THE EXPERIMENTAL RESEARCH OF THE PLASMA-PROPELLANT CHARGE INTERACTION

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[**Abstract**] The ignition and combustion of the propellant charge are very important processes for not only general guns, but also the electro-chemical(ETC) guns. The law of interaction between the ignition system and the propellant charge is the important key to influent the safety and the stability of interior ballistics process. In this paper, the interaction between plasma ignition and the propellant charge has been studied at the conditions of changing the elementary parameter of the electrical energy and the structure of plasmatron and propellant charge. A simulator has been built which inner structure is same with the real gun's chamber. The mixture of real propellant grains and the unreal propellant grains, which were same with the real propellant in the geometry character and the density and the coefficient of the exchange heat, are loaded in the simulator. The maximum pressure in the simulator is about 60MPa in experimental studies. The results are useful to establish the technical foundation to study the structure of the plasmatron and the character of the interior ballistics and propellant charge in ETC guns.
Keywords: plasma, the launch propellant charge, ignition, combustion

1 Introduction

Since 90's of the last century, the technique of the ETC guns has developed very quickly, and some exciting research results in the aspect of the theoretical and experimental investigation has been gotten specially [1-9]. The basic goal of the ETCG is to improve the muzzle kinetic energy of the guns and enhance the battle power of the guns by reasonable matching of the electrical energy and the chemical energy through the plasma with the temperature of the electron at the 10000k～20000k. The main difference between conventional gun and ETC guns is the ignition system was replaced by the plasma ignition system which includes the several important advantages. By using the plasma ignition system, it is enable to increase the loading density of the propellant charge by rather greatness. That is to say, the mass of the charge or the initial chemical total energy of the gun chamber is increased and finally the muzzle velocity of the same type projectile is increased. The second advantage is the characteristic of the electrical explode of the plasmatron enable to get identically and instantaneously ignition for the propellant charge of the gun chamber and avoid from the great pressure wave in the chamber at the process of the ignition. The third advantage is the adjustability of the parameter of the electrical energy has the temperature compensational ability for the launch propellant charge and the control ability of the ballistic process of the gun. The interaction between the plasma and the propellant charge even as the interaction of the common ignition and the propellant charge also is a very important research content and impendency needed to resolving problem. The investigating of the problem was ongoing, which enable to obtain important technical data information by the quantitative and qualitative study for the ignition characteristics of the propellant charge, such as the transmit characteristics of the powder gas pressure wave after the combustion of the propellant charge and the movement status of the propellant charge bed in the condition of the plasma ignition. All these studies enable to provide strongly helps for the design and test research of the interior ballistic and the propellant charge of the ETCG.

2 The content and method of the experiment

2.1 The content of the experiment

The detail experimental methods and results for simulation and determinate about the characteristics of ignition and powder gas pressure wave transmitting and the movement status of the propellant charge bed in the plasma ignition environment have been provided in the paper [10] and [11]. On this base, the investigation of several aspects was done by using the special simulator and test system which are showed in fig 1.

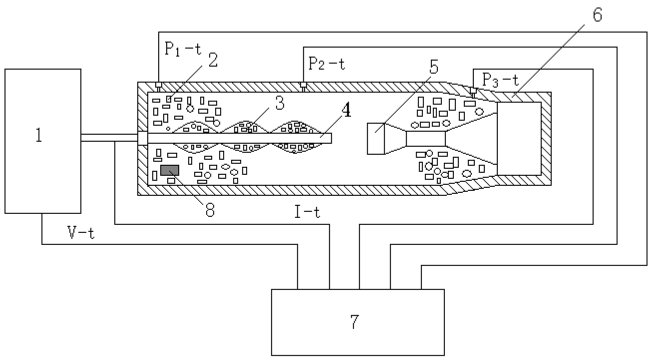
1) By using the same electrical energy parameter and the structure of the plasmatron, the investigation about characteristics of the ignition and the powder gas pressure wave and movement status of the propellant charge bed was done;

2) By using the same electrical energy parameter and the structure of the propellant charge, the characteristics of the plasmatron were studied;

3) The influence on the transformation efficiency of the electrical energy by changing the electrical energy parameter was studied.

