SPECTROSCOPIC DIAGNOSTIC OF TRANSIENT PLASMA PRODUCED BY A SPARK PLUG

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Abstract. The ignition sparks generated by the classical spark plug do not always assure a fast and complete combustion of the mixture hydrocarbon-air. For this reason we propose a new type of double spark plug using two simultaneous discharges generated by a pulsed high voltage power supply. This work presents the spectroscopic analysis of the plasma generated by the classical spark plug in comparison with three electrode spark plug, supplied with trains of pulses containing one or two pulses with variable width. The experiments have been done in air at normal pressure. Because the spectra obtained are clear, stable and repeatable, it was possible to determine the temperatures in the plasma column using a spectroscopic diagnostic method based on the OH UV molecular band spectra.

1. INTRODUCTION

The efficiency and the quality of an ignition system for internal combustion motors require a fast and complete burn of the poor hydrocarbon-air mixtures at high pressure. It was proved that the reducing of exhaust emissions of the engines can be obtained using a low concentration of hydrocarbons in the mixture with air, which leads to a lower fuel consumption, [1] and an increasing of the combustion quality needs a more important energy provided to the spark, [2].

The ignition system proposed 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. Nakamura, [3], 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 reduces the concentration of some pollutants.

Taking into account the conclusions mention above a new ignition system has been proposed and tested in a high pressure air reactor (10 bars), on an engine testing stand (EX1000 type), [4, 5]. The system consists in a double spark system, with three electrodes, that uses two simultaneous sparks generated by a 100 Hz pulsed high voltage power supply, Figure 1. The first electrode, *1*, is connected at the high voltage, the second, *2*, at the ground and the third, *3*, located between the two others, free of potential. The power supply used for the experiments uses an ignition coil (VW AG type) driven by a micro-system based on AT89S52 microcontroller. It permits to choose the pulse duration time (fixed at 1.6 ms in our working conditions), but also the shift control of the pulses and therefore the possibility to control the ignition timing of the combustion process.

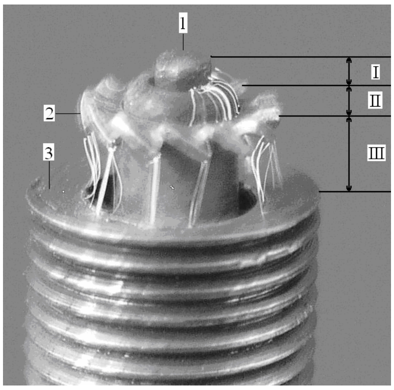

Figure 1 - Double spark plug.

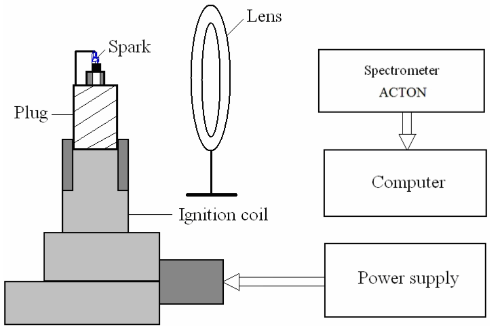

Figure 2 - Experimental set-up for spectroscopic analysis

2. EXPERIMENTAL SET-UP AND RESULTS

The spectroscopic analysis of the spark electrical discharges was made in air at atmospheric pressure using the experimental set-up shown in Figure 2: the plasma image is focused using quartz lens, directly into the inlet slit of a spectrometer ACTON 750i (750 mm focal length) equipped with intensified CCD camera. The exposure time was set to 10 ms to integrate on one period of the process, but to increase the signal to noise ratio, we accumulated on 100 acquisitions.

The spark plug was placed on a step by step motorized table. Then three distinct areas of the discharges can be study side-on, see Figure 1: I – the spark plug inner electrode; II – area near by the washer and III – between the washer and the ground electrode of the spark plug. The emitted light was spatially integrated on the corresponding region shown in white boxes in Figure 3: on can observe that the spark ignites almost always in the same position, and on can consider that, during a complete record (100 accumulations), a similar plasma zone was studied.

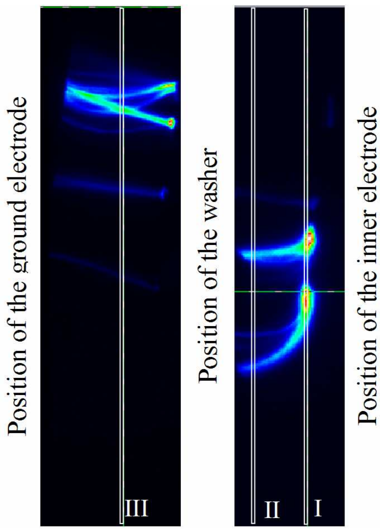

Figure 3 – Observed zones (t_{exp} = 10 ms; 100 acc.)

