

# On the Performances of a 4-Cylinder Automobile Engine with Classical Spark Plug and Laser Ignition Systems

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**Abstract:** A 4-cylinder naturally aspired engine with indirect injection was ignited by classical spark plugs as well as by laser sparks. Engine efficiency parameters, including brake specific fuel consumption, cyclic variability, combustion characteristics and some specific emissions were registered at low 2000 rpm speed and light 2 bar break mean effective pressure for stoichiometric and lean mixtures up to  $\lambda \sim 1.25$ .

## 1. Introduction

It is now well known that in comparison with classical ignition by electric spark plugs, the ignition by laser of an engine can offers several advantages: a) no quenching effect of the combustion flame kernel; b) the laser beam can be delivered at any point within the combustion chamber; c) open possibility to target the beam simultaneously at different positions inside the cylinder or d) the ability to ignite lean air-fuel mixtures. The laser ignition of a single-cylinder engine was first demonstrated in 1978 using a CO<sub>2</sub> laser [1]. In the experiments one-cylinder engine (ASTM-CFR) was operated with air-fuel (A/F) ratio between 12:1 and the lean limit. It took many years of research until a research team from the University of Liverpool reported in 2008, for the first time, results on the operation of a 4-cylinder test engine that was fully ignited only by lasers; two Q-switched Nd:YAG lasers whose beams were electro-optically switched between the engine cylinders were used in the experiments [2]. Advantages of laser ignition (LI) and the developments in the field of laser ignition for internal combustion engines were discussed [3,4].

Following significant body of research, the world first gasoline engine vehicle that was ignited only by laser igniters was presented in 2013 by T. Taira et al. [5]. A Renault engine that was ignited with high-peak power Nd:YAG/Cr<sup>4+</sup>:YAG laser-spark devices was also reported by our group [6-8]. Measurements concluded that stability of the laser-ignited engine is improved appreciably at low speed and moderate load and that CO and HC emissions are decreased in comparison with ignition by classical spark plugs. Still, an increase in NO<sub>x</sub> emission was determined for the engine ignited by lasers.

This work presents results obtained on a 4-cylinder Dacia car petrol engine that was ignited by classical ignition system as well as by LI at 2000 rpm speed and 2 bar brake mean effective pressure (BMEP). The engine operation was done up to a lean air-fuel limit of  $\lambda \sim 1.25$ .

## 2. Experimental conditions

A multipoint fuel injection engine with 4 cylinders in line of 1598 cm<sup>3</sup> total displaced volume and rated power of 64 kW at 5500 rpm speed was used in the experiments (Fig. 1a). The engine was produced by Renault with the code K7M710. It has an open electronic control unit (ECU) type Continental EMS 3132 that is connected to an ECU control system provided by ETAS with dedicated software type INCA v2.1. A Froude Consine AG 250-UK eddy current dynamometer was employed for the control and measurement of the engine torque and speed. The exhaust emissions (CO<sub>2</sub>, CO, NO<sub>x</sub>, THC) were measured and the relative air-fuel ratio  $\lambda$  was delivered by a gas analyzer HORIBA EXSA-1500L. A dynamic fuel meter AVL 733S coupled with a fuel temperature conditioner AVL 753C was used to determine the current real fuel consumption. One pressure sensor AVL GU21D was installed on cylinder 1 of the engine. A data acquisition system type AVL INDIMODUL 621 provided with the corresponding INDICOM software package was used to perform the pressure cylinder registration and post-processing. Acquisitions consisted of batches of 200 consecutive cycles at 2000 rpm and 2 bar BMEP; these conditions are considered as being representative for the city traffic.

The LI system consisted of an integrated four-laser sparks system (Fig. 1b) that was triggered by the engine ECU. Each laser spark yielded pulses with energy up to 4.0 mJ and pulse duration around 0.8 ns. In order to make a comparison of the results in similar conditions, only one laser pulse was used for ignition during all the experiments; thus multi-pulse emission of lean air-fuel mixtures [6] was not considered in the experiments.

