RECORDING IMAGES WITH THE SHADOWGRAPH METHOD FOR THE FLAME FRONT PROPAGATION STUDY

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Abstract: *The shadowgraph method, relatively close to Schlieren's method, its an optical method based on the non-uniformities from transparent environments. One makes a study of the burning process for a CH_4 fuel mixture - synthetic air, of 11.56% concentration, in a static chamber. The mixture is classically ignited with a spark plug and a laser pulse. The experimental installation is also composed of an optical transmitter type "Quanta Ray DCR Nd-YAG" that is pulsed with a repetition frequency of 20 Hz, a rapid filming video camera and a pressure variation measuring and recording system inside the chamber. The fuel mixture is placed in a tank with an adjustable pressure regulator at 150 atm of pressure. Different parameters of the burning process, like the ones we will present, were determined during the experiments: the maximum achieved pressure, the pressure variation in the burning chamber depending on time, the propagation speed of the flame front, all determined for different values of the initial pressure as for different values of the laser pulse energy. In the end of the paper one made an analysis considering the advantages of laser ignition for the fuel mixture instead of the classic one.*

Keywords: static chamber, laser, photographs, shadowgraph, explosion

INTRODUCTION

In the paper one presents a comparative study of the flame front propagation into a static chamber in which the fuel mixture is ignited classically with a spark plug and after with a laser beam.
The laser ignition is a procedure that drives to the implementation of an engine that is more economical and cleaner by increasing the burning speed and efficiency, by controlling the position where the ignition is being started, by eliminating deposits on spark plug electrodes and by improving the cold start qualities. Also there is the possibility of an optimal position for the ignition point in the ignition chamber and the possibility of igniting poorer composition mixtures much better then by using the spark plug, all of those also having favorable effects on the environment. By using the laser ignition we get benefits in the case of using alternative fuels or bio-fuels for our engine. The ignition source is the commanded beam of a laser pulse that will replace the classical spark plug.

Researches in this domain began in the early 1960's but the studies were intensified only after year 2000 when the technological evolution allowed lasers to shrink and today to go even to miniature sizes. This fact made possible introducing laser systems in equipments similar to those where spark plugs are used, mostly in the ignition of mixtures inside of a heat engine.

Until now, laser ignition to Otto engines is not studied enough. Researches in the domain of laser beam ignition of fuel mixtures were made by most of the universities and main vehicle producers. But there are not clearly defined the specifics of a laser pulse that is needed to ignite a fuel mixture from a standard heat engine. There are some problems like the dirt from the optical window where the laser impulse gets to the burning chamber or like theoretical problems of using lasers with a high degree of energy or repetition.

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The optical method used in this paper for determining the flame front of a fuel mixture from within a static chamber, is the shadowgraph method. This one is close to Schlieren's method and is based on visualizing the non-uniformities of transparent environments like air, water or glass. In order to see a shock wave in a transparent environment the method is based on the disorders that reflect rays of light and that cast shadows on leveled lighten surfaces.

THE EXPERIMENTAL INSTALLATION

The experimental installation has in its composition: a static chamber, a gas admission and evacuation system, an ignition system, a measuring and pressure recording system and a rapid filming camera in shadowgraph technique.

The static chamber is obtained of a steel cube with a side of 140 mm in which are drilled 3 holes on the three perpendicular faces, each of 68 mm in diameter, just like in figure 1. So one obtains a cube with the volume of 1083 cm^3.

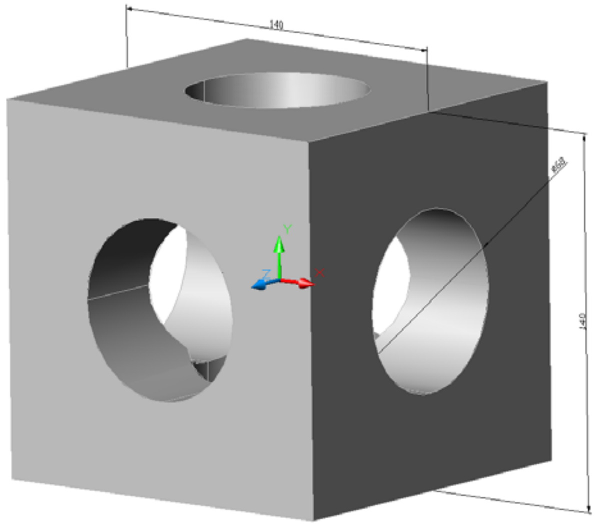


Figure 1. The static chamber

The chamber is provided with four optical glass windows. Two of them, diametrically opposed, allow the viewer to see all the inside of the chamber and the other two, diametrically opposed also, allow introducing the laser impulse. The other two remained faces are used like this: the superior one is used for the admission end exhaust and the inferior one is used for mounting the spark. The plug has prolonged electrodes so that the spark to be in the center of the chamber. The static enclosure also has a safety valve and an amortization system for the flue gasses.

