Closed vessel equipped with capillary plasma generator as the new method of propellant's ignition and pirostatic investigation

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***Abstract**: Contemporary development of new types of ammunition is concentrated to improve the energetic characteristics, chemical stability and operational safety of propellants. Response to this requests are low vulnerability (LOVA) propellants. Previous closed vessel investigations indicated that classical primers (electric or percussion with black powder bedding) when used with LOVA propellants causes unstable burning, deflagration or even lack of ignition. Plasma generators, which create higher energy flux, temperature and make possible to control combustion process are possible solution of this problem. Assuming that in the future Poland may be a manufacturer of LOVA propellants, Military University of Technology began to develop of new closed vessel equipped with capillary plasma generator (CPG) - the new method of low vulnerability propellants ignition. In CPG systems plasma generation is obtained by discharge of high power capacitors through low diameter conductors in polyethylene coating (mainly cooper, aluminium and tungsten wires), causing them to explode (or other metallic vapour generating device). After wire explosion plasma causes burning of polyethylene, giving additional energy to plasma cloud. Plasma is vented to vessel causing high energy and heat flux through radiation and metallic vapour condensation. CPG is one of the most reliable ignition sources which make possible a reduction of temperature gradient effect and control combustion process.*

In this paper, different solutions of plasma ignition devices are briefly described. Furthermore, in the paper are presented: idea of our capillary plasma generator, preliminary experimental results (high speed camera pictures) of free air plasma jet propagation and comparison of pictures the impulse effects of plasma and black powder ignition.

***Keywords**: closed vessel tests, ignition, capillary plasma generator, LOVA propellants*

1. Introduction

Nowadays, artillery ammunition development leads two main directions: to increase the muzzle velocity and an operational safety. One of the most dangerous situations for gun crew (tank, self-propelled guns and howitzers) is being hit into ammunition compartment. Anti-tank projectiles and large fragments of shells can initiate propellant burning process. To avoid this situation Low Vulnerability Ammunition (LOVA) is being developed. Classical primers (electric or percussion with black powder bedding) when used with LOVA propellants causes unstable burning, deflagration or even lack of ignition. Solutions of this problem are plasma generators, which create higher energy flux, temperature and make possible to control combustion process. Guns in which plasma generators are applied as ignition source are known as Electro-Thermal Chemical (ETC) guns [1-3].

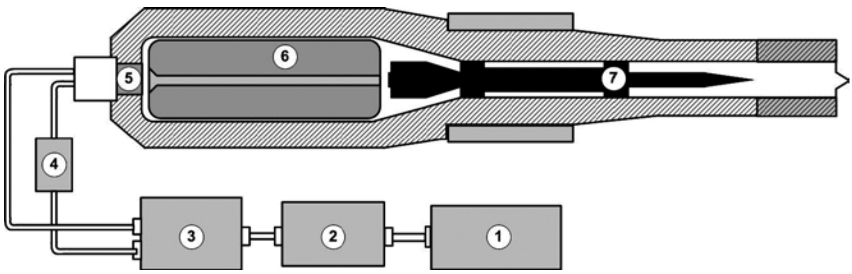


Fig. 1. Concept art of an ETC gun [3]: 1) Primary storage; 2) Secondary storage; 3) Pulse forming network; 4) Firing switch; 5) Plasma cartridge; 6) Propellant; 7) Projectile

ETC technology has the potential to improve performance of conventional guns by enhancing the ignition and combustion characteristics of propellants and enabling the use of advanced charges.

2. Conventional and plasma ignition

Burning a specific amount of propellant in a closed chamber is the most widely used experimental method to determine and to compare energetic and ballistic properties (force, co-volume, coefficients of burning rate law) of different propellants. The ignition of a propellant grain is decided by the temperature of its external surface reached after time t_{ign} from the commencement of its heating with this time being dependent on the intensity of the heat exchange.

Generally, the ignition comes down to supplying an appropriate dose of energy to the propellant's burning surface in order to generate such a chemical and thermal state which would equal that of a constant burn.

In the conditions of closed vessel tests, conventional ignition of the propellant in the closed chamber is realized by way of a small mass of black powder [4-7]. In reality the transfer of energy to the ignited surface of the propellant load being analysed from the ignition gasses takes place with the assistance of [8, 9]:

- free and forced convection,
- radiation of hot ignition gasses and the red-hot solid particles of the igniter material,
- collisions of the hot particles of the igniter material with the surface of the propellant being ignited,
- the thermal conduction in places of contact between solid particles of the igniter material and the grains of propellant being ignited.

