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The study of an electric spark for igniting a fuel mixture

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*Abstract-***The ignition sparks provided by the classical system do not always assure a fast and complete combustion of the hydrocarbon-air mixture. For this reason have been made a lot of studies, most of them trying to implement new types of electronic ignition systems, including power supply and the spark plug itself, which must provide faster, more complete and more efficient-fuel burning, so overall a lower impact on the environment. The aim of such system consists in the generation of an electrical discharge between the spark plug electrodes able to assure a larger and more homogenous volume of the plasma in the engine cylinder.**

The implementing of such a system involves conducting complex electrical, mechanical, chemical and physical analysis, to validate its benefits in comparison to the classical system. The new type of ignition system with two sparks uses a spark plug with three electrodes. The first one is connected at the high voltage, the second at the ground and the third, located between the two others, free of potential. This paper proposes a complex and comparative study to the classical ignition system. Measurement of the electrical parameters and the physical analysis were done mainly by testing ignition systems in a reactor with air. The mechanical and chemical parameters were measured using an engine stand four-stroke.

INTRODUCTION

The development of an electronic ignition system for internal combustion motors, clean and efficient, requires a fast and complete burn of the poor mixture of fuel at high pressure. The previous studies have demonstrated that a reducing of pollutants emissions of the motors (HC, CO, NOx) can be obtained using a low concentration of hydrocarbons in the mixture with air, which lead to a lower consumption of fuel, [1, 2]. In the same time in order to increase the quality of the combustion it is necessary to increase the energy injected into the ignition spark, [3]. For the same purpose a lot of technical solutions have been found to be effective, among which on can mention: ignition in a burned gases, Pulse Jet Combustor, tested by Renault, multi-electrode spark plug (developed by Bosch), pulsed Laser ignition, electrical Corona and Glidarc discharges, [4], etc. Nakamura, [5], has proposed to use more ignition points for a cylinder equipped with several classical spark plugs and he noticed that the combustion cycle evolves faster, the compression ratio of the motor increases and the poor mixture of hydrocarbons reduce the concentration of some pollutants and in the same time increase the efficiency of the combustion.

Taking into account the principles mention above a new ignition system has been proposed and tested in a high pressure air reactor (10 bars) and on an engine stand (EX1000 type). The system consist in a double spark system that used two simultaneous sparks generated by a pulsed high voltage power supply, Fig. 1.

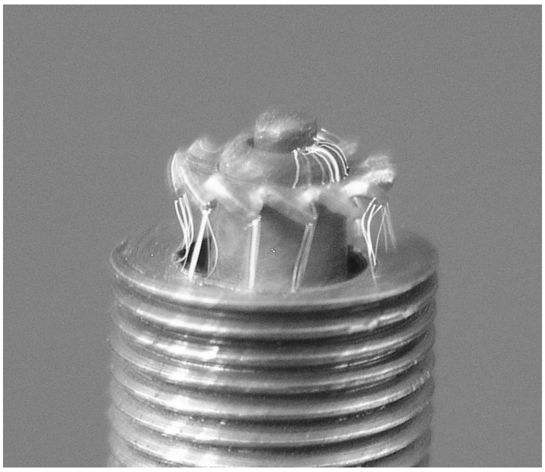

Fig. 1. Photo of a double spark plug.

The ignition system with double spark plug, which has been tested, requires a pulsed power supply that uses an ignition coil (VW AG type) driven by a microsystem based on AT89S52 microcontroller. The power supply used for the experiments permits the shift control of the pulses and therefore the possibility to control the ignition timing of the combustion process. It can provide single or double pulse train, with variable duty cycle for each ignition of fuel mixture, Fig. 2. The experiment focuses on the generation of active species for single or double pulse train and their influence on combustion process. The ignition system has been tested on one - cylinder four stroke engine (Deltalab EX1000 Stand, Honda GX31 engine), aiming the analysis of combustion and mechanical parameters. Electrical and optical investigations have been also made. The electronic and energetic aspects, with respect to electrical parameters measurements of the electrical discharges (current, voltage, power, energy), electrical discharges life time (optical investigation) in the high pressure conditions and pressure

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wave propagation from the moment of ignition of the combustion mixture, [6], have been performed.