The fuel mixture admission system is composed from a tank, where is a methane-air mixture at a concentration of 12%. The tank also has an adjustment system that reduces the pressure from 150 atm down to 1 atm. After passing the adjustment system, the fuel can reach the static chamber through the use of a high pressure faucet. The same faucet allows emptying the chamber and after vacuuming it with a vacuum pomp.

The ignition of the fuel mixture it is done in two ways: classically and with a laser.
The classic ignition system is made of a breaker distributor, an induction coil and a battery of accumulators. One uses the ignition system of type 810-99 engines made from a type 3230 breaker-distributor and a type 3130 induction coil (min. 14 kV in secondary). The power supply is taken from a classic battery of accumulators (12 V, 45 AH) or from a UPS (12 V, 7.5 AH). The breaker distributor engagement is done using a coupling from an electric motor. One prefers this operating mode for the safety of the operator and for the possibility of automating the process.

The laser pulse ignition it is made with a laser emitter with Neodymium, Garnet, Yttrium and pulsed Aluminum (Nd.YAG Laser). The duration of the pulse is 8 ns, the energy is between 12 and 23 mJ and the wave length is λ= 1064 nm. The laser beam is directed inside the room through an optical system. The focal lens of the beam from inside the explosion chamber has a length of 75 mm and the size of the spot of 70 μm in diameter.

For measuring the pressure from the static chamber one uses an integrated SoundBook device. The "hardware" part of the instrument is made of PCP 112B10 pressure transducer, 422E13 charge preamplifier and the data acquiring board that is the integrated part of a 1.1 GHz Panasonic laptop. The "software" part it is made of the data acquiring and processing software called Samurai. The Soundbook is a notebook modified for pressure, temperature, vibrations, sounds measures. Because of the Panasonic CF-19 notebook, the acquirement system becomes universal for measuring and analyzing signals. The Soundbook can be used in tough climate conditions (it has an IP 54 protection and military specifications). It is handled with ease both in the lab or on the field (it is an universal multiphase live analyze tool). For calibration one used the catalog data of the transducer that were introduced into the software that recognizes the PCB transducers pallet.

The rapid filming system has in its componence a video camera type Photron Fast Cam 1024 PCI, model 100 K, that can record with over 100.000 images per second. During our tests was used a recording speed of 3.000 frames/second at a resolution of 512 x 512 pixels. A light source with Xenon was used for recording the flame front. The system has also in its composure a photodiode that when it's lighted (the initial moment of the ignition) an electronical mountage comands the startup of the video camera and the digital data recording .

The parts presented in the upper paragraphs are schematically and physically presented in Figure 2.

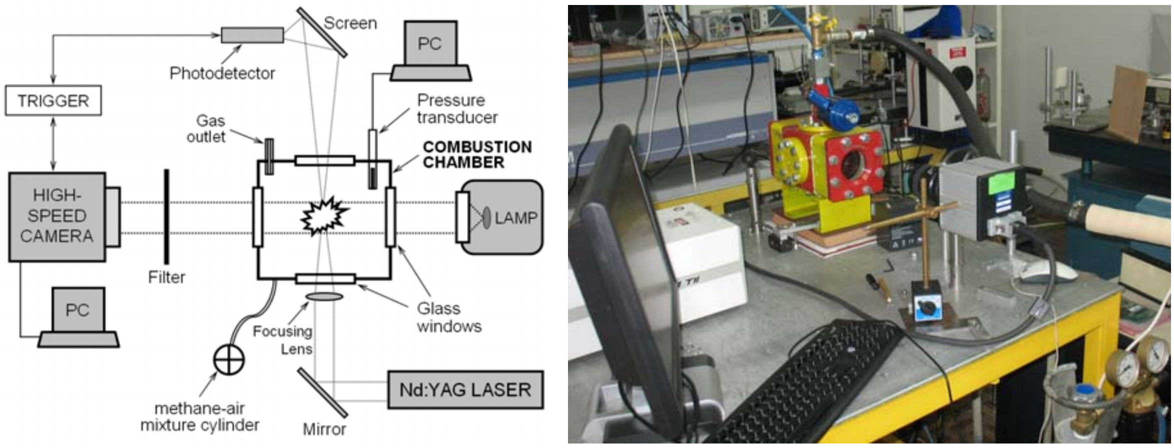


Figure 2. Experimental bench.