Plasma generators create higher energy flux and temperature and make possible to control combustion process. There are two generic types of plasma generators: radial and axial discharge devices. The method of radial discharging electrical energy directly into propellant bed is known as the current injection (Fig. 2). Main disadvantage of the current injection method is interaction of high pressure gases with plasma is not good for the properties of plasma that are required and it needs higher energy to sustain electrical arc.

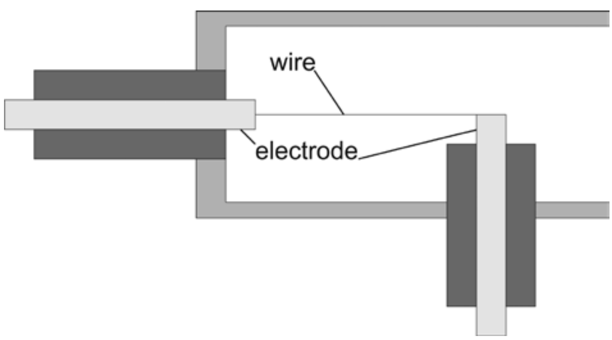


Fig. 2. The schematic view of current injection device

Axial pressure pulse is more desirable and allows to control projectile velocity in barrel. Typical axial discharge device is Capillary Plasma Generator (CPG) presented in Figure 3.
It consists of high density polyethylene (HDPE) tube with discharge wire inside. Plasma generated inside the tube vents into the combustion chamber under its own pressure.

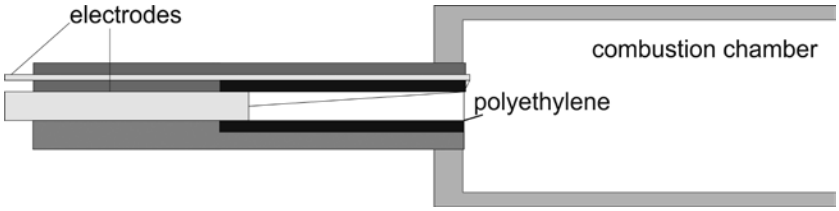


Fig. 3. CPG Plasma generator

Plasma generation in these devices is obtained by discharging high power capacitors. High voltage passing through low diameter conductor causes ohmic heating of wire. In our experiments we have used copper wire in diameter of 0.5 mm and length of 100 mm, which gives 1.75 g of copper. The energy which is needed to evaporate cooper is 830 J. Total energy stored in capacitors was about 1 kJ. Ohmic heating causes wire to boil. Copper in liquid state is still conducting electrical energy until it evaporates. In normal conditions gravity force would cause liquid to drop onto capillary, but in this timescale the gravity force is negligible. Electric arc passing through mixed air and cooper vapour causes plasma to occur. HDPE lining ablation injects "organic" (carbon and hydrogen) particles into plasma effects additional burning enhancing energy of plasma cloud.
Energy transfer from plasma cloud to propellants occurs in three main ways: UV radiation, copper vapour condensation and heat flux. Radiant energy transfer from plasma to propellant does not ignite propellant itself, this interaction produces significant enhancement in initial surface for propellant burning. Also radiation itself increases initial gas generation from propellant and not depends on initial temperature [10-14]. Cooper vapour condensation occurs when plasma cloud contacts with "cold" propellant surface. High velocity of cloud (~ 170 m s^{-1}) combined with high plasma temperatures (6000 – 11 000) K give a uniform and almost instantaneous ignition of propellant.

3. Black powder/plasma effect of ignition – comparable free air investigations

Our comparable investigations into black powder/plasma ignition are first held in Poland, and one of few in the world. First step to conduct closed vessel test with plasma ignition was to build reliable and reproducible plasma generator. As a type of the generator we use CPG. First tests were conducted using copper wire 0.2 mm in diameter and Pulse Forming Network (PFN) of 30 mH induction and 60 μF capacitors charged up to 1.5 kV giving 70 J of electric energy (Fig. 4).

