1. Scientific and Technical Report

Research Report - extended (12 pages)

Summary:

1. General Objectives

The general objectives are referring to the testing, validation, implementation and spectroscopic investigation of a plasma ignition device for an internal combustion motor (EX1000 type) in order to increase the rapidity and the quality of the fuel combustion, therefore the reducing of pollutant emissions. The method consists in the generation of one or more successive electrical discharges between the spark plug electrodes able to assure a larger and more homogenous volume of the plasma in the cylinder.

Among the principles mention above the first one has been proved to be more effective and easier to set up from a technical point of view. The two ignition sparks are obtained by interposing between the electrodes of a classical spark plug of an auxiliary electrode.

2. Objectives of the execution phase of the project

a) The improvement of the electronic ignition system. The study of the opportunity to implement a supersonic electrical discharge Glidarc type, in addition with the ignition system.

b) The set-up of the ignition system on the mono-cylinder motor.

c) The testing of a supersonic electrical discharge Glidarc type set up at the outlet of the exhausted gases path in order to reduce the pollutant emissions.

d) The set-up of electrical discharge Glidarc type into a miniature chamber (made of quartz or metal) in order to study the combustion.

3. Abstract

The activities of the Romanian partner corresponding to the 2nd research phase were:

1. The set-up of a metallic high pressure miniature chamber in order to study the combustion. In a last design phase a pressure piezoelectric probe set up in the spark plug body have been used, instead a shock absorber cylinder of the explosion in the moment of ignition.

The initial idea of the real time analysis of the plasma generated by the ignition spark (using spectroscopic analysis of the light signal of the discharge through an optical fiber) has been possible by using a quartz window made into the pressure chamber. The practical set up of the miniature pressure chamber was the task of the French partner and the design was made in collaboration of both teams.

2. The optimization of the ignition system

The proposed ignition system consists in two components: the two-spark plug and the power supply. The improvement of the two-spark plug was made by attaching of a potential free electrode in a cavity in the insulating body of the spark plug. The testing set up of two-spark plug required a pulsed power supply that use an ignition coil driven by a microsystem with AT89C2051, which permits the shift control of the pulses and therefore the possibility to control the ignition timing of the combustion process. A set of new software has been used to optimize the quality of combustion by applying signals of different waveforms to the primary of the ignition coil. The 3 versions that were used with the variation limits of the electrical parameters are presented in the technical description bellow.

3. The set-up of the ignition system on the mono-cylinder motor

For the experimental part an EX1000 motor stand have been used, provided by the French partner, from a third part. Therefore the experimental inputs consisted only in the replacement of the classical spark plug with a double-spark one. The motor characteristics and the comparison of the exhausted gasses in the two cases have been done. Taking into account the experimental data obtained, which didn't emphasize significant differences, a decision of deep studying of the two spark plugs design and control pulses of the power supply by spectroscopic methods have been taken. A smooth working of the motor was observed in the case when two-sparks plug was used. The implementation of the new power supply on the motor stand wasn't performed, which had been caused a substantial change in its functioning. As was announced in the 1st scientific report, the motor stand communicate with the computer through a serial port, through which it loaded the mechanical characteristics, ignition timing and as a result the functioning control of the motor.

4. The study of the feasibility of implementation of a supersonic electrical discharge Glidarc type, for the reducing of pollutant gases.

The measurement of the pollutant gases of the motor exhausting didn't reveal significant differences for classical and two-spark plugs. More, due to the low power of the mono-cylinder motor of the stand, the set up of a supersonic Glidarc was considerate inopportune, its influence on the noxious gases emission would be very difficult to analyze for the range of the concentration of the exhausted gases of the motor. In addition, the stand is equipped with an electrical system that compensates the low power

of the thermal motor, for a certain load, and lead to a modification of the concentration of exhausted gases (the concentration of the noxious gases can't be considered in direct correspondence with the motor load).

Therefore, the main aim of the research was focused on comparative spectroscopic analyze of the plasma produced by two types of spark plugs for different impulses wave forms of the power supply.

4. Scientific description. Research results and Objectives achievement degree

The experiments were performed on an EX1000 motor stand equipped with a mono-cylinder motor Honda GX31, with fuel injection controlled by an electronic system based on the microcontroller 68HC11. The influence of different parameters on the mechanical characteristics and exhausted gases composition has been studied. The experiments were made for the classical spark plug of the motor and also for the two-spark plug. The experimental data have been published in an article that is gone to appear in a journal considered in IEEE Xplore data base, [1].

