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THE EXPERIMENTAL STUDY OF LASER IMPULSE IGNITION OF THE CH4-AIR MIXTURE

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Abstract: *In this paper are presented the results obtained from igniting the fuel mixture into an explosion bomb that was designed for the comparative study of the fuel mixture by classical methods and by laser impulse. The explosion bomb has an internal volume of 1080 cm3 and was designed for a maximum pressure of 14,7 MPa. The measuring system contain a data acquisition system able to gather pressure information from a pressure probe, a normal video recording system and a fast video recording system. Experiments were conducted at the Măgurele National Institute of Plasma and Radiation Laser Physics and consist in a comparative ignition study of the methane-air mixture, with a spark plug and with a laser impulse.*

Keywords: explosion bomb, laser impulse, burning process, pressure sensor, recording camera.

INTRODUCTION

The paper presents preliminary results obtained by igniting the fuel mixture into an explosion bomb designed for the comparative study of fuel mixture ignition using classical means and laser impulse in order to estimate the opportunities offered by laser ignition instead electric sparking method in the case of SI engines.
Explosion bomb devices of 1080 cm^3 volume has four optical transparent windows. Two of the opposite windows, with a diameter equal to the enclosure, allow visualizing and recording the burning process. The other two smaller windows allow the laser impulse to be transmitted. A valve system allows fuel mixture filling loading, vacuum and empty the gases resulted from the burning process. It was designed for a maximum pressure of 14.7 MPa, being provided with pressure probe and a safety valve.
The first concerns with the possibility of ignition of fuel mixtures in engines developed thermal energy using laser impulse is dating back to '60s, immediately after achieving the first successful laser device UI. Further investigation was started after 2000, when technological developments enabled a considerable reduction in size of lasers and now reaching up to almost miniature size. This made possible the introduction of laser system in equipments of similar size to those used in conventional by spark plugs to igniting the mixture in internal combustion engines.

Laser ignition is a process able to realize a more economical and clean engine by increasing the ignition time and its efficiency, by controlling the position where the spark is triggered, by eliminating the deposits on the spark plug electrodes and by improving the quality at cold start. Also, the possibility to choose the optimal ignition position in the combustion chamber and the possibility of igniting efficient burning of poorer mixtures than using a spark plug, with better effects on the fuel consumption and pollution. The usage of laser ignition is beneficial even in the case where the engines are using alternative fuel and even bio-fuels. The ignition source represents a unidirectional impulse of a pulse laser that is replacing the common spark plug.

DESCRIPTION OF THE COMBUSTION CHAMBER

External shape of the enclosure will be a cube. This cube will have three holes on three sides given equal diameters at right angles, as in Figure 1. To fit various devices, like camera and laser assembly, are provided four optical glass windows. Two windows allow full view of the enclosure and the other two will allow access to the laser impulse to the chamber.