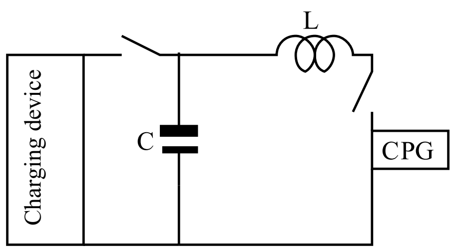
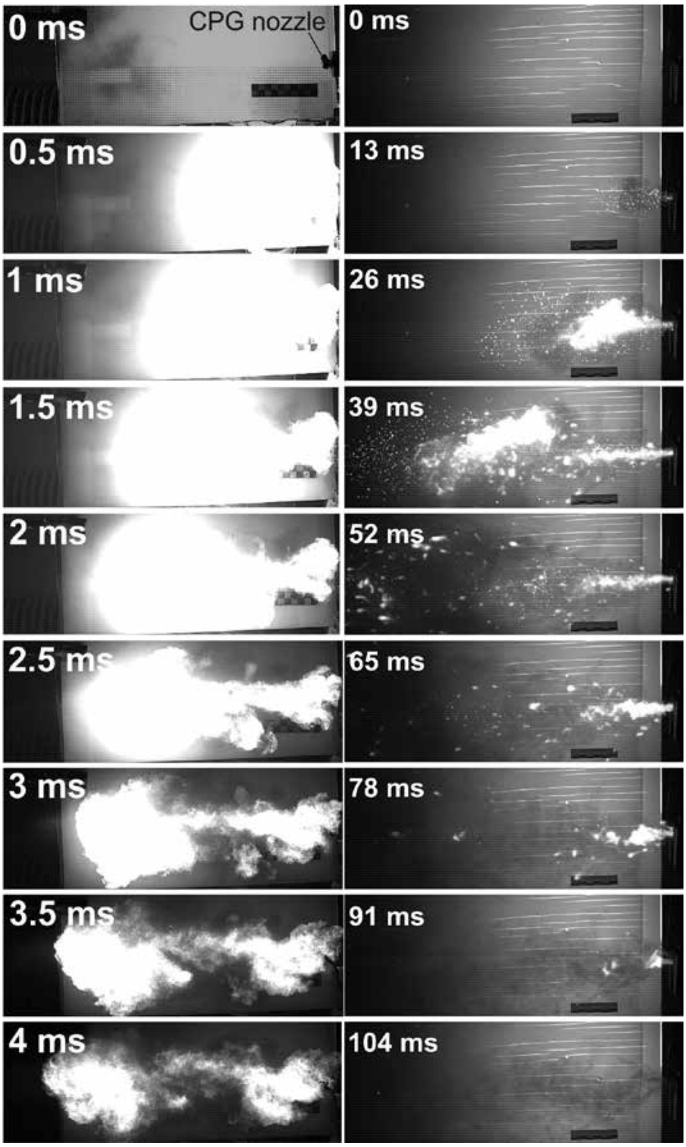


Fig. 4. Scheme of Pulse Forming Network with CPG

Tests were recorded using high speed camera to see how cloud of plasma propagates into free air. Videos recorded showed cloud of plasma being produced, but it wasn't reproducible shot to shot. Main problem we encountered was insufficient gas isolation causing coal to deposit on plasma generator chamber. Deposited coal acted as a conductor and large amounts of energy was transported not by plasma cloud as we wanted, but through metal chamber.

After isolating chamber from produced gases and plasma, shots were given with PFN consisting of 120 μF capacitors charged up to 4 kV giving energy of 960 J. To shorten energy pulse 15 mH induction was used. Obtained plasma cloud is presented in Figure 5a.

To investigation of black powder effect of ignition the CPG plasma generator (Fig. 3) was used too. In this case, the effect of ignition was studied using ignition system consisting of electric match and 0.5 g of black powder. Black powder load is energetic equivalent of plasma energy, assuming that PFN has 70% efficiency. This ignition system was situated inside tube of CPG generator. Polyethylene tube was not used in this situation in opposite to electrodes. Videos recorded black powder effect of ignition is presented in Figure 5b.



a) b)

Fig. 5. Plasma (a) and black powder (b) effect of ignition – comparable investigations

The long ignition delay for conventional ignition is illustrated and it is shown that conventional ignition systems deposit black powder particles onto the surface of propellant, which burn and transfer energy directly to the surface by convection and conduction.

Plasma ignition gives the advantage of short ignition delay and advantage of more intensive heat effect. For comparable heat flux, plasma ignition would be more efficient due simply to increased surface area over which heat energy is transferred.

Now we are attempting to closed vessel test with classic and LOVA propellants. This test requires new closed vessel to be designed because of PFN that uses high voltage and needs special equipment. Next step is to use full charge of batteries that consists of 840 μF capacitors able to withstand 6 kV discharge using only induction of wires used in PFN, to ignite classic and insensitive propellants. Total electrical energy that we can use is 15 kJ.

4. Conclusion

ETC system has the potential to improve performance of conventional guns by enhancing the ignition and combustion characteristics of LOVA propellants and enabling the use of advanced charges therefore theoretically and experimentally investigation of plasma propellant interactions during the plasma ignition of a solid propellant charge system is very important area of study.

So far, our free air investigations show that plasma ignition gives the advantage of short ignition delay and advantage of more intensive heat effect.

Further work is planned to closed vessel test with conventional and LOVA propellants and to measure the radiative energy transfer to propellant surfaces from within propellant grains.

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