PHOTOGRAPHS OF THE FLAME FRONT PROPAGATION

In Figure 3 are presented the photographs of the flame front propagation of the fuel mixture for an energy of 22.8 mJ of the laser pulse.

In the case of spark plug ignition it is observable that the flame front is obstructed by the two electrodes comparing with the laser ignition where flame front can develop almost in a spherical shape, because there is no obstacle to prevent any modifications. In the same time the flame front development is larger in the case of using the laser then by using the classical ignition, for the same propagation time. This phenomenon is due to the absence of the electrodes that could cause turbulences.

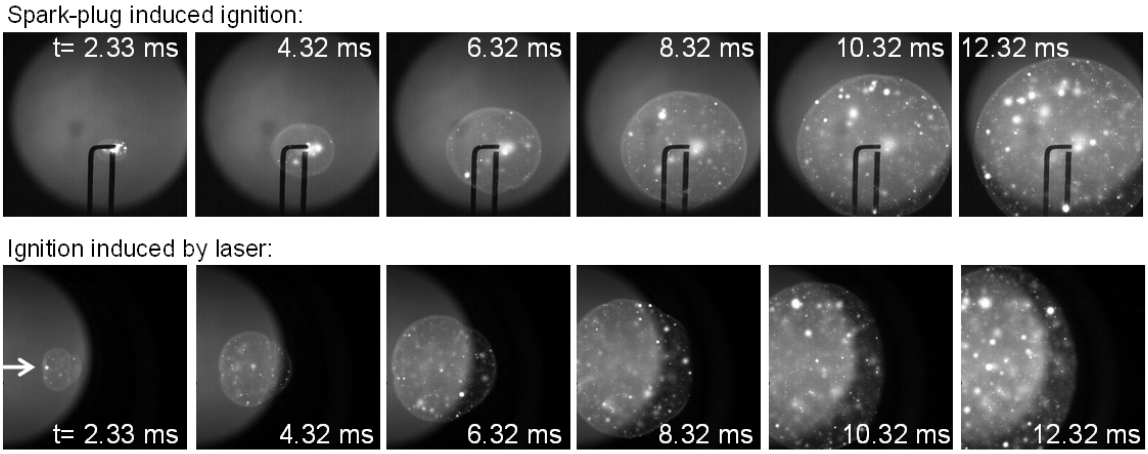


Figure 3. The evolution photographs of the spark plug and laser induced ignition with the conditions: methane-air mixture 12%, initial pressure of 0.1 MPa, the laser pulse energy of 22.8 Mj; the arrow shows the propagation in the case of laser induced ignition.

In Figure 4 one can see the third lobe of the flame front that is generated in the case of laser induced ignition at initial pressure of 0.1 ... 0.5 MPa. The lobe generation facilitates the asymmetrical development of the plasmas contour and this behavior can inhibit the development of the flame front. The apparition of the third lob is not fully explained in this moment but it will be for sure in the future. Anyway, this phenomenon wasn't observed during the classical induced ignition.

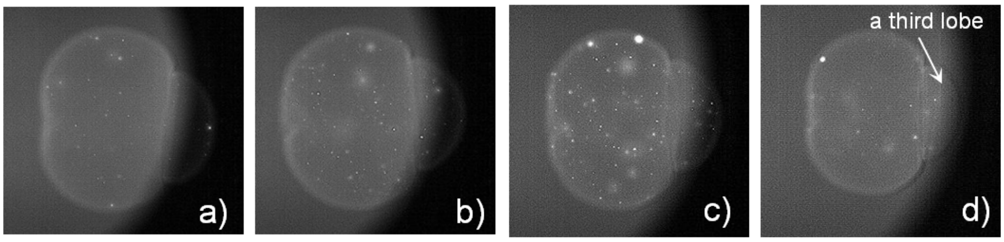


Figure 4. Laser ignition at pressures of: a) 0,1 MPa; b) 0,2 MPa; c) 0,3 MPa; d) 0,5 MPa

In [1] one specifies that alto was observed by plenty researchers the apparition of the third lobe wasn't fully explained. In [2], Spiglanin & co. suggested that it could be generated by the initial flowing field created by transport radiation along the laser fascicle, coming from the high energy transfer rate to the rising front of the plasma. Categorically, the plasma core created by the laser discomposure can be materialized into an ionized front that propagates towards the laser, after [3], with a movement against the focal point. Another gas-dynamic explanation ([3]) attributes the third lobe to the velocity of the gas that is induced in the over–expanding region.