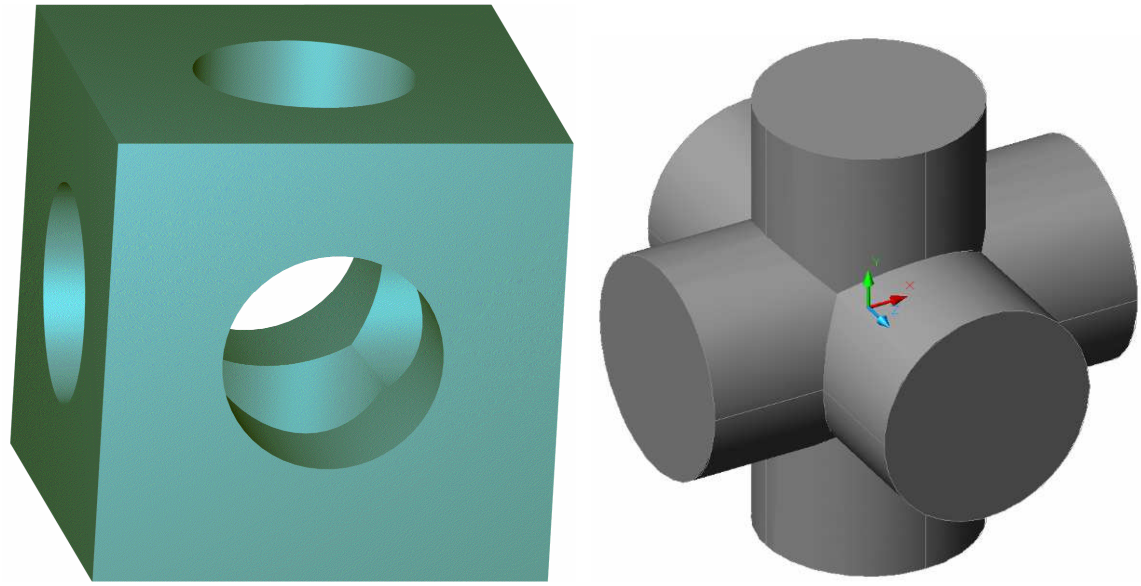


Fig. 1. Spatial representation of the exterior and interior of the explosion bomb.

Windows that allow access to the laser impulse will be smaller because it takes the whole cylindrical surface for this purpose. The other two available sides of the cube will be used to: supply static enclosure, removal and installation of flue gas pressure measuring probe. There is mounted a spark plug for a classical ignition of the fuel mixture. To have an internal volume of approximately 1000 cm^3 was estimated for a cube side length of 140 mm a 68 mm diameter holes. To determine the precise volume of solid, the enclosure was modeled in AutoCAD.

Within an explosion bomb, in the case of unwanted detonation combustion, maximum pressure can reach 75 at. In terms of computing static strength, the inside was designed to withstand a maximum pressure of 14.7 MPa. The steel cube has a thickness more then covering for this' kind of pressure. The four optical glass windows have two types of dimensions. Two of them are those which you see the full enclosure and have square shape, with a side of 100 mm. By being the most vulnerable there was made a calculation of resistance and was taken a safety of $g = 60$ mm thick. Two other glass windows allow the laser impulse inside the static chamber. They have a circular shape with a diameter of 25 mm and 10 mm thick..

The explosion bomb is provided in its upper part a body which is clamped by screwing. This piece is designed to connect devices that allow static chamber measurements, intake and exhaust gases. The body has also has attached a pressure valve as a safety valve and a pressure probe. In the bottom of the enclosure a second flange allows mounting two spark plugs.

For normal and safety use of the enclosure were provided three high pressure taps (150 bar), three low pressure taps, a safety valve (adjustable) and two manometers. Layout is shown in Figure 2.
The valves R_1, R_2 and R_3 are high pressure valves. The valve R_1 isolates the static chamber atmosphere and allows fuel mixture intake and emptying waste gas by vacuum chamber. The valve R_2 allows the chamber empting of fumes and valve R_3 allows vacuuming the explosion bomb.
The R_4 valve isolates the low pressure inside the static atmosphere. The R_5 valve is the supply tap allowing the mixture on site. The R_6 valve is the pressure gauge safety valve protecting in the case of faulty maneuvers occurrence.

