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Closed Vessel Investigation of Propellant Ignition Process with Using Capillary Plasma Generator

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Abstract. Previous published results of closed vessel investigations indicated that classical primers (electric or percussion with black powder bedding) when used with LOVA propellants cause unstable burning, deflagration or even lack of ignition. CPG is one of the most reliable ignition sources which make possible a reduction of temperature gradient effect and control combustion process. Comparable tests of black powder and plasma ignition in closed vessel with conventional NC propellant were done. Shorter ignition time while using plasma was achieved.
Keywords: internal ballistics, closed vessel test, ignition, plasma generator

1. INTRODUCTION

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.

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The ignition of a propellant grain is decided by the temperature of its external surface reached after the 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 be equal to that of a constant burn.

In the conditions of closed vessel tests, conventional ignition of the propellant in the closed chamber is realized by a way of a small mass of black powder. 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:

– free and forced convection,
– radiation of hot ignition gasses and the red-hot solid particles of the igniter material (Fig. 1),
– 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.

Fig. 1. Exemplary picture of black powder ignition process (visible hot solid particles)

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 does not depends on initial temperature [3-8]. Cooper vapour condensation occurs when plasma cloud contacts with „cold" propellant surface (Fig. 2). High velocity of cloud combined with high plasma temperatures (6000-11 000 K) give a uniform and almost instantaneous ignition of propellant.

Fig. 2. Propellant grains with cooper condensed on surface

2. CAPILLARY PLASMA GENERATOR

Capillary Plasma Generator is a device that consists of thin wire (cooper, aluminium or tungsten) in polyethylene tube. Polyethylene protects metal parts of a generator and while burning adds energy to the cloud. Laboratory stand consists of 16 capacitors 30 µF each, and additional 15 mH of induction. Recently tested Capillary Plasma Generator gave us the results of reproducible plasma cloud, which was recorded on high speed camera [9]. Additional Rogowski Coil was used to compare the time and shape of current pulse. Discharges of 4 kV capacitors gave maximum of 12 kA current and pulse duration of 250 µs (Fig. 3).

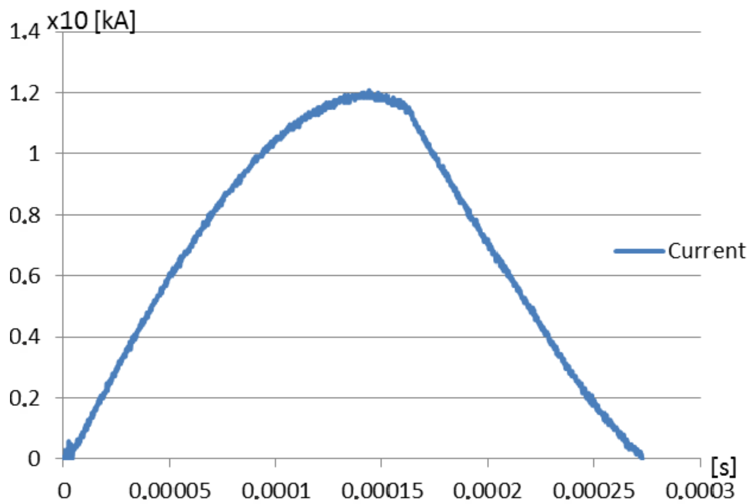

Fig. 3. Current graph

Point of copper wire breaking is a small peak of current at the beginning of a pulse. At 400 A, wire breaks and current drops. It is caused by resistance which in boiling copper is much lower than in solid state copper. Better sealing of the whole stand resulted in full discharge of capacitors without additional pulsation which occurred in previous tests. It also resulted in plasma cloud velocity and length. Shortening discharge pulse gave increase in plasma cloud velocity up to 600 m/s, and length of cloud of approximately 1 m.

3. PLASMA TESTS

Closed vessel test conducted at Ballistics Laboratory showed the difference in velocity of cloud propagation. Black powder igniter, used as a base to which plasma is compared, gave the results almost 20 times slower than propagation of plasma cloud (Fig. 4).

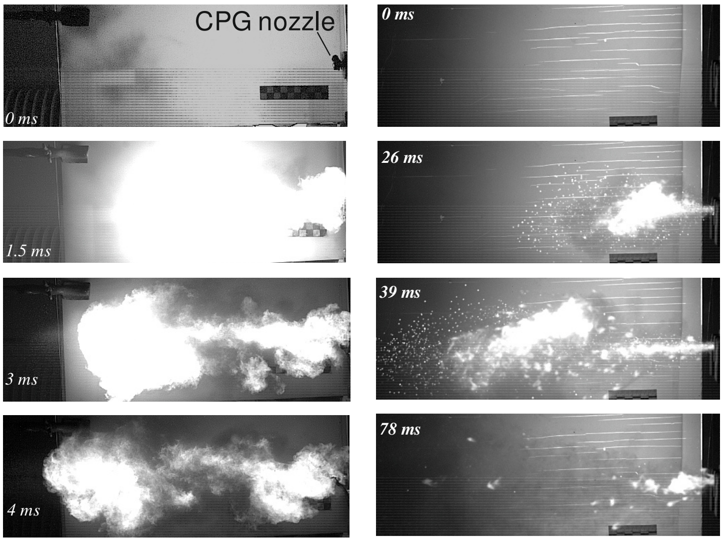

Fig. 4. Comparison of ignition phase (left – plasma, right – black powder)

