure over the impact with space structure and space debris. Today Two-Stage Light Gas Gun (TSLGG) is one of the most powerful accelerators. In Kyushu Institute of Technology, projectile velocity of 7.94 km/s was attained by means of the TSLGG with hydrogen gas. However it is well known that relative impact velocity at the low earth orbit is up to 15km/s. This impact velocity cannot be attained by the current TSLGG because sound velocity of light gas is smaller than 10km/s. Then, we have started a project of counter impacts in order to raise impact velocity. We developed a new TSLGG in which the technology of Electrothermal-Chemical (ETC) gun is applied to the 1st stage of TSLGG. In this paper, we measured delay time of ETC-based TSLGG as well as time variation of current, discharge voltage and pressure. And we succeeded to reduce jitter of the delay time small than ±0.1msec.

1. INTRODUCTION

We have encountered problems of hypervelocity impacts between space structures and space debris which increases in Earth Orbit with progress of space development. Hypervelocity impact tests on the ground are necessary in order to develop a bumper shield against the space debris impacts. In our laboratory, we have obtained the maximum projectile velocity of 7.94km/s using a two-stage light gas gun in which hydrogen gas is employed as light gas[1,2]. In general, it is said that the maximum velocity of a projectile launched by a two-stage light gas gun is limited to be 10km/s because of sound velocity of the light gas. However, it is well known that the relative velocity between space debris and space structure in the low earth orbit is up to 15km/s, and this impact velocity cannot be obtained by TSLGG. In our laboratory, we have started a project of counter impact using two sets of TSLGGs to attain the impact velocity of 15km/s. Young and Smith have already tested counterfire impacts and they obtained 12km/s[3,4]. In their work about 500m test range is required for the counterfire impact because jitter of operational time (delay time) from ignition signal for black and smokeless powder to launch of a projectile is comparatively large, and as a result, an impact position between a projectile and a target, which are launched in the counter impact, is widely changed. For example jitter of tens msec means impact position jitter of hundreds meters at velocity of 10km/s. In this study, we apply ETC gun technology[5,6], in which not only chemical energy but also electric energy is supplied, to the first stage of TSLGG in order to reduce the jitter of the delay time. In this paper, we measured the delay time of the ETC-based TSLGG as well as time variation of current, discharge voltage and pressure. And we tried to reduce jitter of the delay time small than ±0.1msec.

2. ELECTROTHERMAL-CHEMICAL GUN

As mentioned in the previous chapter, ETC gun is a gun in which a projectile is launched by electric energy as well as chemical energy. ETC is one of Electromagnetic Launcher (EML), and has been studied as well as rail gun and coil gun. Figure 1 shows configuration of an ignition chamber of ETC gun.

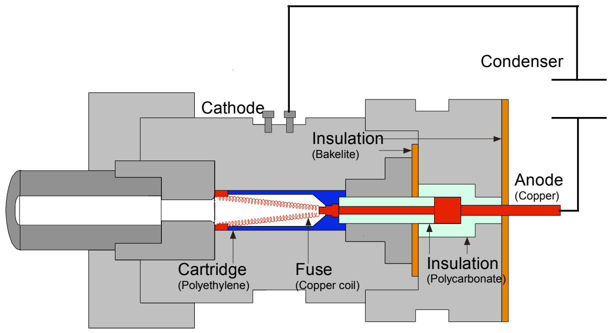

Figure 1 Configuration of Ignition Chamber of ETC gun

Propellant is stored in a cartridge made of polyethylene. Large current discharged from a condenser bank shown in Fig.2 flows in a copper wire, and this copper wire is exploded to be a state of plasma. Propellant is ignited by this plasma, and a projectile is launched by the combustion gas from burned propellant. By applying ETC gun technology to the first stage of TSLGG, it is thought that combustion rate could be stable and that jitter of operation time of ETC-based TSLGG could be smaller than that of conventional TSLGG. Figure 3

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shows electric circuit diagram of 10kJ condenser bank, which has inductance of 80, 160, 320 and 640μH, and charged voltage of 20kV.