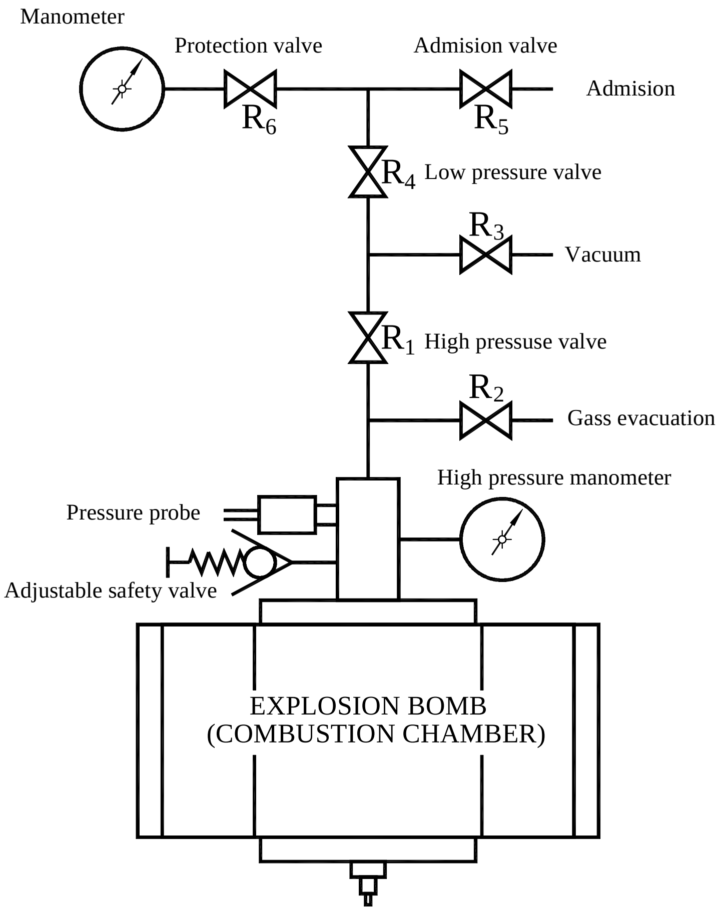


Fig. 2. Hydraulic scheme of the explosion bomb.

The enclosure is fitted with two manometers. The first, high pressure gauge, helps safety valve calibration. The second is dedicated to low pressure measurement of the static gas pressure from bomb inside.

Fuel mixture ignition is done in both two ways, classically and with laser.

The classic ignition supposes the existence of an ignition system made up of: the spark plug, the induction coil, the make-and-break mechanism and battery. The spark plug is mounted at the bottom of the explosion bomb, the spark electrodes being extended over the chamber center. The high voltage system discharge is the classic one, consisting in make-and-break mechanism, induction coil and batteries. We have used the ignition device, which equip engine 810-99, in which induction coil delivers a minimum 14 kV (without charge). The power supply is a battery (12 V, 45 AH). The laser ignition is done on a functional stall using an transmitter type Nd-YAG that is pulsed, lamp pumped having a frequency of repeatability of every 20 Hz and a wavelength of 1064 nm.

THE EXPERIMENTS

Experimental equipments

The experiments were conducted at INFLPR (*National Institute of Plasma and Radiation Laser Physics*) Măgurele and had as goal in testing the equipment in real functioning conditions and obtaining some comparable preliminary results, between the ignition of methane-air mixture with a laser impulse and electric spark plug.

The fuel mixture used was a gas mixture CH_4 – synthetic air, of 11.56% concentration. The equipments that composed the functional stall presented in scheme from Figure 3 are:

