EXPERIMENTAL BENCH FOR RECORDING IMAGES OF THE FLAME FRONT WHEN USING LASER PLUG IGNITION

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INTRODUCTION

In the unfolding of the experimental research of laser ignition systems, several experimental solutions quoted by the specialty literature were took into account that served as inspiration in constructing the experimental bench and having our own research methods. These were thought so that will correspond with the purpose we've set by using the financial and technological resources available. From all of these we've focused our attention on the experiments regarding the initiation of the burning process with methane-air or propane-air fuel mixtures.

In carrying out the experiments one prefers the methane-air mixtures. By choosing this type of fuel mixture one has several advantages like:

- The possibility of getting different concentrations easily,
- The ease of transportation,
- No auxiliary equipment needed to be introduced in the experimental burning chamber (like carburetion or injection equipments),
- The possibility of reaching high pressures in the combustion chamber without the use of any other equipment,
- The interest that the car producing industry has for the poorer methane-air mixtures in fueling internal combustion engines.

By using the methane-air mixture in fueling the spark ignition engines generates few inconveniences, mainly because of their specific chemical properties, specially the strong bond between C and H. These inconveniences are the delay in the fuel mixture ignition, misfires and premature failure of the spark plug. The spark plugs used for that purpose had to be replaced or cleaned every 500-700 hours of functioning at the most engines fuel with methane gas.

STATUS OF RELATED RESEARCH

From the articles published in this field of research, one will mention two in particular that are closer to its own experimental methods used in the laser induced ignition of methane-air mixtures:

[1] “Laser spark ignition and combustion characteristics of methane–air mixtures”, conducted by a team of researchers from the "Department of Electrical and Optical Engineering" from the University of Nebraska-Lincoln SUA, having as authors Jian X. Ma, Dennis R. Alexander and Dana E. Poulain.

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[2] ”Fundamental of high-energy spark ignition with laser” conducted by a team of researchers from School of Mechanical Engineering of the University of Leeds UK, composed of: D. Bradley, C. G. W. Sheppard, I. M. Suardjaja and R. Woolley.

In the first case were conducted experiments regarding the propagation of the flame front in fuel mixtures of CH4-synthetically air, for the case of classical ignition, compared with the laser induced ignition, all taking place in an experimental single cylinder. For initiating the ignition, the following types of lasers were used:

- Gas laser with Krypton Fluoride (KrF) that has a wavelength of λ= 248 nm,
- Gas laser with Argon Fluoride (ArF) that has a wavelength of λ= 193 nm,
- Solid laser with Neodymium and Al and Yttrium Garnet (Nd: YAG) that has a wavelength of λ=1064 nm.

One compared the initial ignition cores by analyzing the initial propagation phases of the fuel mixture. For the investigation an ultra-fast high-speed video camera was used. The burning initiation and radial expansion of the flame front were studied in different conditions of initial pressure and temperature specific to the real engine. The experiments proven that certain length laser beams generates radial expansion flame fronts that are ideal for the good functioning of the engine. The initial dimensions of burning cores and velocity of the flame front are calculated by using Raizer theory. Experiments proven that by using the laser beam to initiate the ignition, in the same conditions and same burning chamber, the time by which the pressure peak is achieved is reduced by 4 to 6 ms.

In the second case, the experiments were conducted in a burning chamber with 4 fans of variable speed, thing that facilitated the study of the flame front propagation in the case of passive and isotopic turbulences. The good viewing access allowed the researchers to record the plasma fronts propagation, the shock waves or the ignition cores with a high speed video camera in Schlieren method. A focalized beam from a laser with Nd: YAG initiated the electrical discomposure with beam energies of 85 to 200 mJ. The shock wave theory applied at the shock waves trajectory proves the necessity of high electrons energy, energy that is reached above 105 K and at high pressures. The values calculated for the absorption coefficient of the laser beam energy prove to be comparable with the one obtained experimentally. The propagation waves that results in the explosion creates mono circles in the flame front incensement areas. These generate a third lobe of the nucleus that is going to the laser focal core.