The synchronization of mechanical parameters of the engine, with the electrical parameters of the ignition system, has been also taking into account.

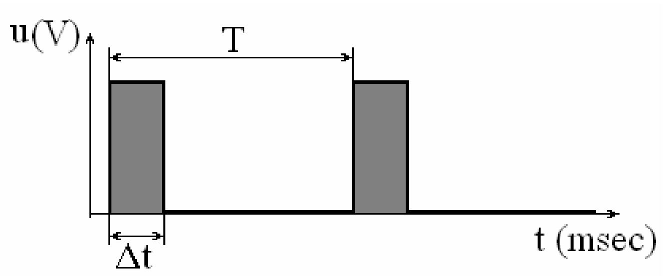


Fig. 2a. Simple pulse train adjustable in width (Δt).

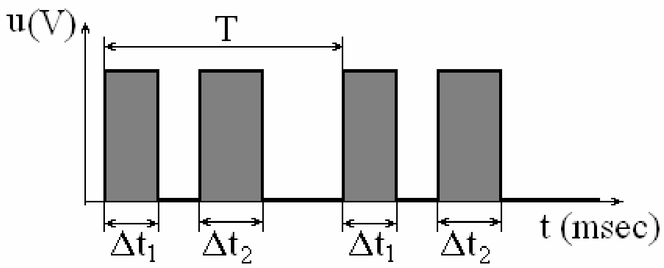


Fig. 2b. Double pulse train adjustable in width (Δt_2).

The spectroscopic analysis of the classical spark and the double one in order to identify active species that could influence the quality of combustion was also conducted.

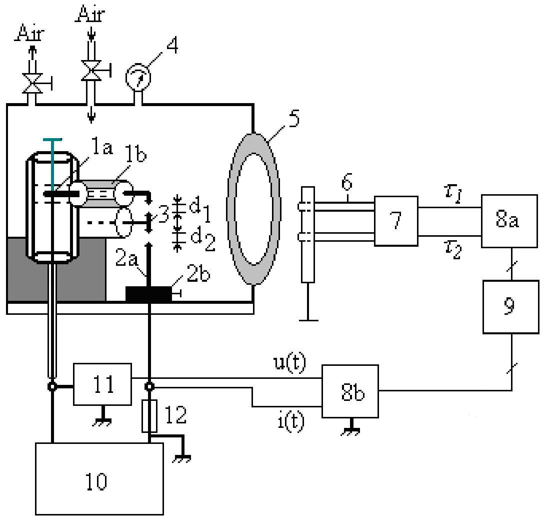
Considering the coil parameters and the very short times of the pulses, the spark plug produces a transient electrical discharge type. Because the electric current value is limited during the discharge lifetime, there is a difference between the electron and of the heavy particles (atoms, ions and molecules) temperatures, due to non-thermal characteristics of the plasma.

EXPERIMENTAL SETUP

The optical and electrical analysis has been done in a high pressure air reactor, Fig. 3. The evolution of the sparks, the correlation between the electrical and optical signals and the time delay between the two sparks as function of the reactor's pressure have been studied.

The electrical parameters of the sparks were also determined on the engine stand. In this case we aimed to study the dependence of pulses provided by the command system, as function of the engine speed, both in primary and secondary winding of the induction coil.

The stand performs under software which can acquire a series of parameters related to its mechanical characteristics, Fig. 4. It was studied the evolution of engine output parameters (fuel consumption and exhaust gas composition) depending on the input ones (engine speed, position of the air regulator and load).



(1a,1b) High voltage electrode clamping system ; (2a,2b) Reference electrode and adjusting system ;(3) Auxiliary electrode ; (4) Manometer ; (5) Lens ; (6) Optical fibers ;(7) Fast phototransistors ; (8a,8b) Digital oscilloscope ; (9) Computer ; (10) High voltage power supply ; (11) High voltage probe ; (12) Shunt.