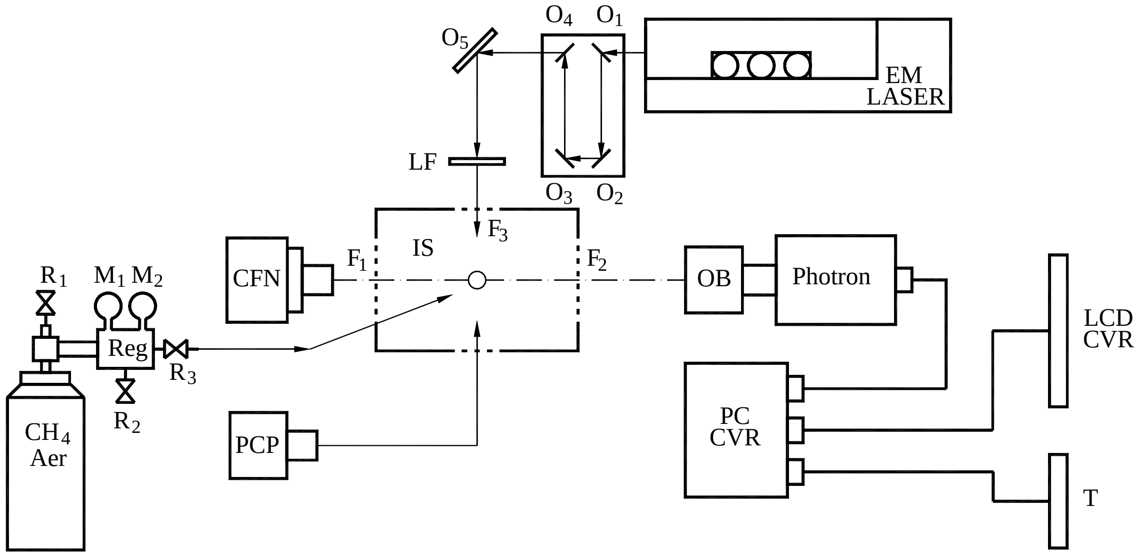


Fig. 3. Functional stall.

- The explosion bomb [IS] is provided with two visiting windows with a diameter of 100 mm, suitable for visualizing and recording the ignition phenomenon from the inside. On the perpendicular axis of those windows are provided another two smaller windows with a diameter of 25 mm that allow the laser beam to enter the burning chamber. The explosion bomb is provided in the inferior part with a screwed hole that allows mounting a car spark plug with elongated electrodes, so that the electrical spark to take place closer to the center of the interior volume.
- A cylinder where the mixture [CH_4 – Air] synthetic (11.56%) is compressed, to an initial pressure of 150 atm. The cylinder is provided in the superior part with a safe system and an adjustment formed of: [R_1] high pressure valve, [R_2] pressure regulator valve, [R_3] low pressure valve, [Reg] regulator that lowers the high pressure from the admission (150 atm) to a low adjustable pressure situated in the margin of error of 1-15 atm, [M_1] high pressure manometer that indicates the pressure existent in the cylinder, [M_2] low pressure manometer that indicated the set pressure in the circuit controlled by the throttle; by using the throttle and the manometer, the pressure that provides the initial loading of the explosion bomb is controlled.
- The laser transmitter [EM LASER] “Quanta Ray DCR Nd-YAG” pulsed type, electronic switched, lamp pumped, having a repetition frequency of 20 Hz, duration of the impulse of 10 ns, the energy of the impulse of 6 mJ, wavelength of λ= 1064 nm. The laser impulse is directed with an optical system from inside the explosion bomb; the focal lenses [LF] is a convex plane and has a focal distance of 75 mm.
- A photographic camera Canon Power Shot A550 [CFN], is used to record color video images through one of the visiting windows of the chamber.
- A rapid video camera [PHOTRON] FAST CAM 1024 PCI, model 100 K, that can develop a recording speed of over 100000 images per second. During the conducted test, the camera was used at the capacity of 1000 frames per second that assures a resolution of 1024 pixels. This thing permitted the acquiring of images that can be developed in a series of photogram spaced in time with a gap of (0.001) seconds one from another. The data is acquired by a system made from a PC [PC CVR] connected to a keyboard [T] and a [LCD CVR] monitor.
- A measuring and recording system [PCP] of the pressure variations from inside the explosion bomb with the characteristics: integrated instrument Soundbook PCB model 112B10, sensitivity 0.145 pC/kPa, maximum pressure 34475 kPa, resonance frequency 200 kHz, response time 3.0 μs, quart sensorial element. The signal received from the pressure probed is amplified by an PCB Piezotronics amplifier, model 422E13, the pressure probe type PCB Piezotronics PFS.