The displacement velocities of the laminar flame fronts are influenced by this dynamic-gas effect, by affecting the velocity of the flame, behavior not met in the classical ignition case. For poorer fuel mixtures that are close to the ignition limit, the strong dynamic-gas fluxes induced by the third lobe can collapse the flame front until extinction and can reduce the chances of laser induced ignition.

The third lobe disappears if the flame front becomes stabile as the initial dynamic-gas effects are repressed by the propagation of the flame front. This phenomenon was met also in the researches conducted by us as you will further.

RESEARCH METHODOLOGY

Stages of research

One established the next stages in the unfolding of the research:

Stage I - the preliminary testing of the fuel mixtures for determining the type of fuel that is most adequate for our research, also preparing and testing the experimental equipments for real usage.

Stage II - the advanced research of the ignition phenomenon that takes place in the static enclosure when initiating the ignition compared to the conventional spark plug or the laser pulse ignition generated by an external transmitter.

Stage III - constructing the laser plug based on the experimental data previously determined; testing the laser pulse ignition generated by the laser plug of the fuel mixture in the static chamber.

Full functional of experimental stand used during the research is presented in figure 1, where:

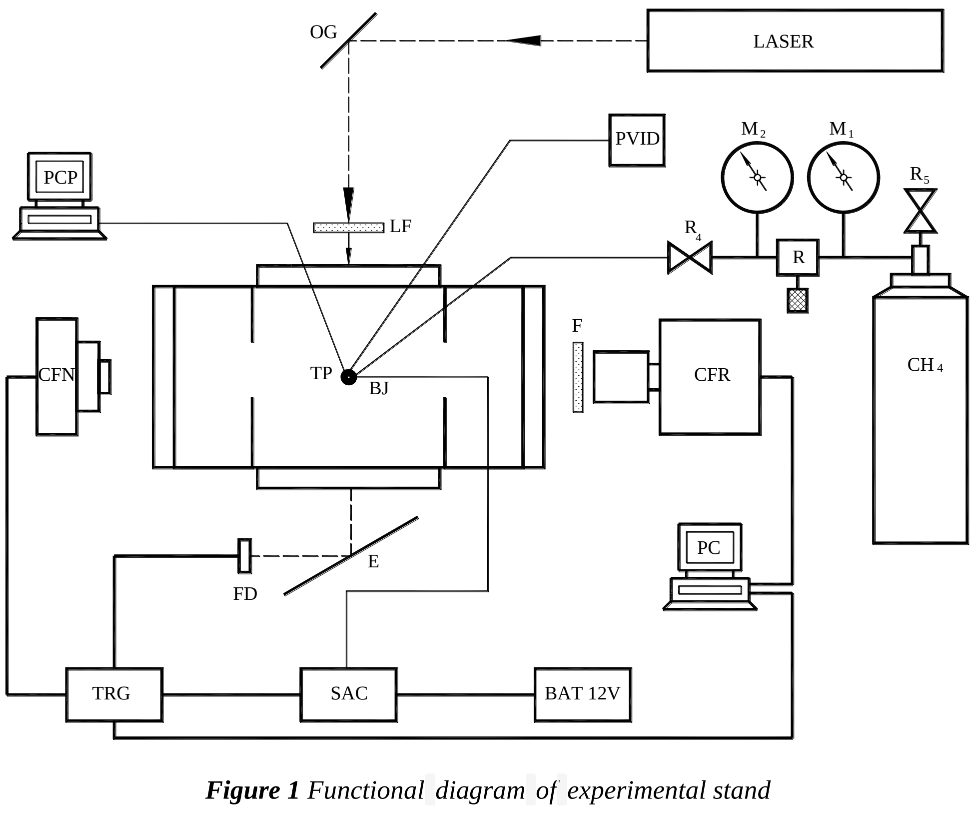

Figure 1 *Functional diagram of experimental stand*

- BAT 12V is a battery voltage of 12 V;
- SAC is the specific classical ignition engines Dacia type 810-99, of compound distributor type 3230 and induction coil type 3130;
- TRG is the trigger system;

- CFN is a video camera normal type of shooting digital Panasonic NV-GS 80 with a shooting speed of 50 frames/s;
- LASER is a laser transmitter type "Quanta Ray DCR, Nd-YAG 'with wavelength λ = 1064 nm;
- LF is a plan lens focusing;
- GO is a laser ray redirection mirror;
- FD photodiode is the role of timing control system;
- E is the screen capture light signal;
- CFR is a camera with fast shooting speed type PHOTRON FAST CAM, which have captured images with a frequency of 1000 that 3000 frames / s;
- F is a filter protection to prevent the incidence of laser radiation with λ = 1064 nm directly on cameras video;
- PC is a computer with dedicated software for processing of images (CFR);
- TP is a transducer that senses pressure variations inside the static chamber and forward them to the system for measuring PCP;
- PCP is a device for measuring and recording pressure variations.