The first experimental protocol was referring to the influence of the input parameters of the stand (motor speed, regulator position and motor load) on the output (fuel consumption, exhausted gases composition, measured with a Testo 330-2LL probe).

In Figure 1 is presented the informational flux and the work principle of the motor for each of the four times.

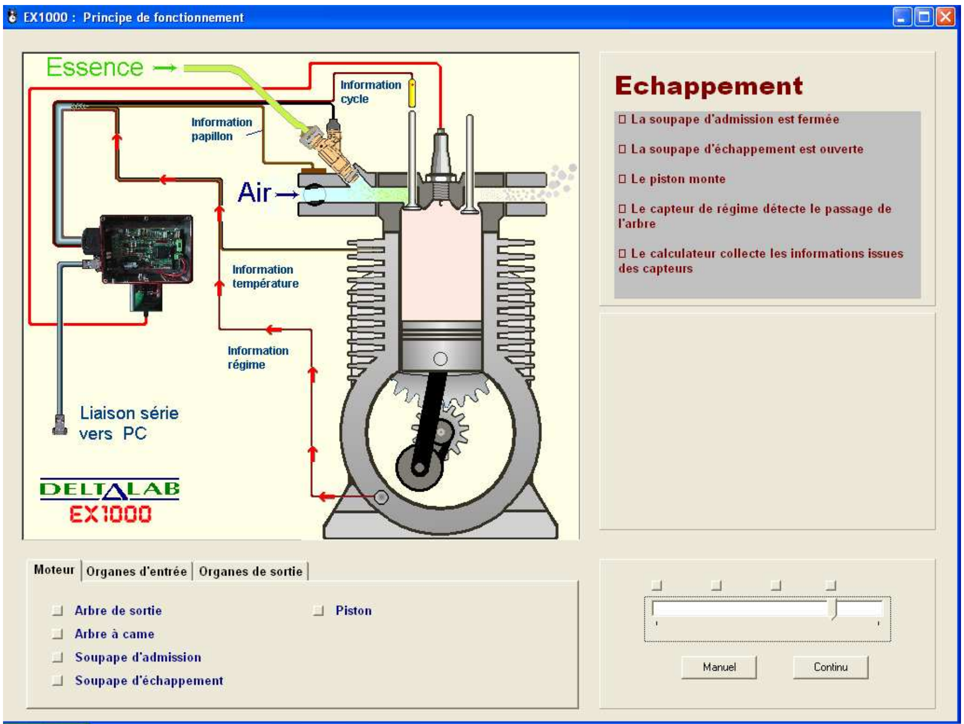
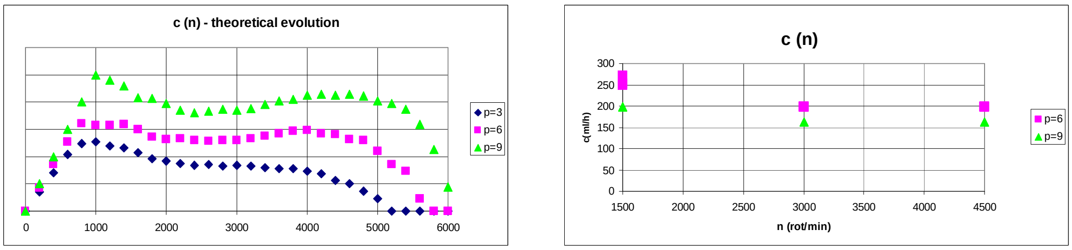


Figure 1 – Schematic of EX1000 test stand

In Figure 2a is presented the theoretical curve of the fuel consumption function of the motor speed, for different position of the air regulator. In Figure 2b is presented the experimental curve. The position of the air regulator determines the combustion mixture air/hydrocarbons.



2a – theoretical curve 2b – experimental curve

Figure 2 –Evolution of the fuel consumption function of the motor speed

In Figure 3 is presented a comparison of the fuel consumption for the two types of spark plugs.