In order to determine the rotational temperature of the plasma, a method based on comparison between experimental and theoretical rotational structure of the molecular emission spectra of the OH band at 306.357 nm, [6], has been used. S.Pellerin *et al.* [6] have shown that (assuming excitation equilibrium in the plasma, and knowing the spectral line intensity I_{nm}^{*} for a given rotational temperature T^{*} (e.g. 3000 K)) the experimental spectrum intensity I_{nm} of the same lines for the rotational temperature T can be determined using the equation:

$$I_{nm} = I^{*}_{nm} \frac{Q(T^{*})}{Q(T)} e^{-\frac{E_n (T^{*} - T)}{k_B T T^{*}}} \qquad (1)$$

where $Q(T)$ is the partition function; E_n – the energy of the state n; and k_B – the Boltzmann constant and T – the temperature.

The line emitted by hot gases are broadened by different effects, but in our experimental conditions, broadening of spectral lines results mainly from the convolution of the emission spectrum with an experimental apparatus function, which is supposed to be Gaussian with a full width at half maximum $\Delta\lambda_{app}$.

Then, the comparison of experimental data with a database of theoretical spectra taking into account the values of T and $\Delta\lambda_{app}$, allows evaluating the rotational temperature in the plasma sources. Particularly, an accurate determination of the rotational temperature can be performed from the ratio of several head bands or isolated lines chosen in [6]:

- In a first stage of the spectroscopic diagnostic method, the offset, considered as linear, was extracted from the experimental spectra, by using Origin software, Figure 4. The spectra are then normalized with the line G_{ref}.
- Considering the result, the experimental apparatus function was determined by analyzing the peaks G_{ref}, Δ_1 and Δ_2 (See Figure 4) that can be considered like relatively well-isolated. Each of the three peaks was examined by matching with a Gauss profile (See Figure 5), obtaining a mean optical apparatus function $\Delta\lambda_{app}$ = 0.026 nm.
- Rotational temperature is then evaluated using the ratios $R_{ij}=I_{0i}/I_{0j}$ between amplitudes of peaks I_{01}, I_{02}, I_{22} and I_{24} advised in [6] identified on Figure 4, by interpolation of data given by S.Pellerin *et al* [6].

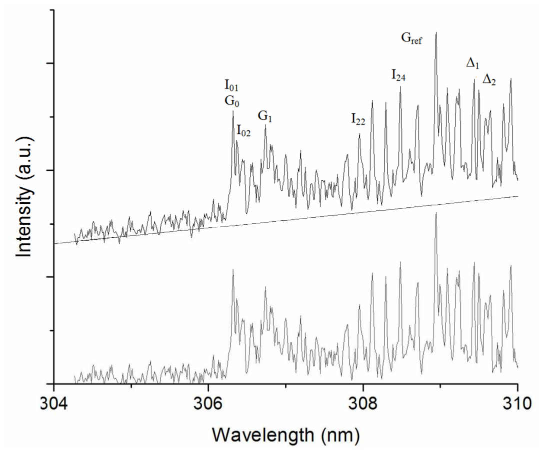

Figure 4 – Typical recorded spectrum with the extraction of the offset

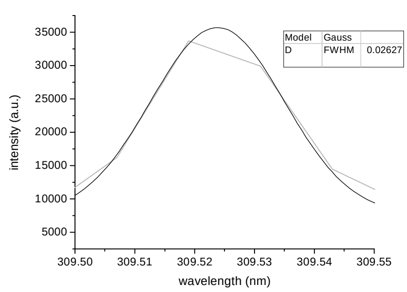

Figure 5 - Evaluation of the apparatus function using Gauss profile.

Rotational temperatures obtained in the three different areas of the double spark plug, are presented in Table 1. We can note that the value of rotational temperature decreases from zone I to zone III. This can be explained by a higher thermal exchange between the spark and the environment.

Spectra	R	Temperature (K)	Average value of the temperature (K)
I - in the vicinity of the spark plugs central electrode	R_{12}=1,53	2700	2800
	R_{14}=1,08	2700	
	R_{22}=1,07	3000	
II – above the washer	R_{12}=1,44	2500	2500
	R_{14}=1,07	2700	
	R_{22}=0,82	2300	
III – between the washer and the body of the spark plug	R_{12}=1,05	1700	1967
	R_{14}=0,99	2200	
	R_{22}=0,79	2000	

Table 1. Average values of the rotational temperature for each area

3. CONCLUSIONS

The experimental tests and analyze have demonstrated that the ignition device with double spark, that assure a greater volume of discharge, are applicable in real working conditions in the case of an internal combustion motor.

Regarding the spectroscopic analysis, the spectra are stable and repeatable and we have verified that the light intensity of the spark increases with the pulse duration. The error in calculating the rotational temperature can be reduced by the elimination of the background noise and by choosing of the apparatus function. However, more intense thermal stress of the spark plug in its upper part is considered for its construction in order to increase its reliability in operation.

ACKNOWLEDGMENT

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