Fig. 3. High pressure air reactor

Analysis of exhaust gas composition was made using a gas analyzer, Testo 330-2LL type, placed at the outlet of the exhausted gases of the engine stand. The evolutions of the concentrations of carbon monoxide and oxygen (or carbon dioxide) have been investigated.

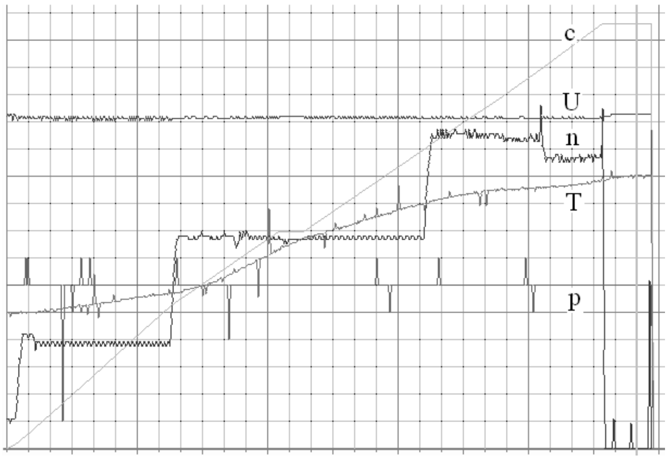


Fig. 4. Mechanical characteristics of the engine: speed (*n*), air regulator position (*p*), battery voltage (*U*), engine temperature (*T*) like time records.

The spectroscopic analysis of the spark electrical discharges was made in air using the experimental set-up as shown in Fig. 5.

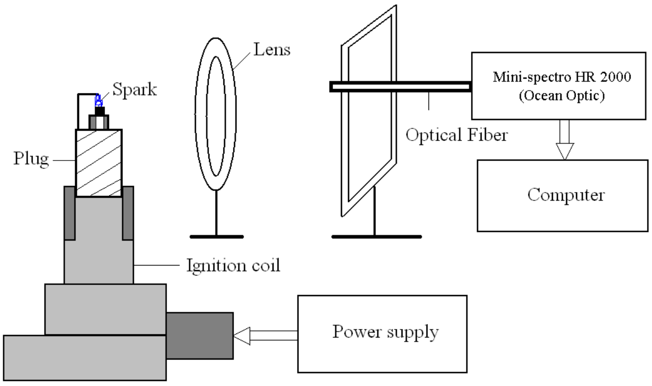


Fig. 5. Experimental set-up for spectroscopic analysis.

The spectroscopic analysis (plasma emission spectroscopy) was made in order to identify and compare species present in plasma produced by the electrical discharge of the classical spark plug and the double spark system. In order to identify the active species produced by the sparks, only radiation peaks with greater amplitude than 800 a.u. of the integrated spectra of the discharge, have been considered.

RESULTS AND DISCUSSIONS

1. Optical and electrical analysis

The lifetime of the sparks has been studied using the schematic shown in Fig. 3. The optical signals were measured using optical fibers, in addition with the electrical current measurement. It was observed a good correlation between the two signals, giving a value of the lifetime of the discharge between 150 and 200 microseconds and a delay between the breakdowns of the sparks of the order of hundreds of nanoseconds. In Fig. 6 and 7 are shown the durations of the sparks, function of the air pressure into reactor [6], [7].

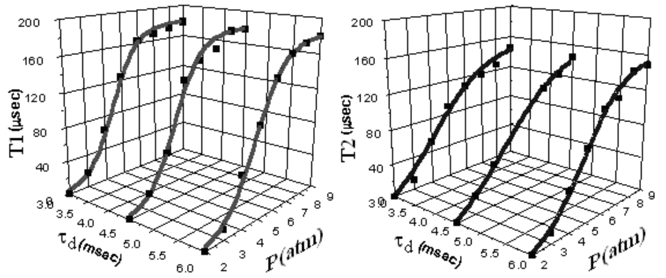


Fig. 6. Sparks duration T_1 and T_2 depending on the pulse width τ and on the air pressure into reactor, P .

One can assume that both sparks participate to the combustion process and that their evolution will be similar on the ignition process of a combustible mixture. In the same time, the duration of the discharges is independent of pulse duration, due to the high pressure in the reactor, for a single pulse applied to the spark plug.