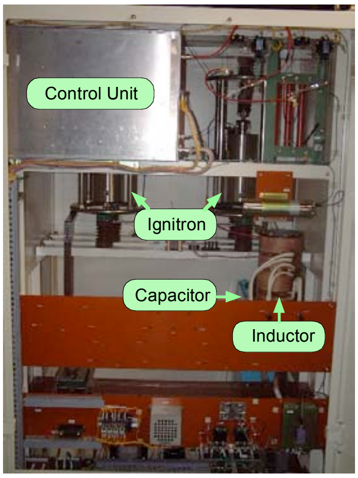


Figure 2 Condenser Bank of 10kJ for ETC gun

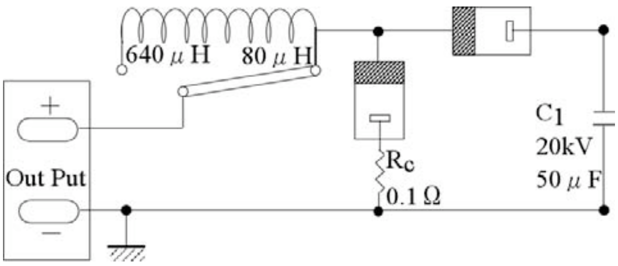
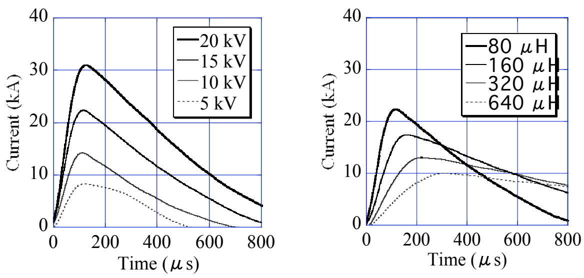


Figure 3 Electric Circuit Diagram of 10kJ Condenser Bank

Figure 4 shows current profile at different charged voltages and inductances.



(a) Dependency of charge voltage (Inductance is fixed to be 80μH.)

(b) Dependency of inductance (Charge voltage is fixed to be 15kV.)

Figure 4 Current Profile of 10kJ Condenser Bank

It is confirmed from this figure that peak current is proportional to charged voltage and that the time of the peak current shifts to the right and the magnitude of the peak current decreases according to the increase of the inductance.

3. ETC-BASED TSLGG

3.1. Operation Parameter

Propellant of ETC-based TSLGG is composed of ammonium nitride(NH_4NO_3), polyoxymethyrene(POM) and aluminum powder, and the mixture ratio is 5:2:1[7]. NH_4NO_3 is used as material of industrial explosive because of its low explosiveness, safety and low cost[8,9]. POM is flammable plastic with a lot of CH2O- and hydrogen is generated by reaction with NH_4NO_3 as shown in Eq.(1).

$$2NH_4NO_3 + CH_2O \rightarrow 2N_2 + 5H_2O + CO_2 \quad (1)$$

Aluminum powder is also added to NH_4NO_3 and sensitivity of NH_4NO_3 increases. The reaction formula of NH_4NO_3 with aluminum powder is as follows.

$$3NH_4NO_3 + 2Al \rightarrow Al_2O_3 + 3N_2 + 6H_2O \quad (2)$$

Table 1 shows design parameters of ETC-based TSLGG, and Table 2 shows its operational parameters. Configuration of ETC-based TSLGG is shown in Fig.5.

Table 1Desing Parameters of ETC-based TSLGG

Cartridge		Pump tube		Taper	Launch tube		Total
Bore	Length	Bore	Length	deg	Bore	Length	length
[mm]	[mm]	[mm]	[mm]	[deg]	[mm]	[mm]	[m]
22	85	20	825	4	5	830	2.5

Table 2 Operational Parameters of ETC-based TSLGG

Mass of propellant			Diaphlagm		Mass of Piston	Initial charged pressure of light gas	Mass of projectile
NH_4NO_3	POM	Al powder	Thickness	Chipping Load			
[g]	[g]	[g]	[mm]	[N]	[g]	[MPa]	[g]
5	2	1	2	0.56	25.5±0.5	0.60(He)	0.2±0.01