2.2 The method of the experiment

The experiment device and test system as show in fig 1, which consists of the 0.5MJ impulse electrical power、 the discharge control system、 the chamber simulator、 the plasmatron、 the real and unreal propellant charge grains、 the multi-channel P-t curve test system and the copper columniation pressure meter etc. The key steps of the experiment process include: assembly plasmatron、 loading real and unreal charge grains、 installing experiment device、 assembly pressure sensor、connecting the electrical device、 charging and discharging impulse electrical power、 releasing the powder gas in the simulator chamber、 disassembly experiment device for the second firing. Test results are recorded for each the experiment, and the test phenomena is noted and observed.



1-impulse electrical power，2-unreal charge grains，3-real charge grains，4-plasmatron（or plasma igniter），5-unreal projectile，6-simulator，7-multi-channel test system，8- the copper columniation pressure meter

Fig 1 The sketch of the experiment device and test system

3 The experiment results and analyses

3.1 The experiment results

According to the above experiment content and method, the experimental results as show in table 1.、 table 2. and fig.2-fig.8.

Table 1. the experiment scheme and the discharge coefficiency of the plasmatron

Scheme number	Scheme symbol	The plasma beginning ressistance (mΩ)	Initial electrical energy (kJ)	Maximum discharge current (kA)	Discharge electrical energy (kJ)	Discharge coefficiency (%)	remark
1	C1F1	171	121.275	52.00	25.370	20.92	
		74	121.275	46.85	61.070	50.36	Fig.2.fig.6
2	C1F2	42	121.275	50.65	52.644	43.41	
		85	121.275	46.85	61.900	51.04	Fig.5.
3	C2F1	102	121.275	50.65	53.347	43.99	Fig.3.fig.7.
4	C2F2	119	121.275	51.24	54.404	44.86	
5	C3F1	80	121.275	43.63	73.620	60.76	
		112	121.275	49.87	57.091	47.08	Fig.4.fig.8

Annotated：C1——plasma igniter with opening orifice and plating with copper film by surface igniter; C2——plasma igniter with opening orifice and metal wire; C3——plasma igniter with opening narrow slot and plating with copper film by surface igniter; F1——mixed loading charge with 25/19 high energy propellant charge grains and unreal propellant charge grains; F2——mixed loading charge with 25/19 high energy propellant charge grains、17/19 low energy coating propellant charge grains and unreal propellant charge grains.

Table 2. The tested P-t curve、 the maximum copper pressure and the status of the propellant charge bed of the every scheme

Scheme number	P_m /MPa（copper）	Ignition delay time /s	P_1（electric.）		P_2（electric.）			P_3（electric.）			Status charge bed
			t_m /ms	P_m /MPa	Δt_0 /ms	t_m /ms	P_m /MPa	Δt_0 /ms	t_m /ms	P_m /MPa	
1	64.4	0.570	35.2	64.5	0.5	33.7	66.8	0.8	33.6	66.4	Loose
2	63.5	0.790	22.1	62.1	0.7	21.3	63.4	0.2	22.3	62.4	Loose
3	64.0	1.535	24.5	66.7	0.0	24.7	66.5	-0.1	24.8	66.1	Loose
4	61.7	1.580	26.9	62.6	0.7	26.4	61.4	1.0	25.3	62.1	Loose
5	63.5	1.390	22.7	63.8	1.0	21.2	64.3	0.4	22.4	63.3	Loose

Annotated: 1. t_m –the time from the beginning moment move up of the gas pressure to the maximum gas pressure; 2. Δt_0-the time difference from the beginning moment move up of the gas pressure of the every point to the beginning moment move up of the gas pressure of the point P_1, plus symbol means delay, minus symbol means forward; 3. The ignition delay time means the time interval between the moment of the discharge and the beginning moment move up of the gas pressure of the point P_1.