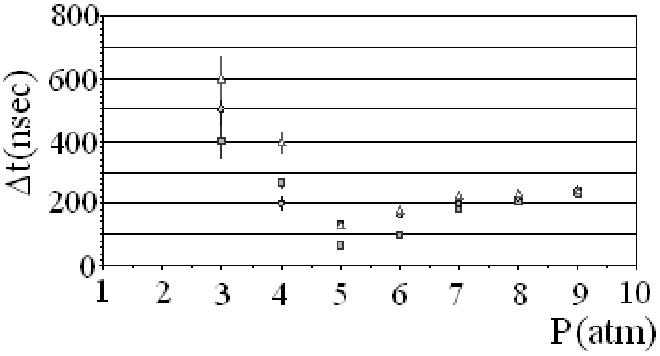


Fig. 7. Evolution of the delay between the breakdowns of the sparks function on the air pressure into reactor
[pulse width: □ τ_d =3.0ms ; ○ τ_d =4.5ms ; △ τ_d =6ms].

The next figure (Fig. 8) shows the evolution of pulses applied by the electronic ignition system of EX1000 stand to the coil, as function of different engine speeds.

Because the ignition timing of the engine is controlled by an inductive positioning sensor, the pulse period measured in the primary winding coil is proportional with the engine speed. It is mentioned that measured pulse width remains constant.

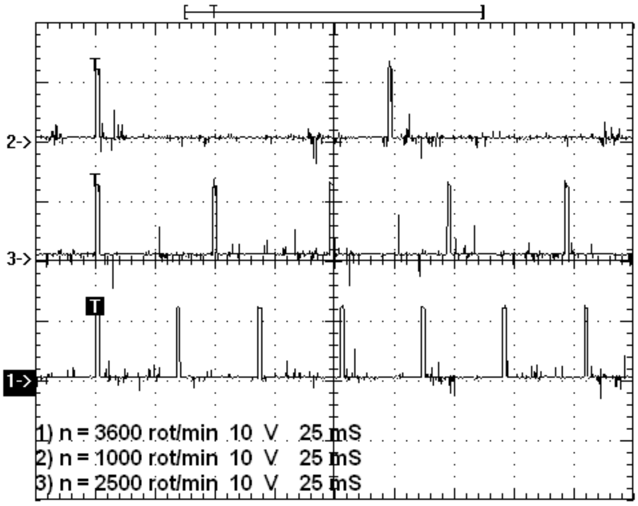


Fig. 8. Evolution of pulse period depending on engine speed.

2. Mechanical characteristics

During starting of the engine it is loaded from the database of the computer the theoretical characteristics of the ignition and injection timing. In Fig. 9 it is shown the evolution of fuel consumption, c, depending on speed, n, for different positions of the air regulator, p, based on theoretical characteristics. The position of the air regulator determines the air – fuel mixture ratio injected into the cylinder of the engine.

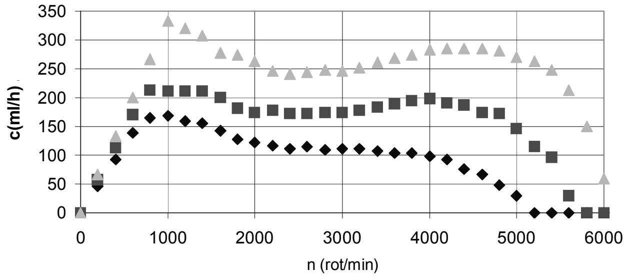


Fig. 9. Theoretical consumption feature *c* depending on engine speed *n* and positions of the air regulator: ♦ *p* = 3 ; ■ *p* = 6 ; ▲ *p* = 9.

In Fig. 10 are shown the experimental evolutions of the fuel consumption, *c*, depending on the speed, *n*, measured for two positions of the air regulator of the fuel mixture. In Fig. 11 it is a comparison between the evolution of fuel consumption, *c*, and the engine speed, *n,* for two geometries, the first one for the simple spark and the second for a double spark. Consumption *c* according to the load of the engine *S* is presented in Fig. 12 for two different positions of the air – fuel mixture regulator.