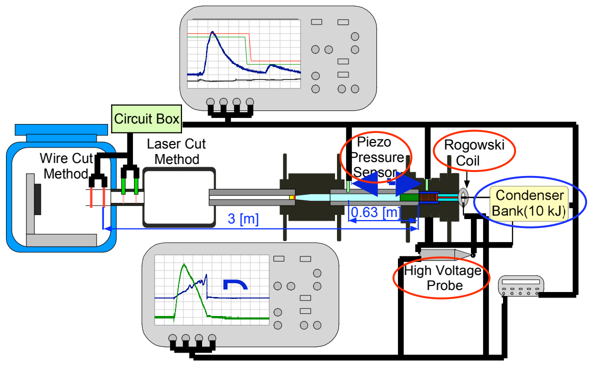
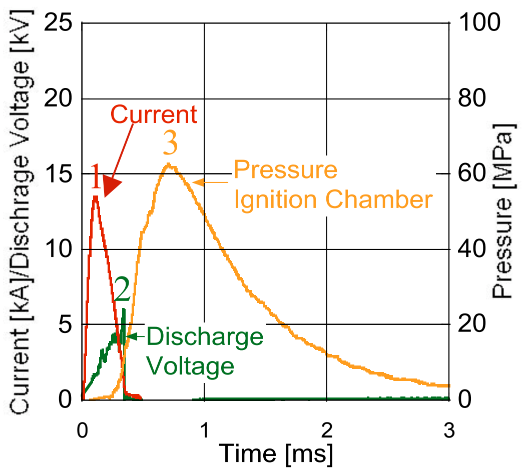


Figure 5 Configuration of ETC-base TSLGG

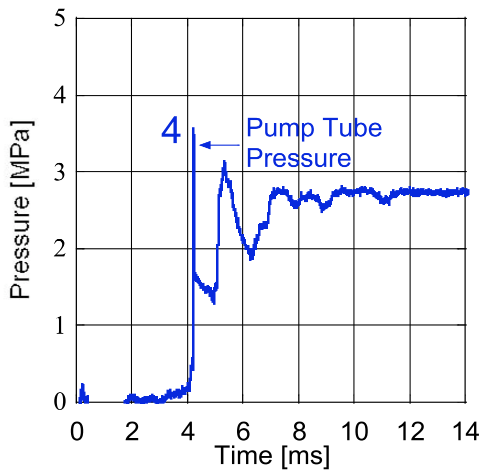
Discharge parameters should be determined in ETC-based TSLGG in addition to conventional parameters of TSLGG. In this study, jitter of ignition and burning rate of the propellant should be controlled to obtain stability of operational time of ETC-based TSLGG. This control requests that large current flows into the copper wire of the combustion chamber in a short duration.

3.2. Measurement Method

Current profile, discharge voltage and pressure profile in the combustion chamber were measured by means of Rogowski coil, high voltage probe and PCB pressure gauge, respectively as shown in Fig.5. And pressure profile in the pump tube and projectile velocity are also measured by means of PCB pressure gauge and laser cut method. Delay time from the ignition signal for the condenser bank to the wire cut signal in the test chamber is also measured. Figure 6(a) shows time variation of current, discharge voltage and pressure in the combustion chamber, and Fig.6(b) shows time variation of pressure in the pump tube.



(a) Time variation of current, discharge voltage and pressure in ignition chamber



(b) Time variation of pressure in pump tube

Figure 6 Profile of Current, Discharge Voltage and Pressure

Here we pay our attention on the peak time of current, discharge voltage and pressures, and number each of the peaks as shown in Fig.6. In addition, number 5 is given to time from the ignition signal to time at which the wire is cut by the projectile.

3.3. Experimental Results

We made three types of experiments. The first one is charge voltage examination, the second is inductance examination and the last one is operational parameter examination. In the charge voltage examination, mass of propellant, initial pressure of He gas in the pump tube and inductance of the condenser bank are fixed to be 8g, 0.6MPa and 80mH, respectively. The charge voltage is changed from 10kV to 15kV. 15kV is about 70% voltage of the full charged voltage, and is selected considering the life time of a capacitor in the condenser bank. Figure 7 shows comparison of the peak time between charge voltage of 10kV and 15kV.

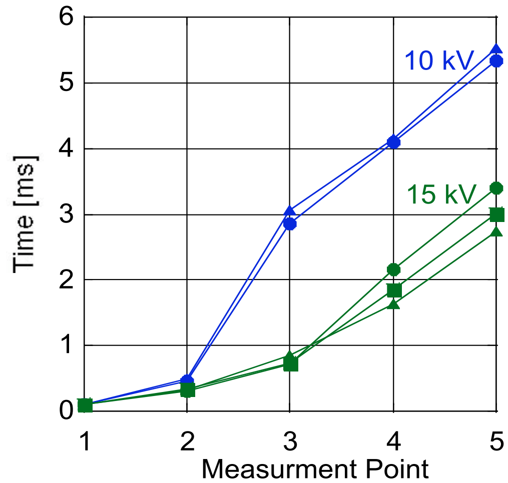


Figure 7 Comparison of Delay Time Between Charge Voltages of 10kV and 15kV

It is found that no significant difference is observed in No.1 and No.2. On the other hand, it should be noted that large difference is observed in No.3. This fact means that combustion rate is dependent on charge voltage, and higher voltage is desired to reduce jitter of combustion. However, as mentioned earlier, the charge voltage is limited up to 15kV considering the life time of the condenser bank.