The third lobe generation is not specif only to laser induced ignition. It was observed by Ishii & co., in [4], in an ignition system with two electrodes and DC power supply. The asymmetry occurs because of different flowing models from around the cathode and anode.

PRESSURE VARIATION IN THE EXPLOSION CHAMBER DURING THE IGNITION PROCESS

In Figure 5 one presents the pressure variation in the explosion chamber during the ignition of the methane-air mixture, for different values of initial pressure. On the other side, the peak pressure generated during the classical ignition was with 10 to 20% higher then the one obtained at the laser ignition. For example, for an initial pressure of 0.101 MPa (1 atm), the peak pressure generated by the classical ignition was of 1.49 MPa and it rise up to 1.21 MPa in the case of laser induced ignition.

To an initial pressure of 0,506 MPa (5 atm), the peak pressure went up to 3.66 MPa in the case of classical ignition and up to 3,33 MPa in the case of laser induced ignition. These results could lead to the presumption that the classical ignition could trigger more energy then the laser, despite the faster development of the flame in the second case.

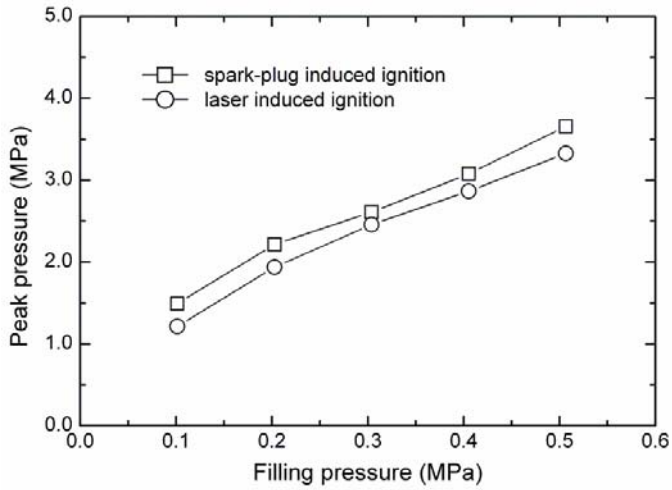


Figure 5. Peak developed pressure depending on the initial pressure in the explosion chamber.

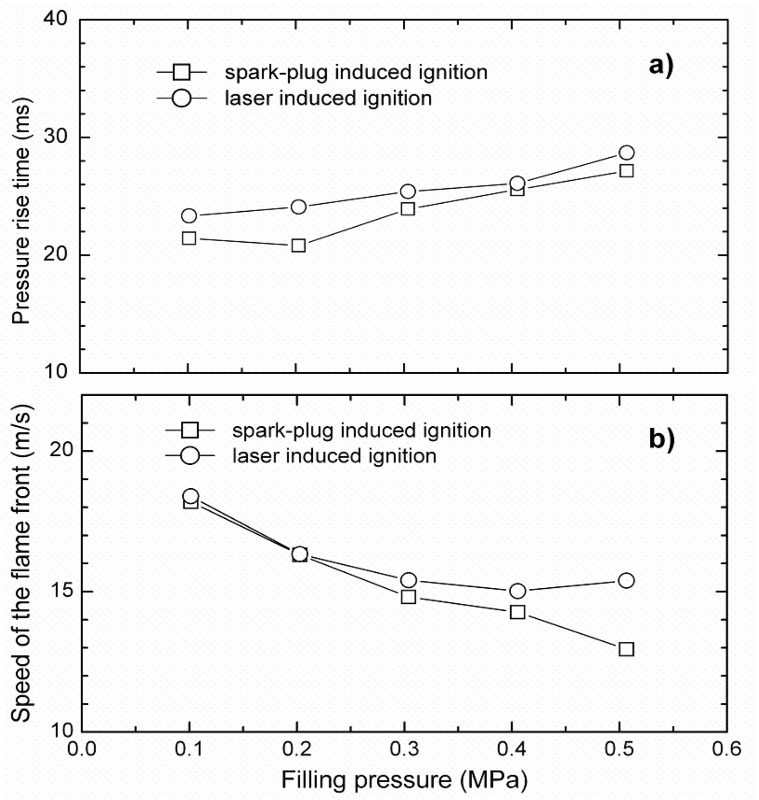
Previous researches of the methane-air mixture ignition conduct to the conclusion that there is a way to raise the peak pressure level, resulted from the explosion, by increasing the energy of the laser pulse. One finds this conclusion very useful for heat engine applications because a rise in the peak pressure level results in increasing the efficiency of the engine.