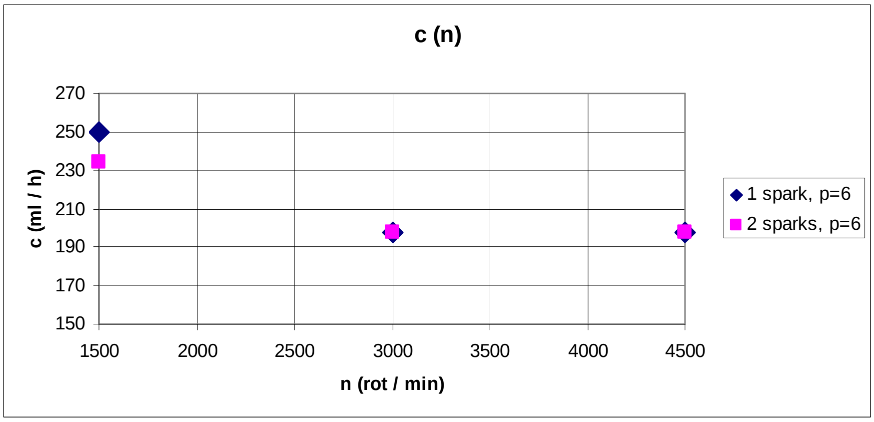


Figura 3 – The comparison of the fuel consumption for the two types of spark plugs.

In Figure 4 presents the evolution of fuel consumption function of the load degree of the motor for 2 different positions of air regulator.

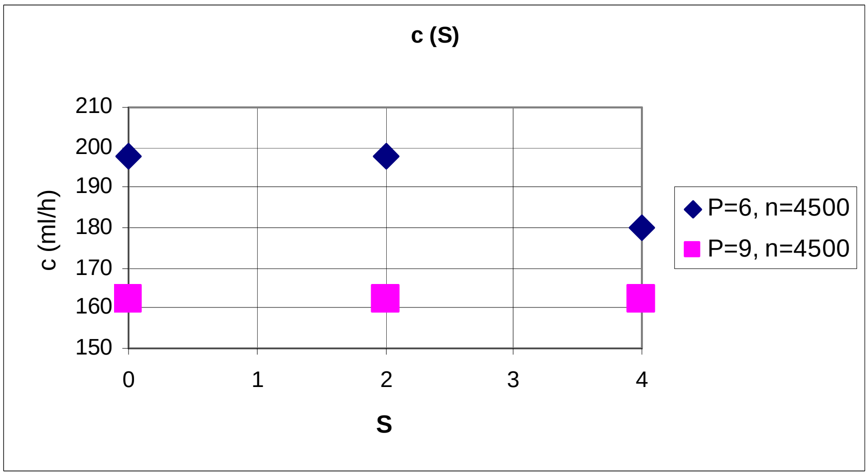


Figure 4 – The evolution of fuel consumption function of the load degree of the motor for 2 different positions of air regulator.

The graphic representations of the characteristics have been possible by experimental data acquisition from the mechanical characteristics of the motor as is presented in Figure 5 for the motor loads up to 4.

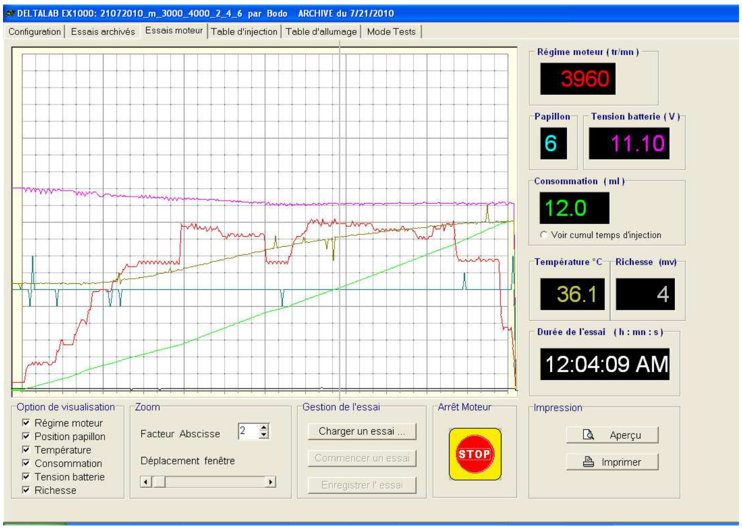


Figure 5 – The evolution of the fuel consumption slope and motor speed for different load degrees

On can conclude that the fuel consumption and the torque of the motor decrease with the air increasing in the combustion mixture. The fuel consumption varies insignificantly with the motor load degree, which is due to the electronic compensation of the motor power the stand is equipped with.