In inductance examination, mass of propellant, initial pressure of He gas and charge voltage are fixed to be 8g, 0.6MPa and 15kV, respectively. Inductance is changed from 80μH to 640μH. Figure 8 shows comparison of the peak time between 80μH and 640μH. Almost the same results as the voltage examination are obtained in the inductance examination. Namely, it can be seen from Fig.8 that no significant difference is observed in No.1 and No.2.

On the other hand, it should be noted that large difference is observed in No.3. This fact means that combustion rate is dependent on inductance, and smaller inductance is desired to reduce jitter of combustion. Through the voltage and inductance examinations, we decide to select combination of voltage of 15kV and inductance of 80μH in the following operational parameter examination.

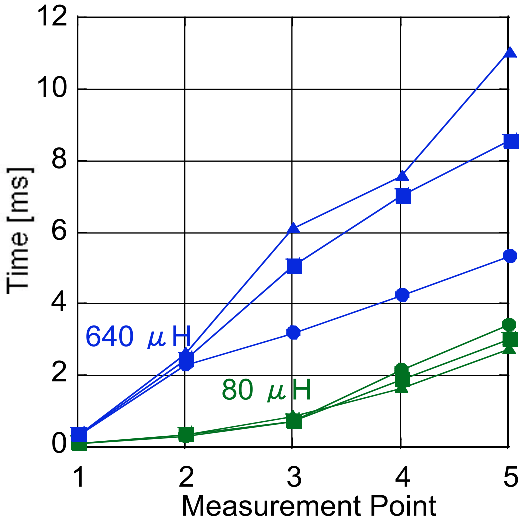


Figure 8 Comparison of Delay Time Between Inductance of 80μH and 640μH

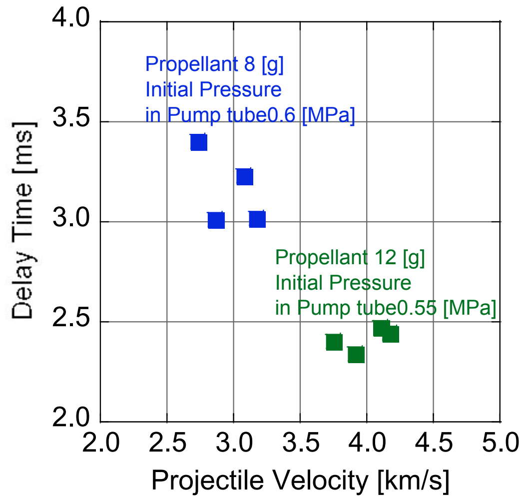


Figure 9 Comparison of Delay Time Between Propellant of 8g and 12g

In the operational parameter examination, charge voltage and inductance are fixed, and mass of propellant and initial pressure of He gas are changed. Initial pressure of He gas should be changed according to mass of propellant. Otherwise, a piston in the pump tube might not stop at desired position and come out from opened hole of a diaphragm. Figure 9 shows comparison of delay time between propellant mass of 8g and 12g. It can be seen from this figure that jitter in the case of 8g is ±0.2msec and that of 12g is ±0.1msec. This fact is explained by movement of the piston. If mass of propellant increase, the piston is positive and negative accelerated quickly. As a result jitter of piston movement becomes smaller and the jitter of the delay time also becomes smaller.

4. CONCLUSION

In this study, we developed ETC-based TSLGG in which propellant is ignited by plasma induced by large current flow from the condenser bank in order to reduce the delay time from ignition signal to launch of a projectile. We decided combination of charge voltage and inductance to obtain stable combustion of propellant. As a result, we succeeded in reduction of jitter of the delay time, and obtained much smaller jitter of ±0.1msec than that of conventional TSLGG in which black and smokeless powder are employed as propellant.

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