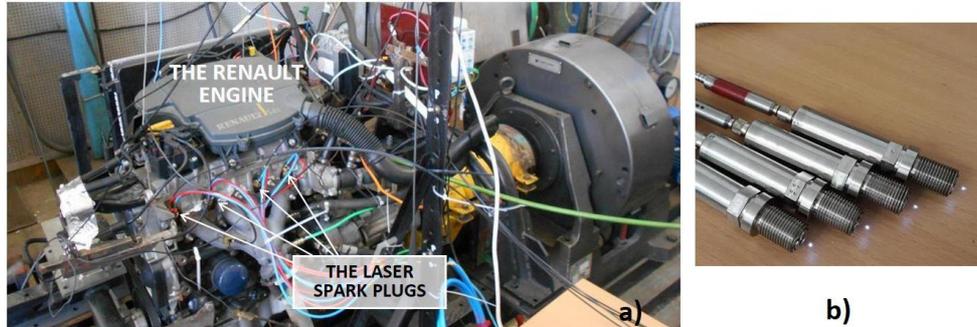


Fig. 1. a) The experimental test bench is shown. b) The four-laser spark plugs used for ignition of the engine are presented.

### 3. Experimental results

Optimized spark timing tests were performed for each ignition system at different air-fuel mixtures, from the stoichiometric mixture ( $\lambda \sim 1$ ) to a leaner mixture ( $\lambda \sim 1.25$ ). The trend in terms of engine efficiency, which was expressed by Brake Specific Fuel Consumption (BSFC), is shown in Fig. 2. Relative deviations from 5% for  $\lambda \sim 1$  (Fig. 2a), up to 21% for  $\lambda \sim 1.25$  (Fig. 2b), were obtained for the LI system in respect to the classical ignition system. The achieved trend encourages research to be made at leaner mixtures with the LI system. The coefficient of variability of indicated mean effective pressure  $COV_{IMEP}$  was smaller (by 44%) for LI compared with conventional ignition for the optimal spark advance at  $\lambda \sim 1$ . A good stability for the LI system was also measured for  $\lambda \sim 1.25$  with a reduced  $COV_{IMEP}$  value by 25%.

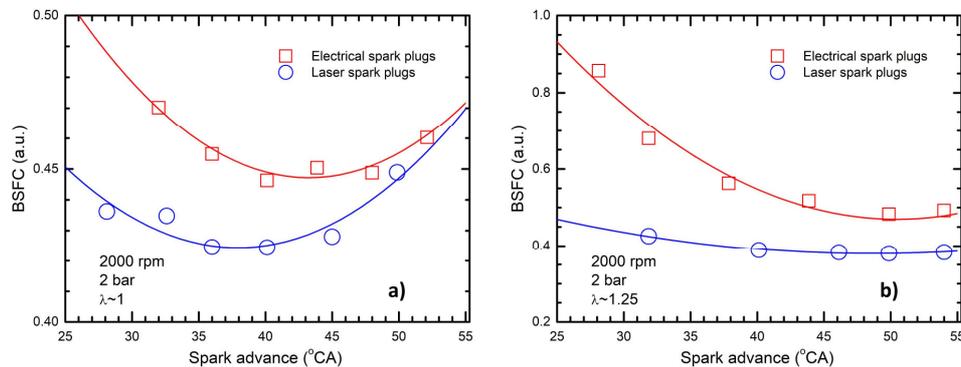


Fig. 2. Variation of BSFC versus spark advance for engine speed of 2000 rpm and BMEP= 2 bar: a) Stoichiometric air-fuel ratio  $\lambda \sim 1.0$ ; b) Lean air-fuel ratio  $\lambda \sim 1.25$ .