EXPERIMENTAL BENCH

Experiments in this stage were aimed at testing equipment under real conditions of operation, and achieve preliminary results that can be compared, analyzed between switching on the air-gas methane mixture with an electrical spark or with laser pulse.

The mixture fuel used was a mixture of synthetic gas, CH_4-air concentration of 12% (11.56%), bottled in a cylinder at 150 bar, equipped with a system for measuring the pressure of high and low, and with adjustable pressure regulator.

In figure 2, 3 and 4, is presented the experimental bench that is composed of: (1) –video camera shooting speed ; (2) – pressure transducer;(3) –the static chamber; (4) – optical window; (5) - normal video camera; (6) – high pressure manometer; (7) –optical window for viewing; (8) - photodiode; (9) – screen.

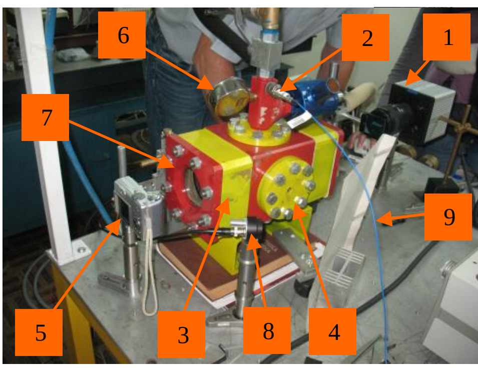

Figure 2 *The experimental bench*

Figure 3 *The experimental bench*

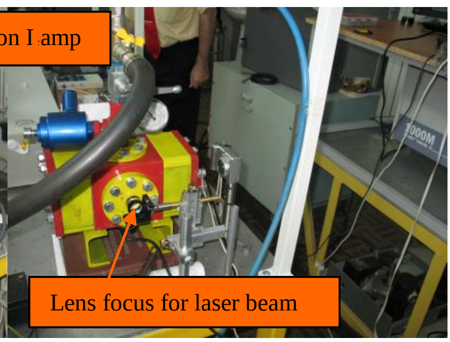

Figure 4 *The experimental bench*

EXPERIMENTAL RESULTS ANALYSIS

In figure 5 are presented the photographs of the fuel mixture flame front propagation, for the electrical spark plug, comparative with laser pulse, transmitted by a fixed laser emitter in the following conditions: 12% methane-air fuel mixture, initial pressure of 0.1 MPa and the energy of the laser pulse of 22.8 mJ. In the case of classical spark ignition, as it can be seen, the flame front is easily obstructed in the inferior part by the electrodes compared to the laser induced ignition where the flame front can develop freely in the same are, because there is no obstacle in this case. In the same time, the flame front development is greater in the case of classical spark ignition for the same burning time. This can also be caused by the absence of the electrodes that causes turbulences.

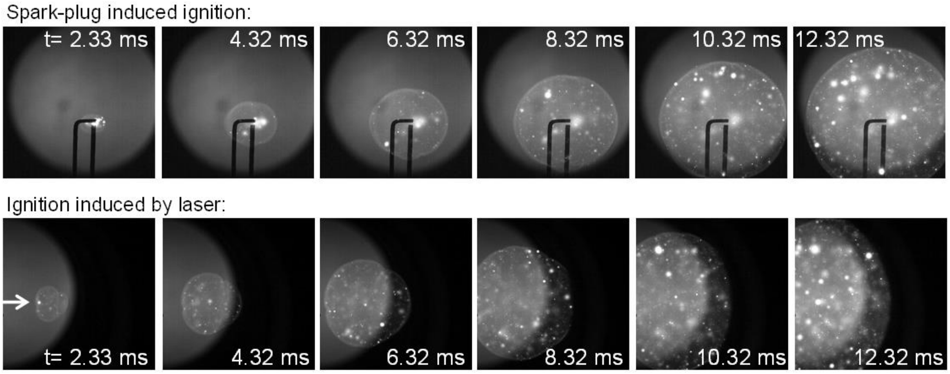

Figure 5 *Photographs of the fuel mixture flame front propagation, for the electrical spark plug, comparative with laser pulse*