The two-spark plug didn't increase the fuel consumption in comparison with the classical spark plug.

The motor had a fuel injection system but it wasn't equipped with a catalytic system for exhausted gases treatment. The probe made the measurements in real time when the readings were stabilized.

In Figure 6 is presented the evolution of the oxygen concentration function of pressure regulator position for 3 different motor speeds.

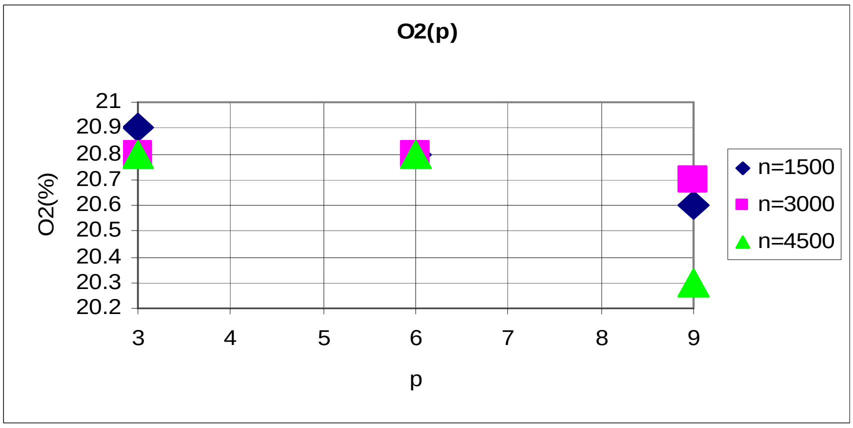


Figure 6 – The evolution of the oxygen concentration function of pressure regulator position for 3 different motor speeds.

The experimental data showed a decreasing of the oxygen concentration in correspondence with the increasing of the load, speed and regulator position of the motor.

The double-spark plug dimensional is smaller than a usual one, which made difficult to shape it. The ground electrode was cut to make place for the potential free electrode fixed in a cavity drill in the ceramic insulator between the high voltage and ground electrode. The potential free electrode was made from a washer cut and then shrinks on its place between other two electrodes. In the end the washer was welded in place, Figure 7.

The spectroscopic analysis of the spark electrical discharges was made in air using the experimental set-up shown in Figure 8.

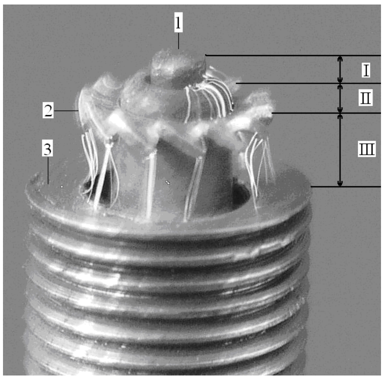


Figure 7 –Double-spark plug

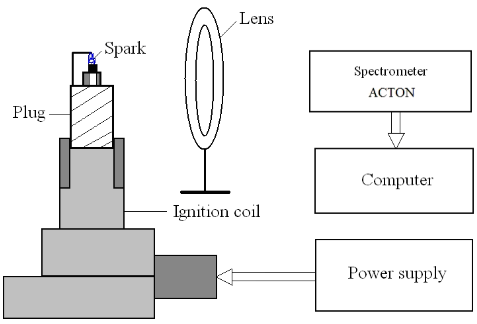


Figure 8 – Spectroscopic measurement set up

In the first phase the spectroscopic analysis was done in the 3 regions of the spark discharge, Figure 7, for one width controlled pulse [2]. Image of the spark is transmitted to the spectrophotometer ACTON 750i (750 mm) equipped with a CCD camera through a quartz window and an optical fiber. The exposition time was set at 10 ms and for 100 acquisition spectra. The spark plug was positioned on the step-by-step moving device and the light emitted by the spark was spatially integrated for each of the 3 regions defined by thee-electrodes, Figure 9.