Pressure measuring chain description

For the experimental measuring of the pressure from inside the chamber, it was used an integrated instrument Soundbook. The “hardware” part of the instrument is made from the pressure transmitter type PCB 112B10 togeder with the charge preamplifier type 422E13 and the data acquisition board inserted to a laptop Panasonic of 1.1 GHz (Soundbook system). The virtual part (software), was designed by using a software specialiezed in acquisition and processing of data called “Samurai”.
Soundbook is a notebook modified for pressure measuring, temperature, vibrations, sounds etc. Because of the notebook Panasonic CF-19, the complete acquisition system is a universal instrument that measures and analyses signals, that is compact, flexible and strong. It can be also used in tough weather conditions (IP 54 protection and military specifications). Is easy to handle with and it can be used both in the laboratory and the field. Soundbook is a real-time multichannel universal analysis instrument.

Describing the experiments

There were conducted two sets of experiments for the ignition of the methane-air mixture.

a) Conventional ignition produced by a classical spark plug is used by a breaker-distributor adapted from a Dacia 810.99 engine. It was initiated the ignition of the mixture by recording images with the rapid camera PHOTRON FAST CAM, and with a photo camera Canon PS A550. Pressure variations from the explosion bomb were recorded, values from table 1 being the result of the fuel mixture explosion.

Table 1. Pressure values at the conventional ignition.

Nr. Exp.	Initial pressure [bars]	Maximum pressure [bars]	Time pressure rise [ms]
1	1	4.8	3
2	2	7.5	2.8
3	4	13.1	2.5

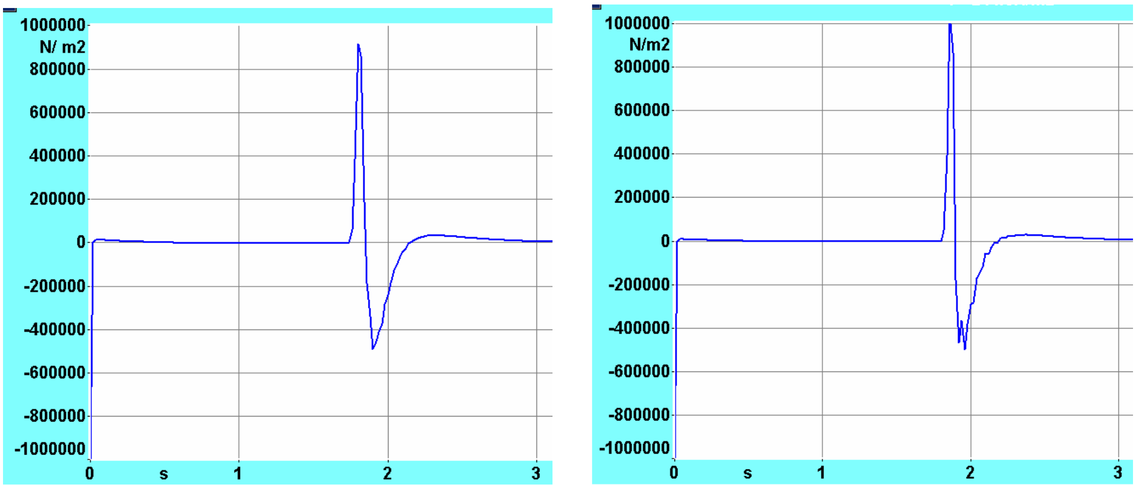
b) By igniting the fuel mixture using a laser impulse we have the characteristics presented in the upper table. It was initiated the ignition of the mixture by recording images with the rapid camera PHOTRON FAST CAM, and with a photo camera Canon PS A550. Pressure variations from the explosion bomb were recorded, values from table 1 being the result of the fuel mixture explosion.

Table 2. Pressure values at the laser impulse ignition.

Nr. exp.	Initial pressure [bars]	Maximum pressure [bars]	Time pressure rise [ms]
1	1	5.1	1.5
2	2	8.0	1.7
3	3	12.6	1.4
4	4	14.2	1.6

Pressure transducer measures only changes and as a result the real pressure is the pressure measured on site plus the initial pressure. In Figure 4 the comparison presented charts to time pressure obtained for a pressure of 4 bar fuel mixture, in the case of conventional and laser ignition.

In Figures 5 and 6 are presented colored photogram cut from the recordings made with the camera Canon PS A550.



a) Spark plug ignition. **b) Laser impulse ignition.**

Fig. 4. Graphics p(t).