In Figure 6, you can see the third lob of flame front. Asymmetrical beam facilitates generation of plasma surface contour, and this behavior can inhibit development of the propagation of the flame.

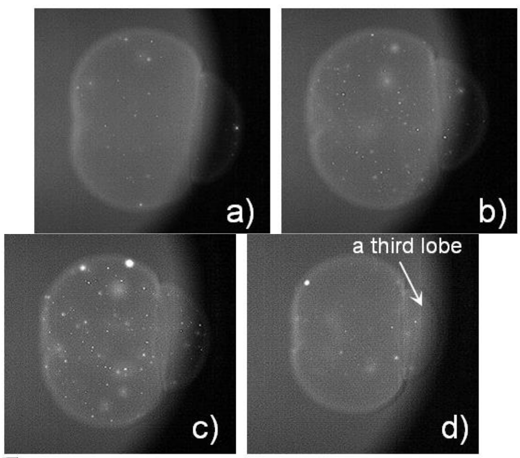

Figure 6 *View the third lob; initial pressure:*
a) 0.1 MPa*; b)* 0.2 MPa*; c)* 0.3 MPa*: d)* 0.5 MPa

Figure 7 presents the peak pressure variation in the explosion chamber of the methane-air fuel mixture ignition, for different values of the initial pressure, and the energy of the laser pulse of 22.8 mJ. For example, at an initial pressure of 0.101 MPa (1 atm), the peak pressure generated In the case of classical spark ignition was of 1.49 MPa and of 1.21 MPa in the case of laser induced ignition. At an initial pressure of 0.506 MPa (5 atm), the peak pressure raised to 3.66 MPa in the case of classical spark ignition and at 3.33 MPa in the case of laser induced ignition. These results could reveal that the presumption that the classical ignition could produce more energy then the laser ignition is false, even though the propagation in the second case was faster.

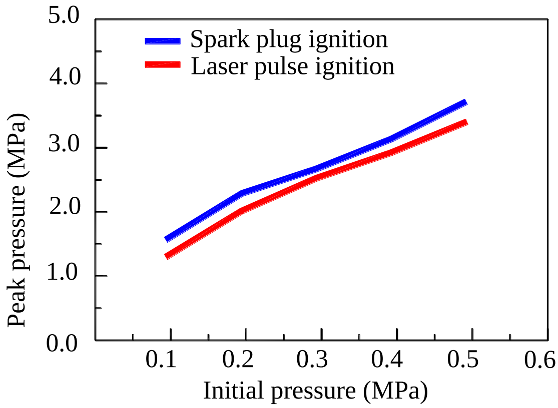

Figure 7 *Peak pressure variation for different values of the initial pressure, and the energy of the laser pulse of* 22.8 m.

In figure 8 is presented the time to the pressure developed by explosion increase from 10% of the peak value, to the maximum value of pressure, and the energy of the laser pulse of 22.8 mJ. Generally, the time to reach peak pressure is directly correlated with the initial pressure level. In the case of classical spark ignition the time to reach peak pressure raises 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 peak pressure is almost 10% higher in the case of laser induced ignition.