On can observe that the sparks ignite mostly in the same place and therefore on can consider that for a complete recording (100 accumulations) a similar plasma zone have been studied.

In order to determine the rotational temperature of the plasma a method based on the comparison of the theoretical and experimental structure of the emission spectra of OH band from 306.357 nm have been used [3].

After background noise removing and using the method mention above the following results have been obtained, Figure 10, see Table 1.

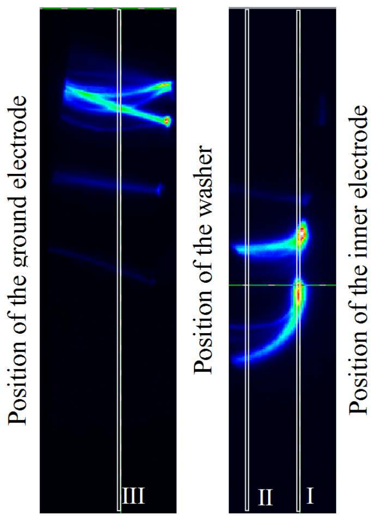


Figure 9 – Observed zones (t_{exp} = 10 ms)

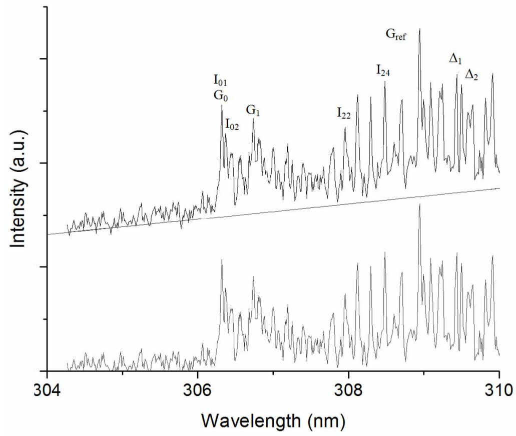


Figure 10 – Spectra recorded without offset

Tabelul 1. Average values of the temperature for each area (first method)

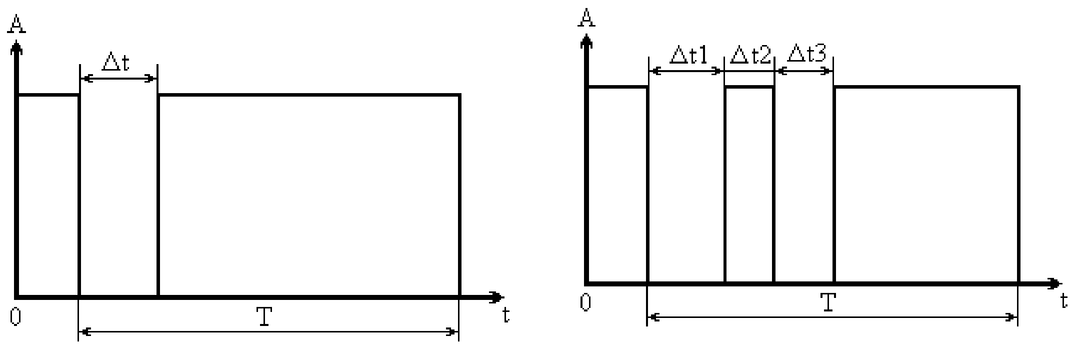
Spectra	R	Temperature (K)	Average value of the temperature (K)
I - in the vicinity of the spark plugs central electrode	R_{12}=1,53	2700	2800
	R_{14}=1,08	2700	
	R_{22}=1,07	3000	
II – above the washer	R_{12}=1,44	2500	2500
	R_{14}=1,07	2700	
	R_{22}=0,82	2300	
III – between the washer and the body of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

The results calculated with the Method I have been compared with the results calculated with a similar method, [4], Table 2. By using the second method correspondence between values reported in Table 2 and rotational temperature was done by using tables for different values of delta, which is in this case the pulse width at half amplitude (Δ = 0,031 nm).