The frames are framed to a velocity of 1/15 of a second that means 0.066 seconds. You can visually show the differences in flame front propagation.

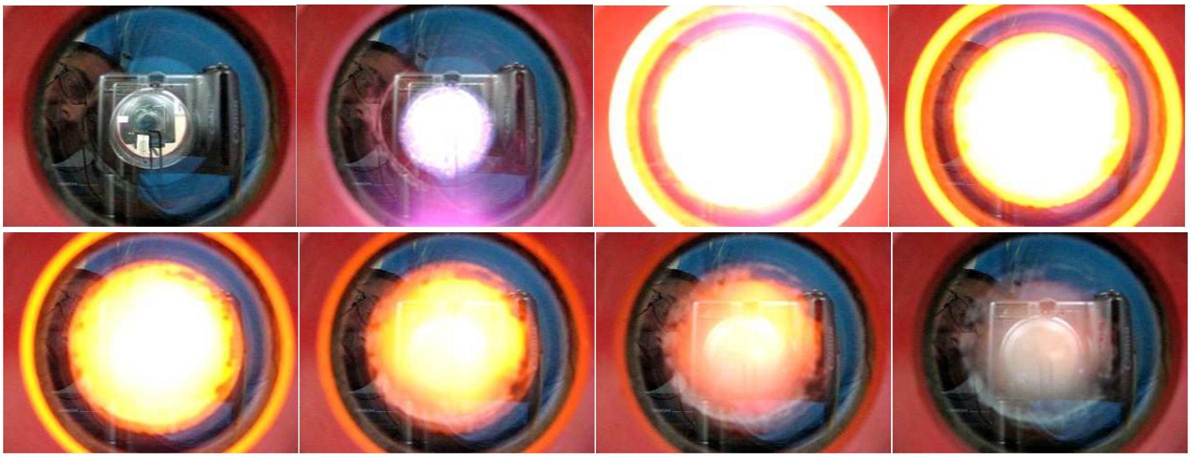


Fig. 5. Frames from the recording using classical ignition.

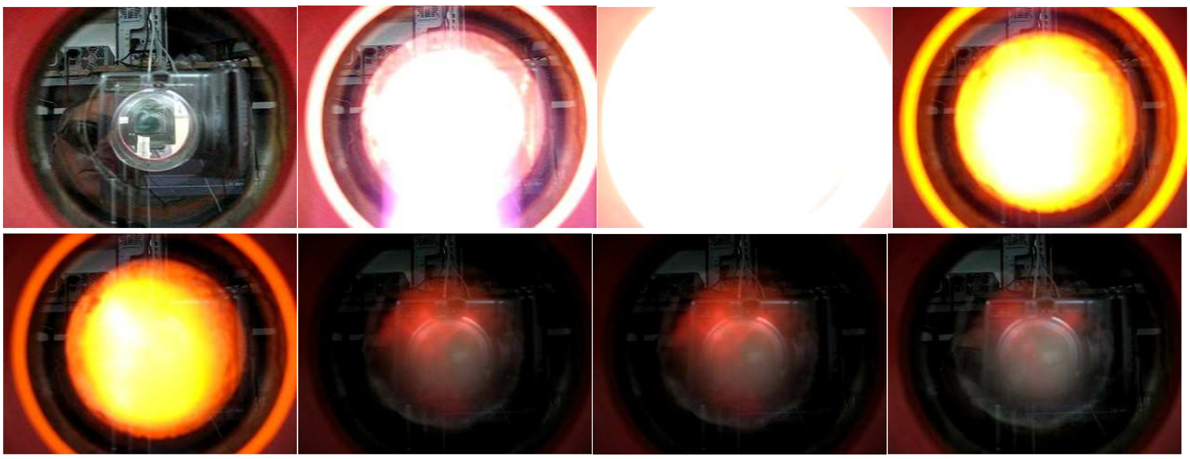
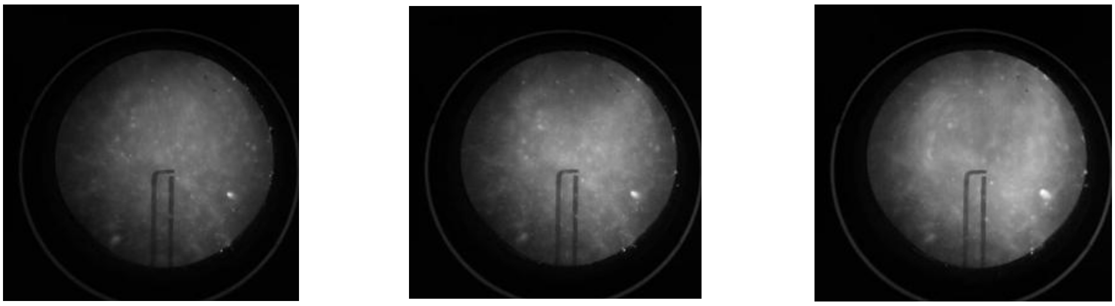


