CAPILLARY PLASMA GENERATOR AS THE NEW METHOD OF PROPELLANTS IGNITION IN CLOSSED VESSEL TEST

Jakub MICHALSKI [1], Zbigniew LECIEJEWSKI [2]*

[1]*Military University of Technolog, Kaliskiego 2, 01 925, Warsaw, Poland*

[2] *Military University of Technolog, Kaliskiego 2, 01 925, Warsaw, Poland*

**Corresponding author E-mail address: jmichalski@wat.edu.pl*

Received 23.10.2013; accepted 15.11.2013

Abstract

Contemporary development of new types of ammunition is focused to improve the energetic characteristics, chemical stability and operational safety of propellants. Response to this requests are low vulnerability (LOVA) propellants. Therefore in Laboratory of Ballistics (Military University of Technology in Warsaw) began to develop a new method of low vulnerability propellants ignition and investigation - a new closed vessel equipped with the capillary plasma generator (CPG). Previous published results of 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. 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, generating metallic vapour which still conducts current. 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. Comparable test of black powder and plasma ignition in closed vessel with conventional propellant were done. This paper (presented as a poster form) is mainly devoted to initial testing of free air plasma jet and black powder ignition comparable investigation but initial results of laboratory closed vessel tests are shown too.

Keywords: Plasma, Inner Ballistics, CPG, Insensitive Munition

1 Introduction

As propellants development is going towards "green ammunition" and "insensitive ammunition" (IM) gun durability is limited by gun weight and barrel strength. Possibility to increase velocity without increase gun weight is to improve ballistic process. Another path in ammunition development is operational safety. One of the most dangerous situation 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 situations Low Vulnerability Ammunition (LOVA) is being developed. International IM test procedures consists of six threats. As presented in table 1 acceptable response to almost all of them is burning, only sympathetic reaction and shaped charge jet impact can cause explosion. In table 1 we can compare different standards for IM.

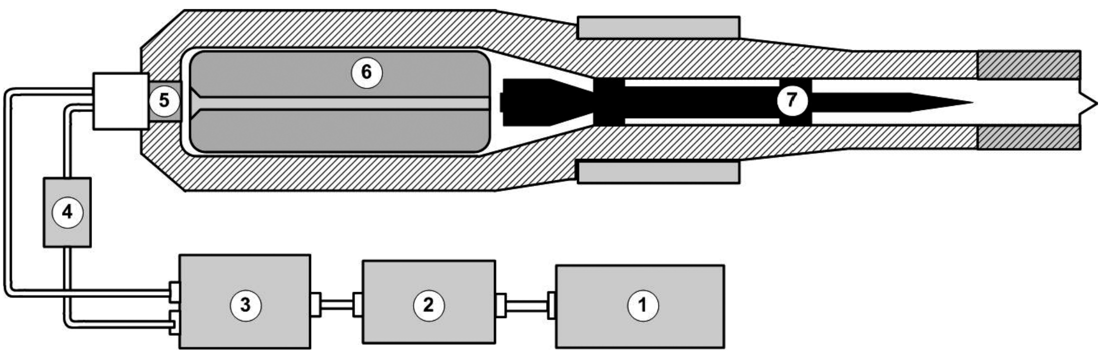

Fig.1. *Concept art of an ETC gun [8]*

1- Primary storage, 2- Secondary storage, 3- Pulse forming network, 4- Firing switch, 5- Plasma cartridge, 6- Propellant, 7- Projectile

Classic primers used in large bore guns (electric or percussion with black powder bedding) when used with LOVA propellants causes unstable burning or lack of ignition. Solution of this problems are plasma generators, which creates higher energy flux, high temperature and makes possible to control some aspects of combustion process.[5] Guns in which plasma generators are applied as ignition source are known as Electro-Thermal Chemical (ETC) guns.