As a conclusion to the experiments, it was noted a small reduction of the maximum pressure, up to 10%, for an energy value of the pulse of 12.8 mJ (the minimum energy of the pulse that allows ignition to be made). So, in the conditions of our experiment, the maximum value depends directly on the energy of the laser pulse, in the case of ignitions over the initiation threshold. On the other side, calculations show that the intensity of the laser pulse to a value around 10^{11} W/cm^2 it is enough to initiate the ignition of the methane-air mixture.

The time necessary to increase the pressure value from within the ignition chamber, from 10% of the peak value to the maximum value, was recorded with the pressure transducer and the electronic recording equipment. The graphs of pressure evolution through time are presented in Figure 6 a. Generally, the time to achieve maximum pressure increases in direct correlation with the level of the initial pressure from inside the chamber.

In the case of classical ignition the time to reach peak pressure increases from 23.3 ms, for an initial pressure of 0.101 MPa (1 atm), to 28.7 ms for an initial pressure of 0.506 MPa (5 atm). The time to reach the peak it is almost 10% higher in the case of laser ignition.

In Figure 6, b is presented the variation for the flame from propagation depending on the initial pressure for the two modalities of ignition. It is observable that the flame front propagation velocity is higher in the case of laser induced ignition, specially at higher initial pressures. This behavior can be produced by the turbulent movement of the hot gas core generated by the laser plasma and by the influence of the spark plug electrodes over the displacement of the flame front.



a) The time that the pressure developed by the explosion increases from 10% of the peak level to the maximum value.

b) The velocity of the flame front propagation depending on the initial pressure (the case of 22.8 mJ laser pulse energy).

Figure 6. The time and velocity of flame propagation.

Finally, the propagation velocity of the flame front in the case of laser induced ignition was determined depending on the different values of the pulses energy and different initial pressure in the combustion chamber.

Results are graphically presented in Figure 7 where one observes the rise in the energy level for the laser pulse that conducts to a small increase of the flame front displacement.

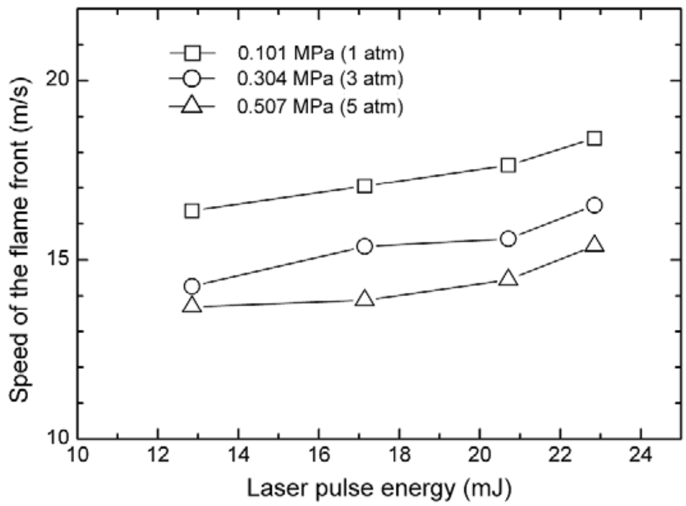


Figure 7. The velocity of the flame front propagation depending on the initial pressure in the combustion chamber and the energy of the laser pulse.

For example, for an initial pressure of 0.101 MPa (1 atm) the velocity of the flame front, for an energetic level of 12.8 mJ of the laser pulse, is of 16.4 m/s; the velocity increases up to 18.4 m/s when the energy of the pulse reaches 22.8 mJ.

Also, one can observe that the flame front propagation speed decreases once with the increase of the initial pressure in the combustion chamber, so, for an initial value of 0.507 MPa (5 atm) the propagation velocity drops to 15.4 m/s for a laser pulse of 22.8 mJ of energy.

CONCLUSIONS

In this paper one intended to determine, record and comparatively analyze the parameters resulted from the burning process of a 12% concentration methane-air mixture, with a spark plug and a laser impulse.

For one to investigate the first phases of the burning process it was used the shadowgraph method. The recorded parameters from within the combustion chamber that were taken during the experiments are: the peak pressure reached in the explosion, the variation of pressure through time, the velocity of the flame front propagation depending on the initial pressure and the energy of the laser pulse.

One noticed that the flame front generated by the laser ignition has a shape similar to a sphere and propagates with a higher velocity then the one generated by the spark plug. On the other hand, the maximum pressure achieved with the laser induced ignition, in the same initial conditions, it is slightly smaller considering the spark plug case, when there were certain values for the energy of the laser pulse.

The propagation speed increases with the increase in the laser pulse energy and drops when the initial pressure from the combustion chamber also increases.

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