Comparative research results of CFR Octane Rating Unit Engine and Dacia Single Cylinder SI Engine equipped with classical Spark Plug and LASER Ignition

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Abstract. Nowadays, research has developed new technologies for a better control of the combustion process. Among the new technologies used for Ignition and combustion control, the LASER spark plug system is defined as an innovative technology which could overcome several limitations of classical spark plug. The purpose of the paper is the experimental research of the LASER spark plug used in the spark ignition(SI) engine. Improved performance, ensuring rapid and robust combustion, depends on how the Ignition stage is achieved. An Ignition system that could provide such an enhanced combustion process is the one based on plasma generation using a Q switched solid state LASER that delivers pulses with high MW peak power. The LI device used in the current research was a LASER medium Nd:YAG/Cr4+:YAG ceramic structure (Baikowski Co., Japan) that consisted of a 8.0-mm long, 1.0-at.% Nd:YAG ceramic, optically-bonded to a Cr4+:YAG ceramic with saturable absorption. It was designed, integrated and built to resemble a classical Spark Plug and could be mounted directly on the cylinder of a CFR Octane Rating Unit Engine as well as on a Dacia Single Cylinder SI Engine which led to several results among which: indicated, mediated pressures and their wave dispersion.

1. Introduction

Recently, a large number of engine manufacturers have been directing their efforts towards enhancing electric mobility, in particular, the internal combustion engine. It is currently widely accepted that Ignition in most engines is produced by electrical system of the engine at a certain moment of the operating cycle and at a specific position in the combustion chamber where the spark plug is located.

Spark plug engine operation, unfortunately, still has several areas requiring improvement such as poor efficiency in the case of low loads, knock tendency in the case of high loads, nanoparticles emissions and elevated level of the global pollutant emissions. Future combustion technologies applied to heat engine will need to solve the problems of ignitability of lean mixtures and the stability of combustion in lean and diluted mixtures i.e. with high EGR, in spark ignited engines [1]. In other words, faster Ignition and combustion over very lean mixtures have considerable benefits concerning fuel efficiency and emissions, due to the extremely high-power Ignition sources such as LASER Ignition and offer several advantages in comparison with classical Spark Plug Ignition [2,3]. This type of Ignition was tested initially in 1978, when a single-cylinder research engine was ignited by a CO2 LASER [4]. In 2008, advanced Q-switched Nd:YAG LASERs were used to ignite a four-cylinder engine [5] but T. Taira et al. [6] made public the first gasoline engine ignited only by LASER.

Following the research, Nd:YAG/Cr4+:YAG LASERs which were either side pumped [7] or longitudinally pumped and that delivered one beam [7] or multi-beam output [8] proved to be feasible for engines.

2. Experimental investigation

Experimental investigations were carried out in a research laboratory of the Faculty of Mechanical Engineering and Mechatronics, Department of Thermotechnics, Engines, Thermal Equipments and Refrigeration Installations, University POLITEHNICA of Bucharest.

The experimental research was developed on an experimental single cylinder SI engine, equipped with LASER Ignition on two engines. The Dacia Single Cylinder SI Engine (figure 1) operating regime was 2800 rev/min, 90 % load and the CFR Octane Rating Unit Engine (figure 2) operating regime was 900/min. Both experimental engines were single-cylinder and were mounted on test beds adequately instrumented.

The LASER spark plug used in the experiments was provided by INFLPR, Laboratory of Solid-State Quantum Electronics, Magurele, Romania. A photo of the LASER spark plug is shown in figure 3. The LASER medium was a Nd:YAG/Cr4+:YAG ceramic structure (Baikowski Co., Japan) [9,10,11].