Table 1 *NATO requirements for Insensitive Munition.*

		NATO		**UK**	**GERMANY**	**ITALY**			**FRANCE**			**USA**
THREAT	Test procedures	STANAG 4439										
						DG-AT IM Guidelines 2000			MURAT Doctrine Instruction DGA/IPE 260			MIL-Std 2105-D
	Stanag	IM requirements	AASTP-1 SsD 1.2.3	JSP 520	Fü S IV 3	Φ	ΦΦ	ΦΦΦ	★	★★	★★★	
Fast heating	4240	V	V	V	V	V	V	V	IV	V	V	V
Slow heating	4382	V	V	V	V	V	V	V	III	V	V	V
Bullet impact	4241	V	V	V	V	V	V	V	III	III	V	V
Sympathetic reaction	4396	III	III	III	III	III	III	III	III	III	IV	III
Fragment impact	4496	V		V	V		I	V	I	III	V	V
Shaped charge jet impact	4526	III		III	III			III			III	III
TYPE OF RESPONSE: VI – No Reaction; V – Burn; IV – Deflagration; III – Explosion; II – Partial detonation; I – Detonation;												

2 Plasma generators for ETC gun

Two commonly known types of plasma generators are: 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 disturbing propagation of plasma and is not good for the properties of plasma, that are required and it needs higher energy to sustain electrical arc.

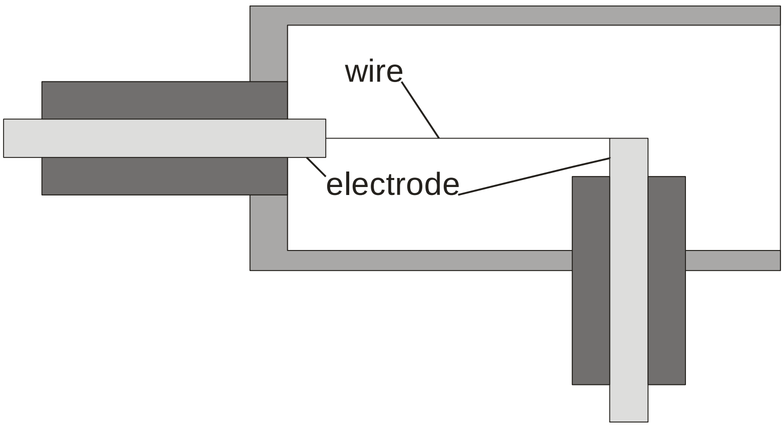

***Fig. 2**.: The schematic view of current injection device*

To overcome this disadvantages Piccolo Tube was introduced (Fig. 3). It consists metallic tube (1 in fig. 3) located in axis of combustion chamber, with radial holes, in which plasma initiation wire is located. The plasma develops and is sustained inside the tube and vented into combustion chamber (2 in fig. 3). Common disadvantage of radial discharge devices is that pressure pulse produced by generator puts additional stress to the chamber (or case). Axial pressure pulse is more desirable and allows to control projectile velocity in barrel.

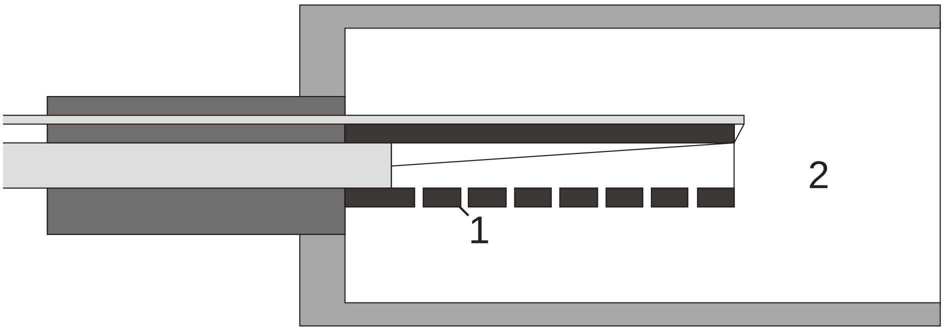

***Fig. 3**: Piccolo tube device*

Typical axial discharge device is Capillary Plasma Generator (CPG) presented in figure 4. It consists of high density polyethylene (HDPE) tube (3 in fig. 4) with discharge wire inside. Plasma generated inside the tube vents into the combustion chamber under its own pressure.