Increasing energy of discharge gives shorter time to maximum pressure (Fig. 5) despite the 4 kV discharge which showed large gas leakage. After upgrading laboratory stand to withstand greater gas pressures, we conducted closed vessel test with conventional propellants. Test conducted with standard setup showed long plateau before propellant burning occurred.

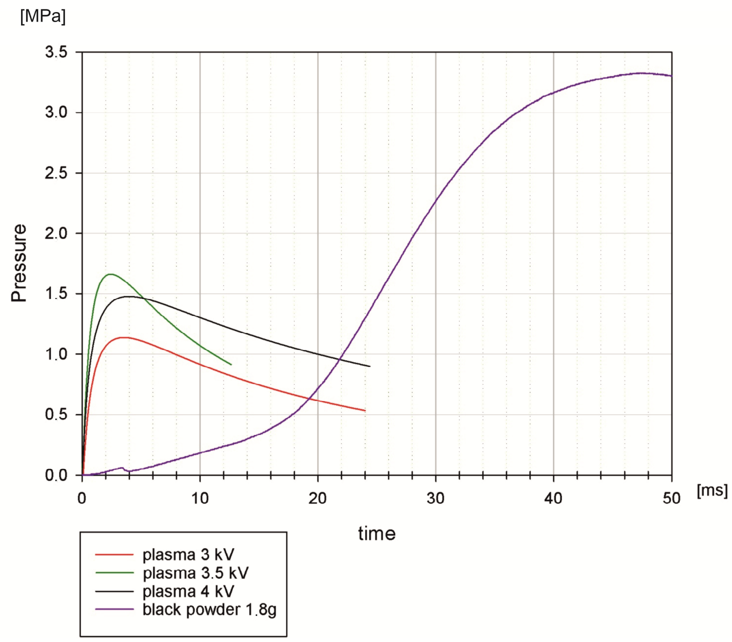

Fig. 5. Initial vessel pressurization

Comparing to black powder ignition (black powder is the quickest burning powder and still used as ignition agent in artillery shells) it gave the same time results as 2.66 g of black powder for achieving 4 MPa of ignition pressure (Fig. 6).

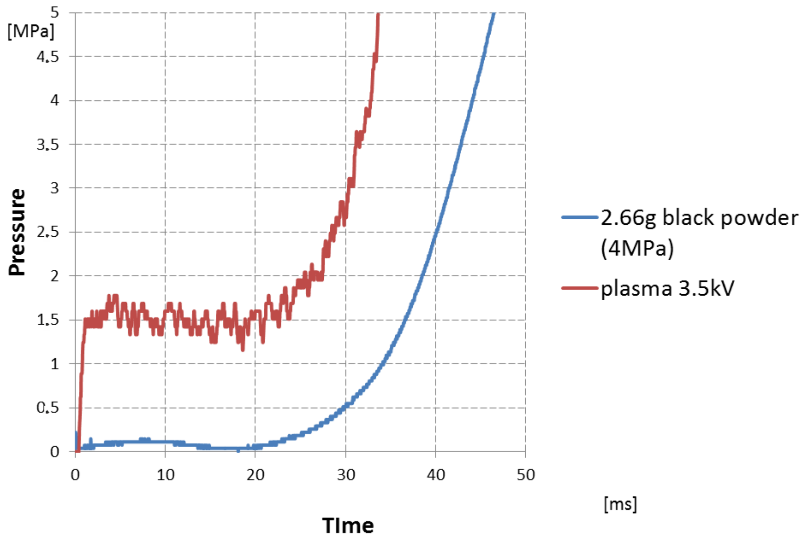

Fig. 6. Pressure graph for different types of ignition

But as we can see further, pressure rise is quicker that implies greater area of propellant had been ignited. Additionally, we can go even further in decreasing ignition time by increasing discharge energy twice as in standard test setup.

4. CONCLUSIONS

The results presented in this paper show that using CPG as ignition source provide us much greater abilities in LOVA propellants usage, and the possibility of controlling combustion processes and achievement of more stable and homogenous ignition. Especially with high loading densities, plasma gasses without solid particles and different energy transfer gives us great advantage comparing to classic black powder ignition. Much shorter ignition time (1,5 MPa near 20 ms vs 4 MPa in 44 ms with black powder) was achieved showing plasma's better penetration abilities, which results in more homogenous ignition.

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