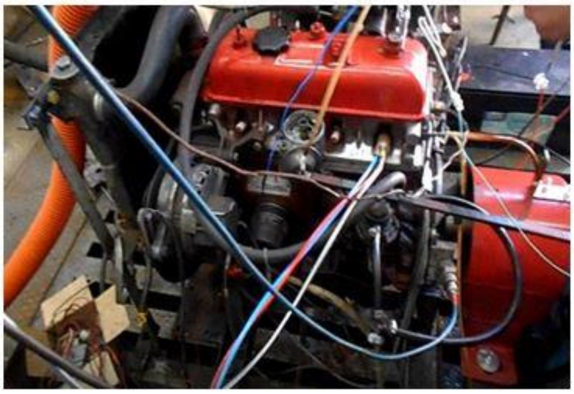

Figure 1. Dacia Single Cylinder SI Engine equipped with LASER Ignition

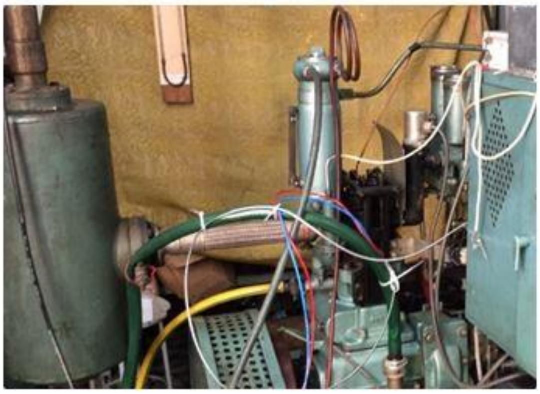

Figure 2. CFR Octane Rating Unit Engine equipped with LASER Ignition

Figure. 3. A photo of a LASER spark plug is shown in comparison with a classical spark plug. The plasma induced in air by optical breakdown is visible.
(Courtesy of INFLPR, Laboratory of Solid-State Quantum Electronics, Magurele, Romania)

3. Results and discussion

Figure 4 shows the pressure values of the CFR engine for 491 cycles, n=400 rev/min, Ignition advance β=28.5 °RAC and λ=1.1 excess air coefficient.

The graphs also indicate the external outlines of the 491 cycles as well as the related maximum values for the classical spark plug (figure 4a) and the LASER spark plug (figure 4b). As noticeable in the 2 graphs, the maximum pressure values range was 22-26.3 bar in the case of the classical spark plug while the range for the LASER spark plug was 22.4-26.9 bar. As seen and expected, figure 4, shows the existence of the cyclic dispersion phenomenon. According to scientific literature, cyclic dispersion is defined, as a rule, by the coefficient of variation (COV), which for a given value *x*, represents the ratio between the standard deviation σ_x and the average value m_x:

$$COV_x = \frac{\sigma_x}{m_x} \tag{1}$$

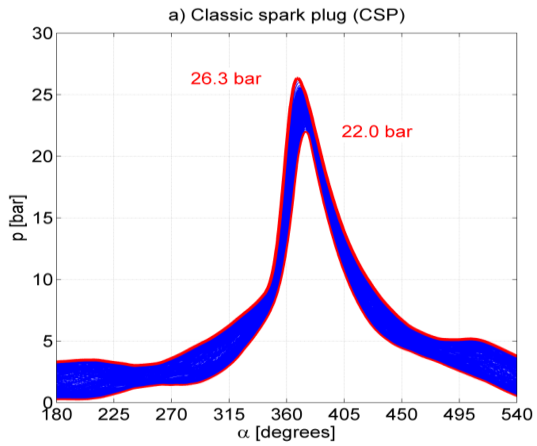

Figure. 4. The indicated pressure, instantaneous values and cycle tires the CFR engine for 491 cycles, n=400 rev/min, β=28.5 °CAD and λ=1.1.

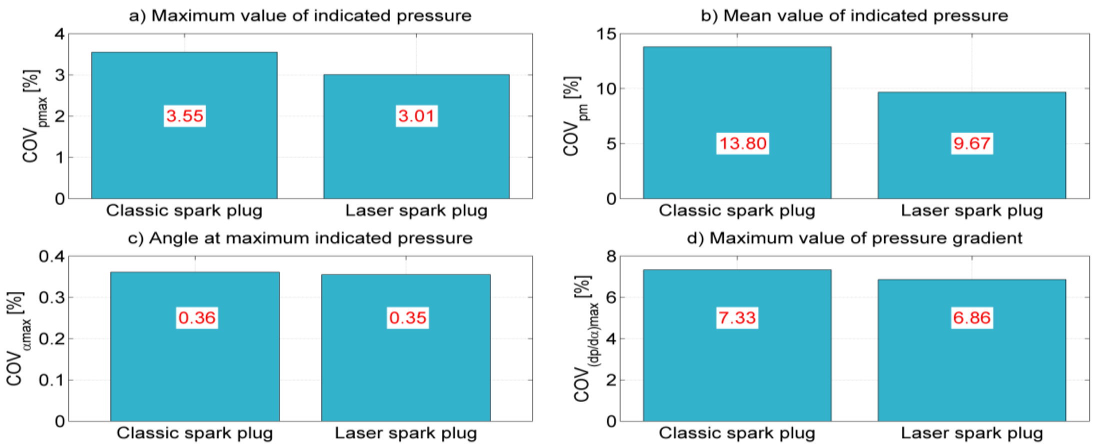

Figure 5. Coefficients of variation for maximum pressure, mean pressure, maximum pressure angle, maximum pressure gradient, CFR engine for: 491 cycles; n = 900 rev/min; β = 28.5°CAD; λ = 1.1