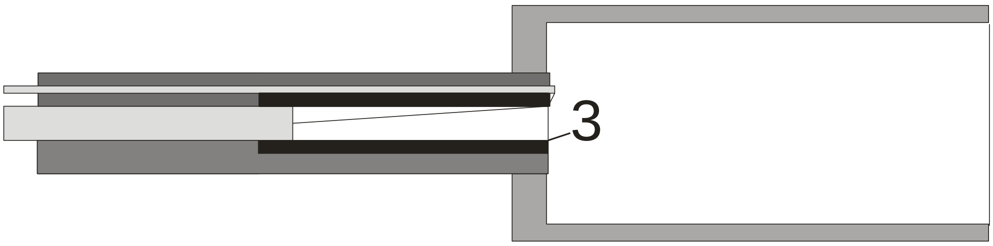

***Fig. 4**: CPG Plasma generator*

2.1 Plasma generation and energy transfer

Plasma generation in this 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 copper 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 depend on initial temperature [6]. Initial gas generation and initial surface enhancement makes ignition more easier.
Cooper vapour condensation occurs when plasma cloud contacts with “cold” propellant surface. High velocity of cloud (~170 m/s) combined with high plasma temperatures (6000 K – 11 000 K) give a uniform and almost instantaneous ignition of propellant on whole surface. Low density of plasma gases and lack of big chunks (like in black powder bedding) enables plasma to penetrate whole volume of combustion chamber.

2.2 Balistic gain and reduction of temperature gradient

The term of “ballistic gain” will be understood as the same muzzle velocity is reached with lower maximum breach pressure. That implicates the same pressure impulse but achieved with lower maximum pressure values in the same time. According to data presented in [7] for 105 mm gun, difference in maximum pressure between conventional ignition and plasma ignition for 3 muzzle velocities are: for 1510 m/s, 14.5 MPa; 1600 m/s, 24.6 MPa; and for 1640 m/s, 40.6 MPa. Experiment shows that for larger loading densities (higher velocities) the ballistic gain is more significant. It can be explained that the ignition process is more homogeneous, plasma better penetrates dense packed propellant which leads to burnout.

There are significant differences of pressure and muzzle velocity for various initial propellant temperatures. As in closed vessel test the initial temperature can be precisely measured in whole volume, in real shooting it can be various across chamber, and initial temperature can be only estimated. Data presented by Zoel et al [7] shows significant reduction of initial temperature influence. Pressures and muzzle velocities with standard loading densities are for 21 ºC: 364 MPa and 1430 m/s. For temperature of 52 ºC: 445 MPa and 1514 m/s. Differences are: 81.2 MPa and 84 m/s. For the same initial conditions but ignited with plasma differences obtained are: in pressure 28.9 MPa and in velocity 25 m/s. For higher loading densities differences even rise. And for 105 % of standard charge mass and initial temperatures of 10 ºC and 52 ºC for conventional ignition differences of velocity and pressure are: 85 m/s and 110.2 MPa. For plasma ignition respectively: 14 m/s and 10.5 MPa.

3 Free air plasma generator in initial expermients

Our investigations into plasma ignition are first published in Poland, and one of few held 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 capacitor charged up to 1.5 kV giving 70 J of electric energy. Total energy held in 4 capacitors was 280J. Test 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.

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 7.