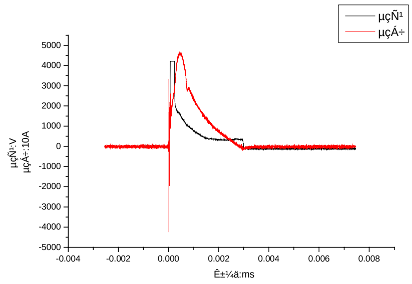


Fig.2. The curve I-t、V-t of the C1F1 scheme

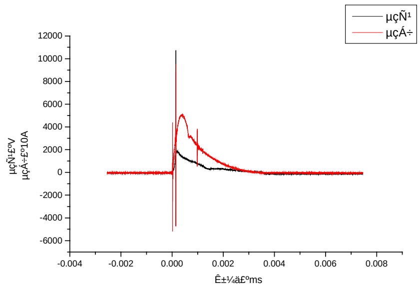


Fig.3. The curve I-t、V-t of the C2F1 scheme

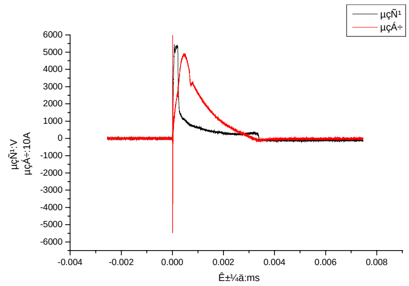


Fig.4. The curve I-t、V-t of the C3F1 scheme

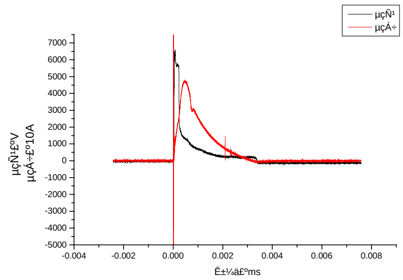


Fig.5. The curve I-t、V-t of the C1F2 scheme

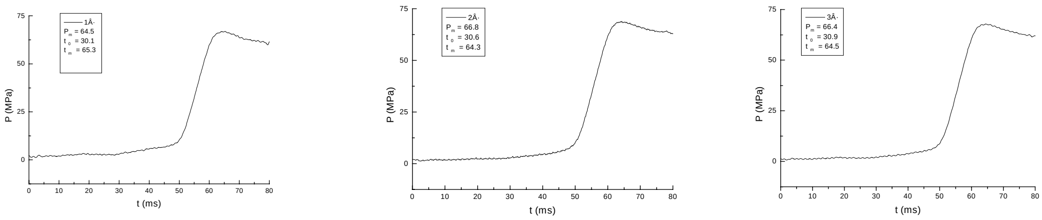


Fig.6. The curve P-tof the C1F1 scheme

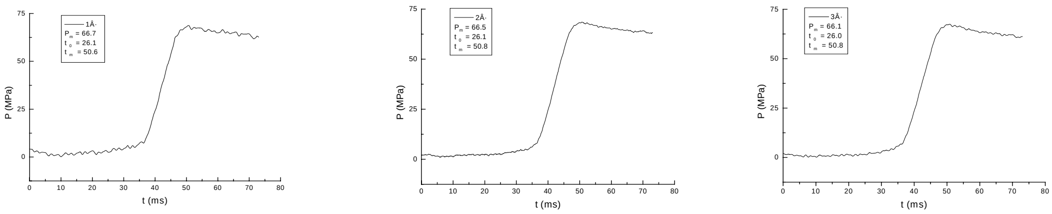


Fig.7. The curve P-t of the C2F1 scheme

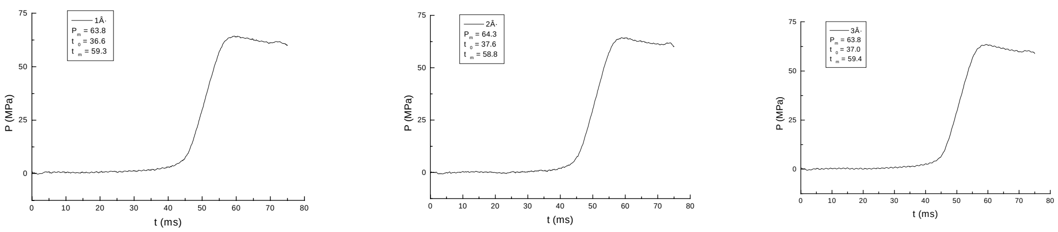


Fig.8. The curve P-t of the C3F1 scheme

3.2 The analyses of the experiment results

3.2.1 From table 1 we can make out the fellow results.

1) To compare scheme 1 and scheme 2、scheme 3, the difference of the propellant charge structure has little influence on the discharge efficiency of the plasmatron under the condition of the same beginning parameter of the electrical power and loading density;

2) To compare the scheme 1、3、5, the difference of the opening style orifice and electrical explode carriers(plating film and metal wire) has great influence on the discharge efficiency of the plasmatron under the same propellant charge structure. When there is the same area of the opening orifice, the style of the groove slot opening orifice and the plating film on the surface igniter was favourable for increasing discharge efficiency. The main reason was the style of the narrow opening groove slot is useful to equably create and vent out plasma from the plasma igniter and assure the balance and equality of the ion and electron in the plasma channel. As show in fig.4, the discharge pulse width is bigger than others, and the style of the round opening orifice is shorter. Comparing the style of the plating film and the metal wire, the main advantage of the plating film by surface of the plasma igniter was that the production and the distribution of the plasma alone the plasma igniter was very uniform, and at the same time the wave of the plasma flow in the channel is smaller. So at this condition the width of discharge pulse is wider than explode metal wire (fig.2 and fig.3).

3）By using the gun simulator experiment (scheme 1、2、5), we founded that the scale of the elementary electrical resistance of the plasma igniter obviously influent on the discharge efficiency. And there is a optimum value for the elementary electrical resistance of the plasma igniter to assure obtaining the maximum discharge efficiency at the same condition of the initial parameter of the electrical energy.