Figure 5 presents the variation coefficient values for the pressure curves in figure 4 and for the four values mentioned in the graph: the maximum and average pressure values indicated, the rotation angle of the crankshaft(CAD) related to the maximum pressure and the maximum value of the pressure gradient. As the graphs show, the LASER spak plug variation coefficient has lower values by comparison with the classical spark plug, for all the four above-mentioned values. Consequently, in this case, based on the variation coefficient, the scale of cyclic dispersion is smaller than in the case of LASER spark plugs.

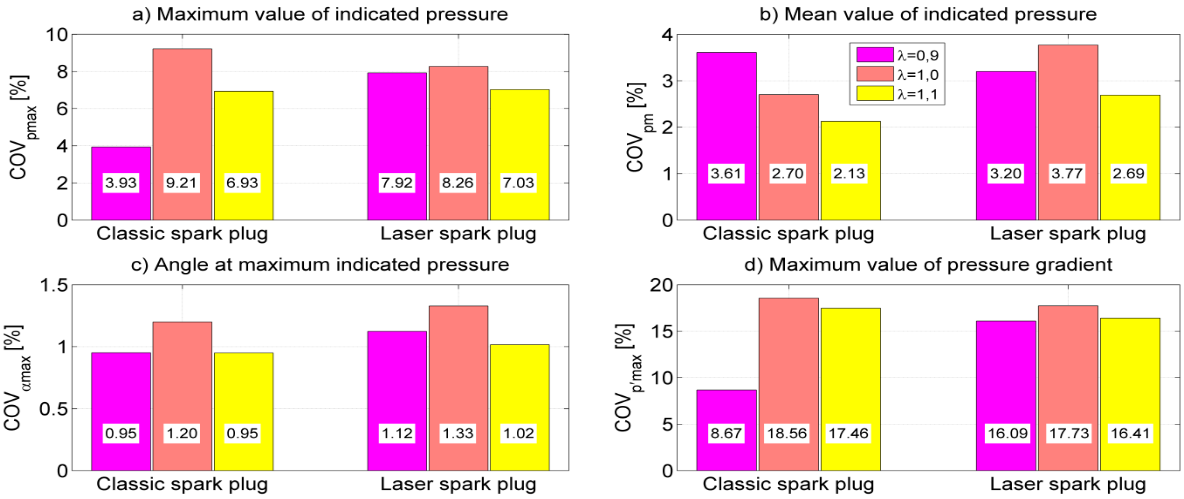

Figure. 6. Coefficients of variation for maximum pressure, mean pressure, maximum pressure angle, pressure gradient, Dacia monociller for: 50 cycles; n = 2800 rev/min; κ = 90%; λ = [0.9; 1.0; 1.1]

Similarly, Fig.6 presents the variation coefficient values in the case of the indicated pressure curves of the Dacia monocylinder engine, for three values of the excess air coeffcient λ as well as for the same four before-mentioned values. As the graphs show, this time the variation coefficient does not always have lower values in the case of the LASER spark plug by comparison with the classical spark plug, for all the four values mentioned and for all the excess air coefficient values. With reference to the above statements, one particular aspect related to the variation coefficient should be mentioned. As resulting from the relationship (1), this coefficient represents a ratio of two values: standard deviation and average value.

Consequently, COV can be higher both in the case of a high standard deviation, and in the case of a low average value. As a result, estimating cyclic dispersion by means of the variation coefficient proves not to be the best solution. In this sense, estimating cyclic dispersion based only on dispersion (square of standard deviation) is ultimately a better solution.

In conclusion, it is recommended to estimate cyclic dispersion by dispersing the curves at each angle of the crankshaft rotation, in other words based on the distance between the external outlines of the curves. This type of estimation is closer to the cyclic dispersion concept and gives a better evaluation of the phenomenon.

5. Conclusions

The experimental results obtained from the LASER spark plug used in the spark Ignition engine compared to the classic Ignition system have led to several important conclusions presented as follows:

a. the use of the variation coefficient to estimate cyclic dispersion has the disadvantage of representing the ratio of two values and as a result cannot lead to veridical conclusions;
b. the use of the distance between the external outlines of the curves of the diagram to estimate cyclic dispersion allows the highlighting of the real phenomenon, the study thus showing that cyclic dispersion varies depending on the crankshaft rotation angle and is not constant, as resulting from the variation coefficient;

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