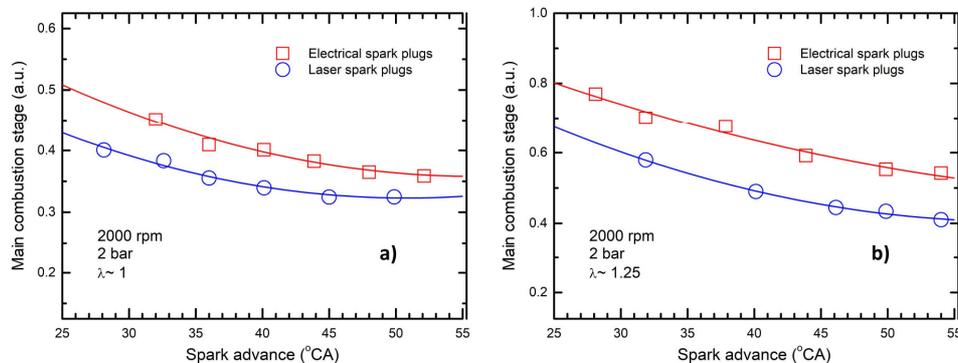


Fig. 3. Duration of the main stage of combustion versus spark advance for 2000 rpm speed, BMEP= 2 bar for a) air-fuel ratio  $\lambda \sim 1.0$ . b) air-fuel ratio  $\lambda \sim 1.25$ .

Another important combustion characteristic analyzed was the duration of the initial and the main stages of combustion process. Considered as the main duration of combustion, measured in crank angle degrees, being the difference between the angle where 90% of the total mass fraction was burned (CA90) and the angle where 5% of the total mass fraction was burned (CA05), is presented in the Fig. 3. In addition, the duration of initial stage of combustion was calculated from the ECU ignition command signal (spark advance) to the angle where 5% of the total mass fraction was burned (CA05). This duration contains few initial steps which have an important effect on the duration of the main combustion. The trends obtained for different spark timings and different  $\lambda$  values are presented in Fig.4.

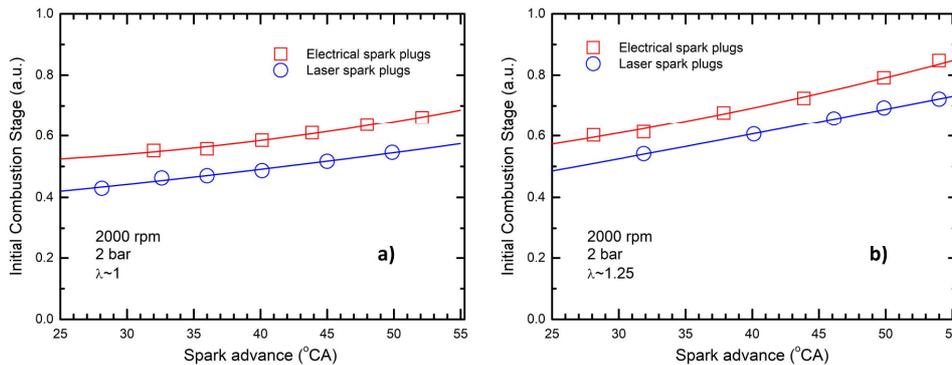


Fig. 4. Duration of the initial stage of combustion versus spark advance for 2000 rpm speed, BMEP= 2 bar for a) air-fuel ratio  $\lambda\sim 1.0$ . b) air-fuel ratio  $\lambda\sim 1.25$ .

#### 4. Conclusions

Some conclusions can be addressed based on the preliminary results that were obtained in this study:

1. A significant improvement in fuel efficiency conversion by 5% for stoichiometric mixture,  $\lambda\sim 1$  and by 21% for lean mixtures at  $\lambda\sim 1.25$  was achieved at low speed and light load;
2. A better stability in engine operation condition expressed by a reduction of  $COV_{IMEP}$  by 44% for  $\lambda\sim 1$  and by 25% for  $\lambda\sim 1.25$ ;
3. These results registered for optimum spark timings are correlated with 17% reduction of initial combustion stage duration for  $\lambda\sim 1$  and with 12% for lean mixture at  $\lambda\sim 1.25$ ;
4. Similar reductions were registered also for the main combustion stage duration by 15% for  $\lambda\sim 1$  and by 21% for lean mixture  $\lambda\sim 1.25$  emphasizing the major influence exercised on combustion by the initial formation and development of the flame kernel.

At this stage of the study further analysis is necessary in order to discuss on a clear trend regarding emissions. Results will be presented at the conference time.

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