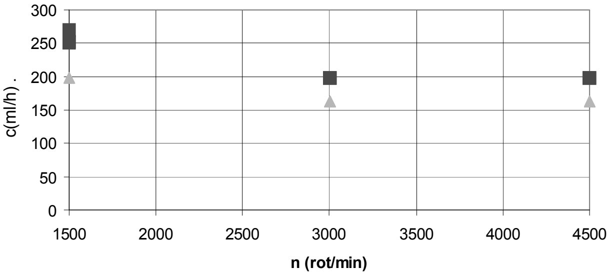


Fig. 10. Fuel consumption *c* depending on the engine speed *n* for different positions of the air regulator: ■ *p* = 6 ; ▲ *p* = 9.

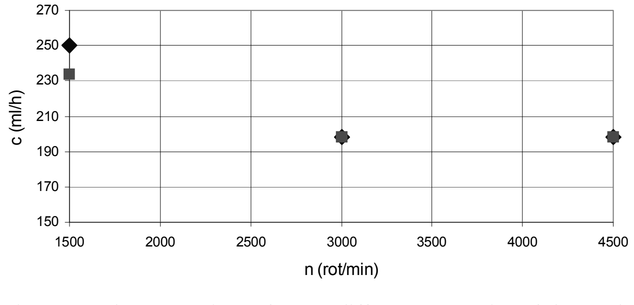


Fig. 11. Fuel consumption *c* for two different geometries of the spark ♦ 1 spark ; ■ 2 sparks - Position of the air regulator *p* = 6

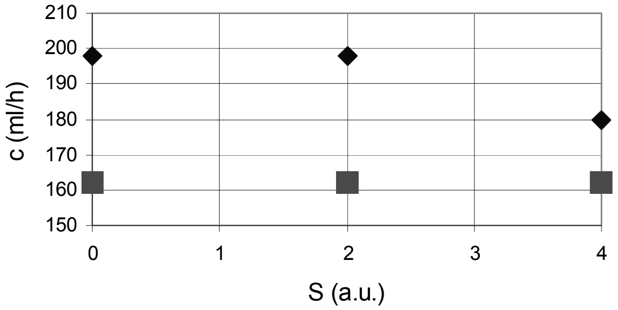


Fig. 12. Fuel consumption *c* depending on the load of the engine *s* for different positions of the air regulator: ♦ *p* = 6 ; ■ *p* = 9 - engine speed *n* = 4500 rot/min.

It can be said that fuel consumption decreases with increasing of the position of the air regulator. In these conditions the torque developed by the engine will certainly decrease. Fuel consumption varies little with the engine speed or to engine load value, which it makes sense if we analyze the theoretical characteristics loaded on engine control stand. The system with a double spark does not affect fuel consumption compared with the case of a conventional spark plug.

3. Exhausted gas

The engine has a fuel injection system, but the exit is not equipped with a catalyst or other emission reduction system. The measurement of the exhaust gases was made in continuous mode. The stabilization time of each sensor of the gas probe is different and for each set of values it was waited a stabilization of the device indications.

In Fig. 13 is presented the gas concentrations evolution (O_2 and CO_2 concentrations) function of the load of the engine. Fig. 14 shows the evolution of the oxygen concentration in the exhaust gas depending on speed for two different values of the position of pressure regulator. Fig. 15 shows the evolution of oxygen concentration in the exhaust gas of the engine, depending on the position of the pressure regulator for three different values of the engine speed.

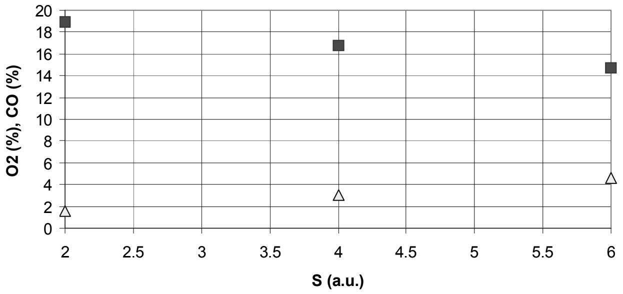


Fig. 13. Production of exhaust gas function on the engine load, *S:* ■ % O_2; ▲ % CO_2.