4) The range of the maximum discharge current is about 40-55kA in the experiment, the discharge efficiency is among 40%-60%.

3.2.2 We can find out the fellow results from table 2.

1) The igniting delay time of the C1 scheme is shortest than others, the igniting delay time of the C2 scheme is 1.4s at the second place, and that the igniting delay time of the C3 scheme is more then 1.5s. The main reason about these schemes having so long the igniting delay time is that the ratio of the unreal charge grains is up to about 90%, which result in the effect of the decalescence is very strong.

2) The startup times difference of the test pressure of the points P_1、P_2 and P_3 are among 1ms. The good consistency and instantaneous of the plasma ignition can be seen from this.

3) The times from startup to the maximum gas pressure of the points P_1、P_2 and P_3 are essentially instantaneous which mean that the ignition is uniform and the combustion of the real charge grains are stability and no abnormal phenomena in the gun simulator.

4) At the condition of the same propellant charge quality of the every scheme, the copper gas pressure obtaining from the same test is about 60MPa.

3.2.3 From the test curve V-t、I-t of the fig.2.、fig.3. and fig.4, we find that the discharge process are different between the styles of the explode by plating film and metal wires. The plating film by using the chemical plating method to achieve the goal of the uniformly plating can result in the stability and the high ionization of the discharge explode process to compare with the single or many wires. Therefore the time of the discharge process is longer and the impulse width of the discharge is wider in the limit plasma igniter channel.

3.2.4 From table 2、fig.6.、fig.7. and fig.8, we can find that all the test curve P-t of the all igniters and propellant charges schemes are smooth and no pressure wave phenomena, and even its consistence were very good. When we checked the status of the charge bed in the gun simulator after every test firing, we found the status of the propellant charge bed were all loosen status and no stuff phenomena which means that the instantaneity and consistence of the plasma igniter are very good.