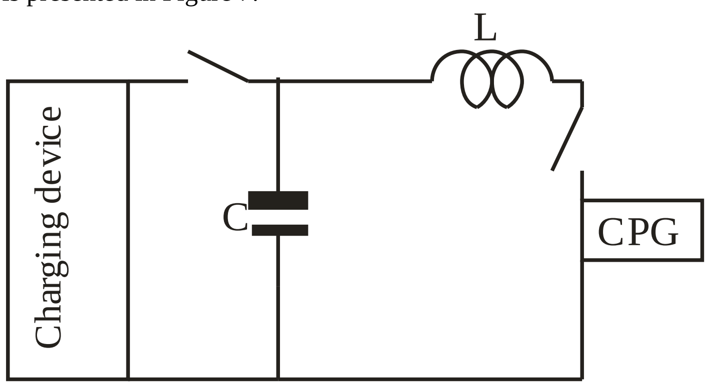

***Fig. 5**: Scheme of Pulse Forming Network with CPG*

Now we are attempting to closed vessel test with classic propellants. These test requires new closed vessel 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.

Firstly to compare black powder with plasma ignition time of full "burnout" was obtained. Free air black powder burning gave result of 250ms (Fig. 6) comparing to 4 ms with plasma (Fig. 7). To investigate black powder effect of ignition the CPG plasma generator 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. Due to higher pressure inside the tube shorter time was achieved, approximately 100ms. Videos recorded black powder effect of ignition is presented in Figure 7b.