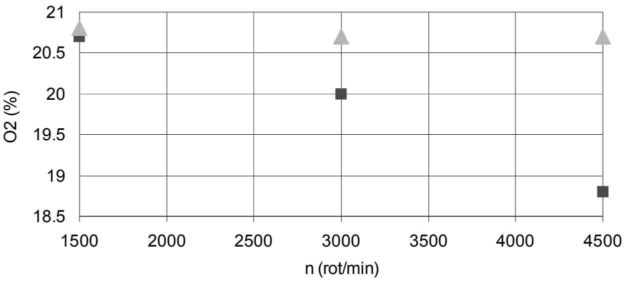


Fig. 14. Exhaust Oxygen concentration versus engine speed *n* for different positions of the air regulator: ■ *p* = 6 ; ▲ *p* = 9.

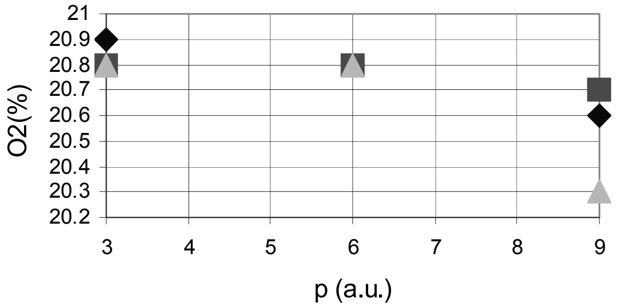


Fig. 15. Exhaust Oxygen concentration versus air regulator position *p* for different engine speeds *n* [rot/min]: ▲ 1500 ; ■ 3000 ; ▲ 4500.

It has been found a decreasing of oxygen concentration, with the increasing of the engine load, motor speed and position of the air regulator. This means an increasing of the concentration of toxic exhaust gases (carbon monoxide or carbon dioxide), which is normal for any increasing of engine speed or load. A medium or lower value of the air regulator position (a poor air – fuel mixture) involves a lower combustion quality with significant amounts of toxic exhaust gases. At poor air-fuel mixtures, oxygen concentration in exhaust gases remains constant, independent of motor speed.

4. Spectroscopic analysis

A comparison between spectra obtained for a classical spark by applying single or double pulses of variable duration from 1.5 to 5.5 milliseconds (100 Hz frequency, spark produced in air). In Fig. 16 are given several spectra recorded in the same conditions at different time intervals for single pulses with duration of 3 milliseconds. In Fig. 17 are represented the spectra obtained for two sparks corresponding to increasing of the pulse duration from 3 to 4.5 milliseconds.

Note that in Fig. 16 spectra recorded at different times in the same conditions are identical. As shown in Fig. 17, the peaks of the spectrum taken at 4,5 msec are consistently higher than those taken for the other pulse spectrum.

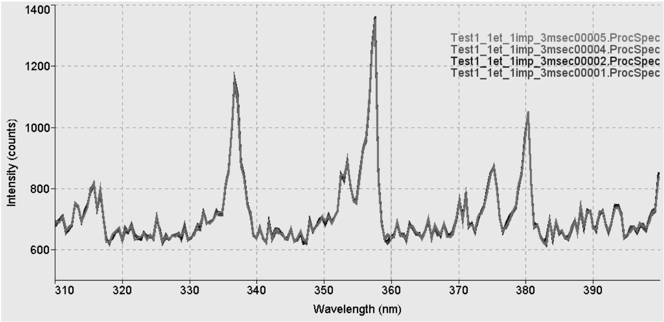


Fig. 16. Spectra taken in the same conditions at different time intervals.