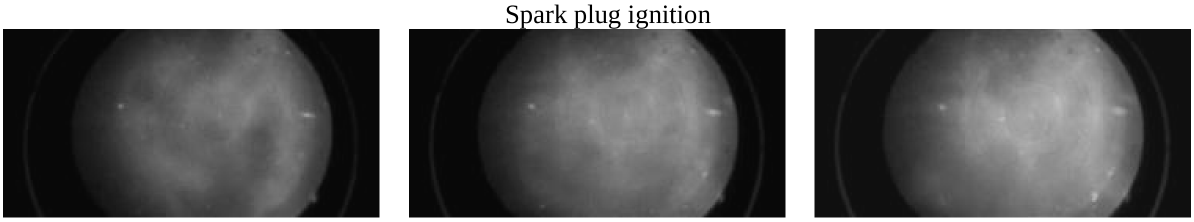
Fig. 6. Frames from the recording using laser impulse ignition.

In Figure 7 can be seen some of the photogram generated by the rapid camera for the two types of ignition.



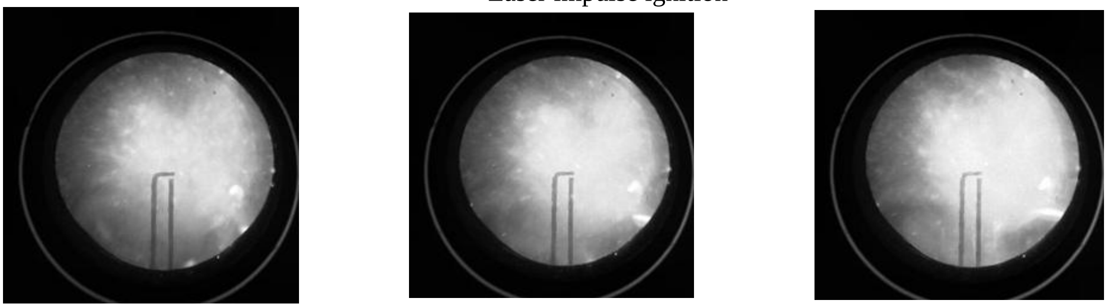
0.001s 0.002s 0.003

Spark plug ignition



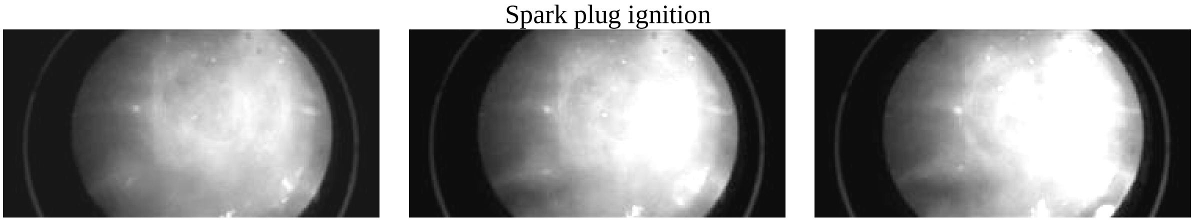
0.001s 0.002s 0.003s

Laser impulse ignition



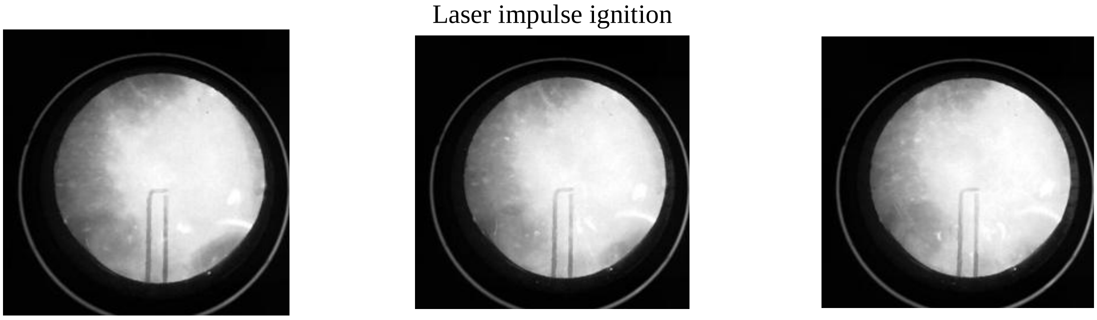
0.004s 0.005s 0.006

Spark plug ignition



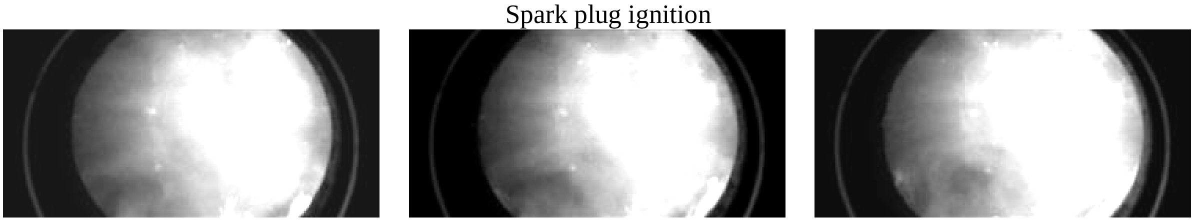
0.004s 0.005s 0.006

Laser impulse ignition



0.007s 0.008s 0.009s

Spark plug ignition



0.007s 0.008s 0.009s

Laser impulse ignition

Fig. 7. Frames from the recordings done with the rapid camera.

CONCLUSIONS

The static enclosure designed and constructed to study the combustion of fuel mixtures has resulted from the intersection of three cylinders with a diameter of 68 mm arranged on the faces sides of a cube with sides of 120 mm each.

To view the combustion phenomenon were used four antipodal optical glass windows. Two are squares of 100x100 mm and 60 mm thick and two are cylindrical with a diameter of 25 mm and 10 mm thick. On the other two sides of the cube were mounted devices that allow the measurement, the intake and the exhaust of the gases, respectively the classic plug ignition.

Experiments were realized with the ignition rate of the methane-technical air mixture of 11.56 %. The process was recorded with a normal camera and a rapid camera in the case of igniting the mixture from the spark plug by using a laser impulse.

In the case of laser ignition, the pressure rising level is higher, the ignition is faster and uniformly. For exposing the procedures, we need to record the process in Schlieren technique, problem that will be discussed in a future paper. It is mentioned that in [6] the Schlieren technique was used for recording a stoichiometric mixture of methane-air of 5.23% concentration, the recording being made with a normal camera.

Researching specifically laser ignition processes in a explosion bomb, highlighted the fact that the ignition can build up from 100 ms to a few seconds, depending on the quality of the mixture, initial pressure, the energy of the laser impulse, initial temperature etc.

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