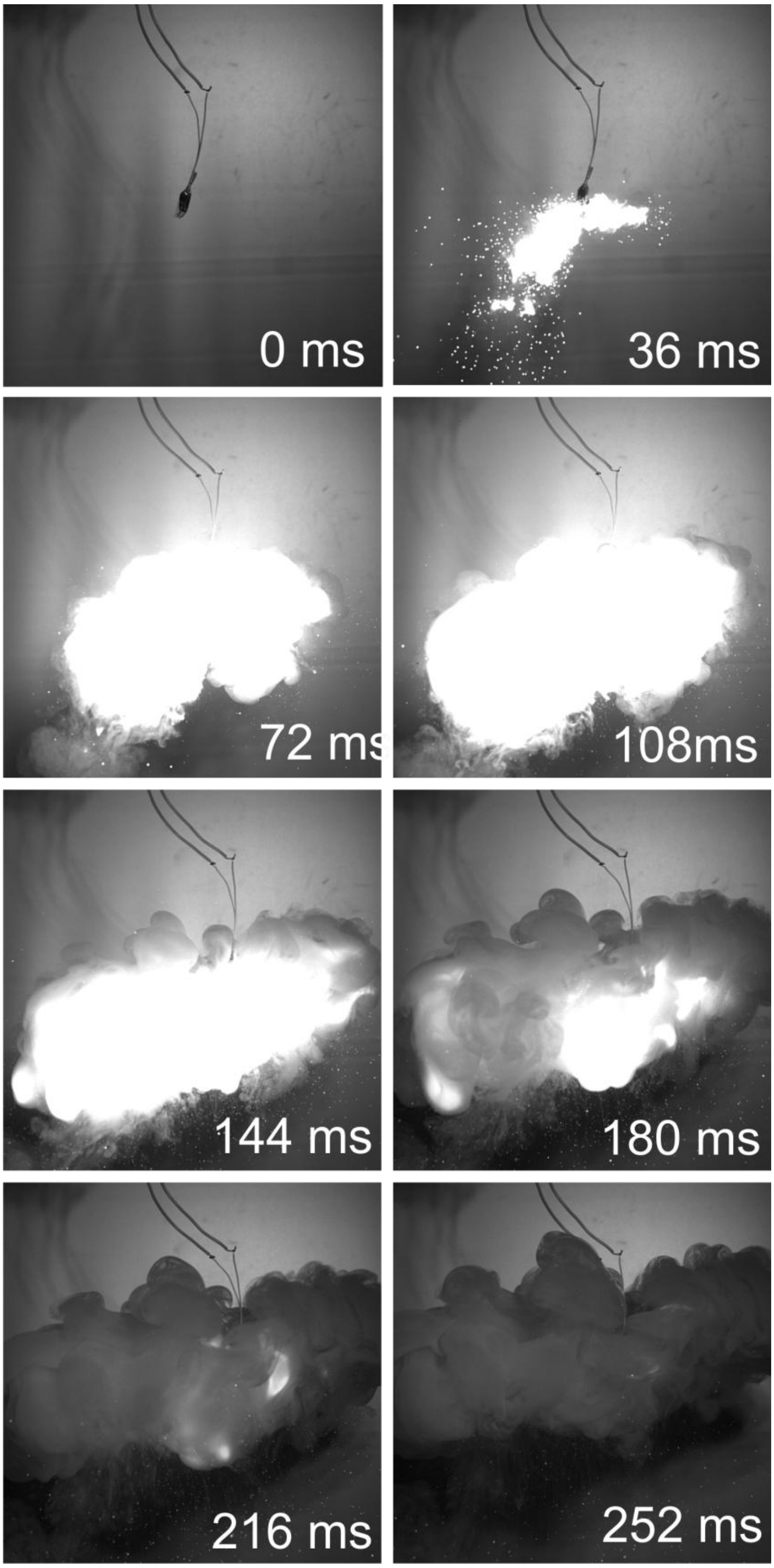

Fig. 6 *Free air black powder ignition.*

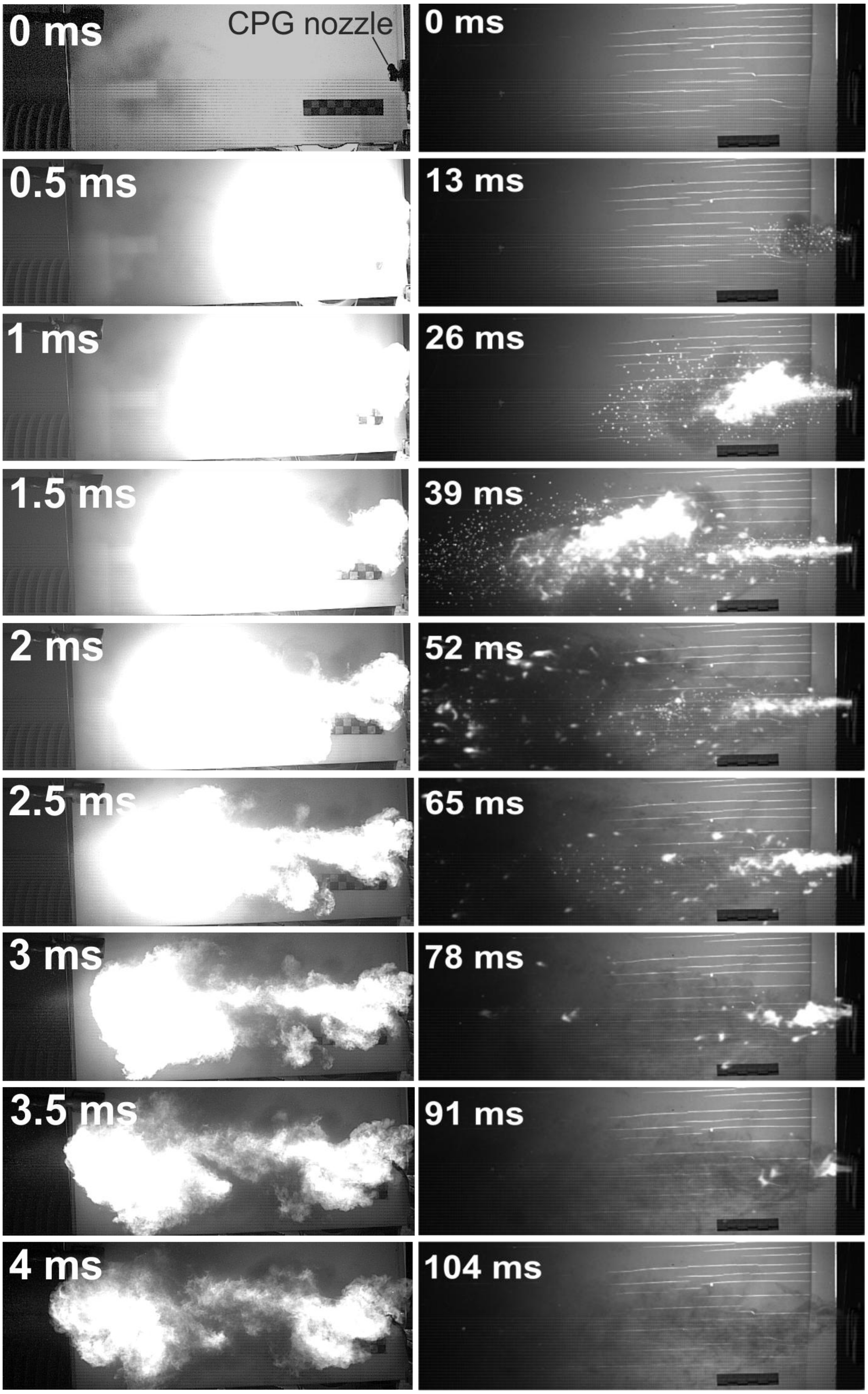

***Fig. 7**: Plasma (left) and black powder (right) ignition – comparable investigation*

Conclusion

Concluding, experiments with plasma generator as new method of ignition permits to improve ballistic process. As we find it very perspective method, we will continue to explore it, including classical and LOVA propellants.

Acknowledgements

We would like to give our gratitude to Col. PhD Eng Z. Surma, PhD Eng W. Pichola and Col. PhD Eng J. Janiszewski for their contribution into our work.

References

[1] D. Grune, D. Hensel*; Combustion Behavior of LOVA-Solid-Propellant by Ignition with Hot Plasma Gases and its Influence on the Interior Ballistic Cycle;* Proceedings of 17th International Symposium on Ballistics, pp.359-366, Midrand, South Africa, 1998

[2] L. Chen; *Relationship Between Discharge parameters of Capillary and Combustion Behavior of Propellant;* Proceedings of 18th International Symposium on Ballistics, pp.215--219, San Antonio, USA. 1999.