4 Conclusion

By using the analysis of the experiment results, we can draw the fellow conclusions:

4.1 All designed schemes of the plasma igniters can efficiently ignite the propellant charge, and the combustion of the propellant charge is stable、no obvious gas pressure wave and no stuff phenomena in the chamber.

4.2 The different structures of the plasmatron have obvious influent on the ignition characteristics and process of the propellant charge. And the change of the structure of the propellant charge by using the same loading density is small influent on the interaction between plasma and propellant charge.

4.3 At the same condition of the propellant charge, the different structure of the plasmatron is strongly influent on the discharge efficiency and igniting delay time.

4.4 At the same condition of the initial parameter of the electrical energy, there is a optimum initial electrical resistance of the plasmatron to assure obtaining the maximum discharge efficiency.

Reference of the literatures

[1]. R.M.Ogorkiewicz, Future tank guns Part □:Electromagnetic and electrothermal guns, International Defense Review 1/1991,61～64.

[2]. G.P.Wren and W.F.Oberl etc, Spatial Effects of an Electrically Generated Plasma On the Interior Ballistics of Electrothermal-chemical (ETC) Guns, IEEE Transactions on Magnetics, Vol.31,No.1,JANUARY 1995,457～462.

[3]. William F. Oberl AND Bradly D.Goodell, The role of Electrothermal-chemical (ETC) gun propulsion in enhancing direct-fire gun lethality,16th international symposium on ballistics,SAN FRANCISCO,CA,23-28 September,1996,59～69.

[4]. A.Chaboki,S.zelenak,B.Isle, Recent Advances in Electrothermal-chemical Gun Propusion at United Defense,L.P., IEEE Transactions on Magnetics, Vol.33,No.1,JANUARY 1997,284～288.

[5]. Kevin J.White,Irvin Stobie,William Oberle,Gary Katulka and Simon Driense, Combustion Control Requirements in High Louding Density, Solid Propellant ETC Gun Firings, IEEE Transactions on Magnetics, Vol.33,No.1,JANUARY 1997,350～355.

[6]. William Oberle, Bradley Goodell,John Dyvik,Dick Staiert and Amir Chboki, Potential U.S. Army Applications of Electrotherma-chemical (ETC) Gun Propusions, 17th International Symposium on Ballistics, Midrand,South Africa,23～27 March 1998,1-47～1-54.

[7]. Thomas H.G.G.Weise,Joseph Kruse, Paul Schaffers and Hans-Karl Haak, Status and Results of the German R&D Program on ETC Technologies,IEEE Transactions on Magnetics, Vol.37,No.1,JANUARY 2001,46～51.

[8]. Gloria P.Wren and William F.Oberle, Influence of High loading Density Charge Configurations On Performance of Electrothermal-chemical (ETC) Guns, IEEE Transactions on Magnetics, Vol.37,No.1,JANUARY 2001,211～215.

[9]. Hans K.Haak,Paul Schaffers,Thomas H.G.G.Weise and Holger G.Wisken, Basic Investigations in a 70mm Firing Simulator, IEEE Transactions on Magnetics, Vol.39,No.1,JANUARY 2003,231～234.

[10]. Chay Goldenberg,David Zoler, Noam Shapira, Plasma-Propellant Interaction at Low Plasma Energies in ETC Guns, IEEE Transactions on Magnetics, Vol.39,No.1,JANUARY 2003,227～230.

[11]. David Zoler, Gabriel Appelbaum, Noam Shafir,Shoshi Roshu, Chay Goldenberg, Shlomo Wald and Moshe Shapira, A New in Situ Method for the Measurement of Ignition Delays ang the Propagation of the Ignition Wave in Gun Charges, IEEE Transactions on Magnetics, Vol.39,No.1,JANUARY 2003,275～279.