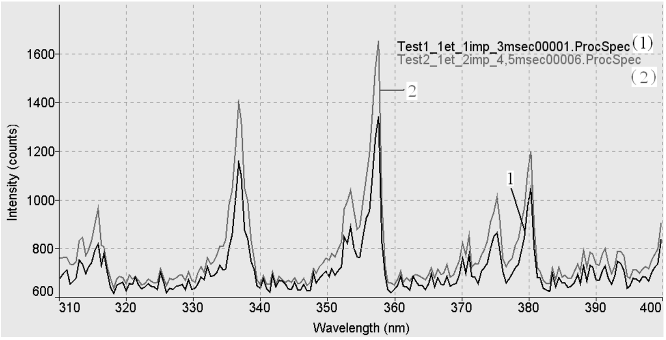


Fig. 17. The evolution of integrated spectra for increasing pulse duration.

The main elements identified in the atomic spectra are those contained in spark plug: tungsten, iron and cadmium. These elements are found in all spectra, which are similar in shape and really stable. The majority of identified peaks are found in the range from 300 to 400 nm.

What differs is the radiation intensity that varies with pulse duration applied to the coil, therefore with the energy that is injected into ignition sparks. Molecular spectra obtained can be identified by comparison with those conventional non – integrated spectra (e.g. grouping OH), but not allow further interpretation due to the low sensitivity of the spectrophotometer, see Fig. 18.

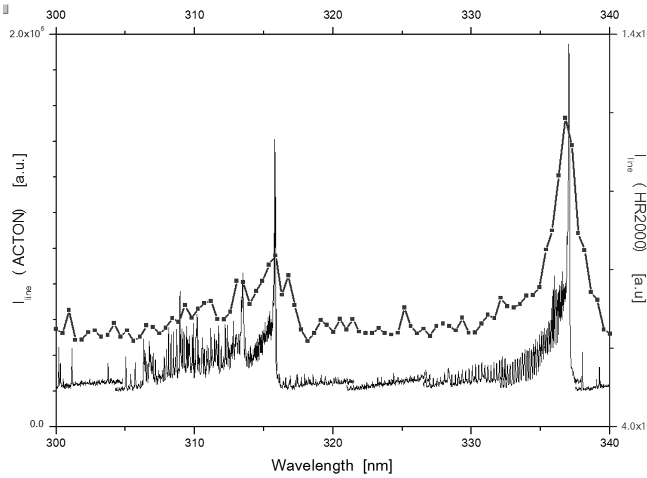
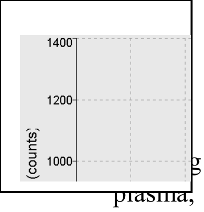


Fig. 18. Comparison between low resolution spectrum (-■-) and high resolution spectrum (full line).



g a spectroscopic method with a direct exposure of plasma, it could be obtained some spectra easier to be used, see Fig. 18, which allow spatial and temporal study of the plasma, with a more precise diagnosis, associated with different operating modes.

CONCLUSIONS

The experimental tests and analyze have demonstrated that the ignition device with double spark are applicable in real conditions of working of a one cylinder motor. The double spark plug ensures a greater volume of discharge by doubling the length of the sparks. The experiments done in a high pressure chamber with air showed that the two sparks breakdown at a time interval of hundreds of nanoseconds and their lifetime are between 150 – 200 microseconds.

The fuel consumption decreases with increasing of the air from the fuel mixture, but at the same time decreases the torque of the engine. It varies insignificantly in relation to engine speed or load engine value, which is understandable if we analyze the theoretical characteristics communicated to the command system of the engine stand.

The engine speed increases when shifting in a regime with a sufficient engine torque and decreases for a poor fuel mixture or for a high value of the engine load.

Exhaust gas measurement had some problems because one of the gas probe sensor (the CO) was saturated at relatively low critical value, with another timer compared to other sensors of the probe. This problem can be avoided by equipping the engine stand with a λ specific probe or by performing a chromatographic analysis.

Concerning spectroscopic analysis it is apparent that the spectra are stable and repeatable, regardless of the pulse power supply and the light intensity increases with adjustable pulse duration. It can be noticed that there are differences between the spectra obtained for a pulse of short duration and those obtained for two relatively large pulse duration (to see the trio of 400 nm).

Validation of quality improvement by using the double spark ignition system, compared with the conventional system, requires a complex study with chemical and mechanical analysis.

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