[3] J.M.Lombard, B. Baschung, D. Grune, A. Carriere, P. Andre; *Analysis of ETC or Classical Manometric Closed Vessel Tests with Coupling of Thermodynamic Equilibrum Calculations:Combustion Rate, Energy Losses;* Proceedings of 19th International Symposium on Ballistics, pp.171-178, Interlaken, Switzerland. 2000

[4] M.J. Taylor, C.R.Woodley; *Variation in Enhanced Gas Generation Rates in Electrothermal-Chemical Closed Chamber Studies;* Proceedings of 19th International Symposium on Ballistics, pp.179-185, Interlaken, Switzerland. 2000

[5] R. Alimi, L. Bakashi, E. Kot, M. Sudai; *Temperature Compensation and Improved Ballistic Performance in a Solid-Propellant Electrothermal-chemical (SPETC) 40-mm Gun.;*IEEE Transactions on Magnetics, vol.35 No.1 January 2007

[6] R. A. Beyer, R. A. Pesce-Rodriguez *The Response of Propellants to Plasma Radiation* IEEE Transactions on Magnetics, vol. 41 No.1 January 2005

[7] D. Zoler, N. Shafir, D. Forte, E. Kot, A. Ravid, S. Wald, and M. Sudai *Study of Plasma Jet Capabilities to Produce Uniform Ignition of Propellants.* IEEE Transactions on Magnetics, vol. 43, No. 1, Januray 2007

[8] Z.K.Leciejewski, S. Cudziło; *Trends in Development of Propellants in Aspects of Requirements of Future Gun Propellant System* (in Polish), Materiały Wysokoenergetyczne, str. 7-14, Warszawa, 2012

Review: Harold Mäsiar
Ján Tvarožek