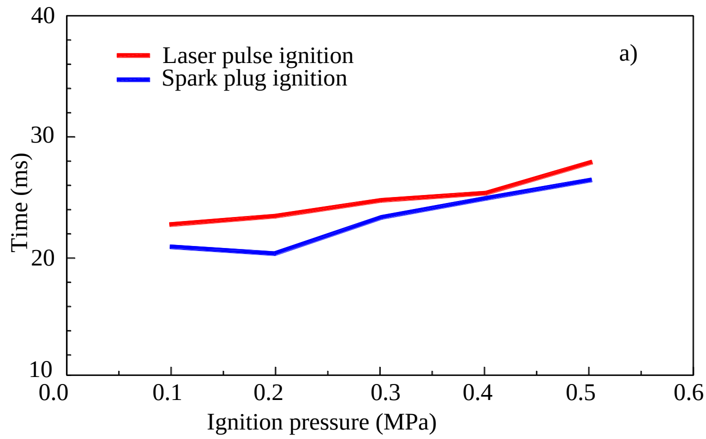

Figure 8 *Time to explosion pressure increase from 10% of the peak value of the maximum value of pressure*

In figure 9 are presented the variations of the flame front propagation velocity in the case of laser ignition and spark plug ignition, for different values of the initial pressures, pulse en and the energy of the laser pulse of 22.8 mJ. One can observe that the flame front propagation velocity is higher in the case of laser induced ignition, especially at high initial pressure. This behavior can be determined by the turbulent movements of the hot gas core generated by the plasma laser and by the influence of the spark plug electrodes over the flame front in the case of classical ignition.

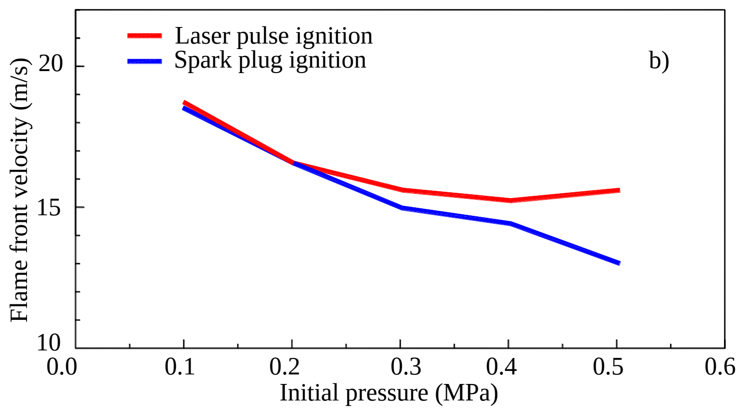

Figure 9 *Variation of the flame front velocity depending on the initial pressure*

In figure 10 are presented the variations of the flame front propagation velocity in the case of laser ignition and spark plug ignition, for different values of the initial pressures and for different value of energy pulse. One notices that a slight increase in the laser pulse energy conducts to a slight increase in the flame front displacement velocity. For example, for an initial pressure of 0.101 MPa (1 atm) the flame front velocity for a laser pulse energy level of 12.8 mJ, is of 16.4 m/s; the velocity increases at 18.4 m/s where the laser pulse energy reaches 22.8 mJ. Also one notates that the propagation velocity decreases once with the increase in the initial pressure, so for a value of 0.507 MPa (5 atm) the propagation velocity drops to 15.4 m/s for a laser with the pulse energy of 22.8 mJ.

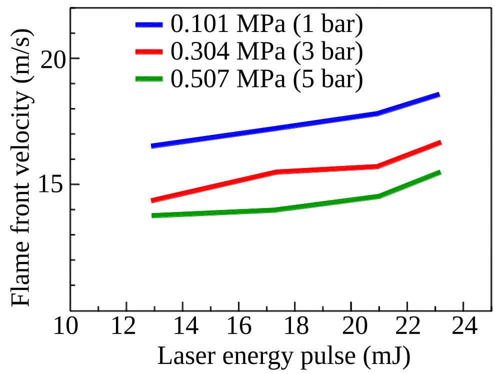

Figure 10 *Variations of the flame front propagation velocity, for different values of the pulse energy and different initial pressures, laser ignition*

CONCLUSIONS

The investigation of the preliminary phases of the burning process was done using the "shadowgraph" method, for capturing images of the flame front development from inside the chamber.

One concluded that the flame front generated by the laser induced ignition has the surface closest to the sphere and also has a much higher velocity then the one generated by the conventional spark plug; but the maximum pressure that was measured when using laser ignition, in the same initial condition, is slightly lower then the spark plug ignition.

The propagation velocity increases once with the increment of laser pulse energy and drops with the increment of the initial pressure in the combustion chamber.

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