Tabelul 2. Average values of the temperature for first area (second method)

Spectra	G (a.u.)	Temperature (K)	Average value of the temperature (K)
I - in the vicinity of the spark plugs central electrode	G_0 / G_{ref} = 0,57	2700	2750
	G_1 / G_{ref} = 0,52	2800	

On can observe that the values obtained with the both two methods differ insignificantly. The results obtained have been taken into account for the double spark plug design and used on the test stand. On the other hand the study performed seems to be original and conclusive, therefore a comparison between the plasma of the sparks of the two types of spark plugs have been made. The study have been performed on the classical spark plug divided in 3 regions and the double-spark divided on 5 regions, for 3 types of pulses wave forms Figure 11a and 11b.



a) One pulse per the period b) Two pulse per the period

Figure 11. Pulses wave forms with variable time duration

The power supply designed uses the microcontroller AT89S52 that permit the control of some external devices in the same time by a pulse (ex. The control of the spectrophotometer camera) and in the same time permits the width control of the pulses. Even the signal period were 10 ms the power supply can generate pulses of variable period impose by an external sensor (inductive sensor of the motor). Three different software have been created as follows:

a) one pulse with period variable between and 3.8 msec (Figure 11a);

b) two pulses per period with the variable pause time between them (Δt_1=Δt_3=1.6 msec, Δt_2 = (0, 6.5) msec, Figure 11b)

c) two pulses per period, the first one of constant duration (0.9 msec), the time gap between them (1 msec) and the second one of variable duration Δt_3 = (0, 6.5) msec, Figure 11b.

The double spark plug have been divided in 5 regions of study as shown below: I – inferior part of the high voltage electrode, II – the superior part of the potential free electrode, III – inferior part of the potential free electrode, IV – the middle distance between the potential free electrode and the ground electrode, V – superior part of the ground electrode. Adding to this 5 regions the 3 wave forms types of pulses we have obtained a lot of spectra that are to be analyzed and on basis of the results that will be obtain we look forward to publish at least 2 scientific papers.

The data analysis is referring to the identification of the species formed in plasma (molecular spectra, atomic spectra), Figure 12, in order to compare them function of the region of the signal acquired and the wave forms of the pulses. In addition the diagnostic of the plasma will be taking into account

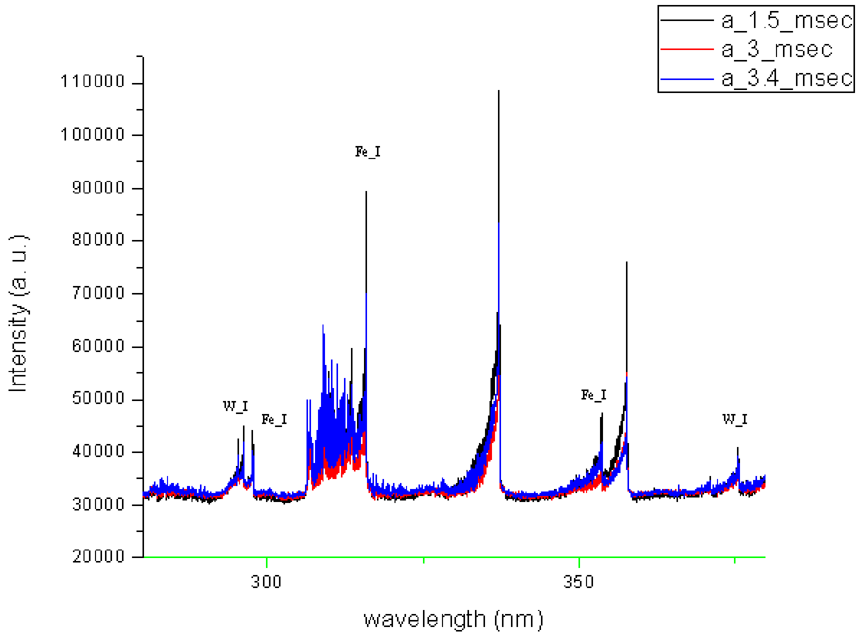


Figure 12 –Elements identification starting from the recorded spectra

The diagnostic part of the plasma consists in the preliminary calculation of the rotational temperature starting from the OH band from 306.357 nm, [3, 4], and from the molecular bands of N_2^+ (end band at 391.4 nm) and N2 (end band at 337.1 nm), Figure 13. Also, the rotational temperature calculation using a different method, the vibration temperature and species density will be performed [5]. There will be used the band ends of the second positive system N_2 corresponding to P1: $\Delta\nu = 0$ at 337.1 nm, P2 : $\Delta\nu = -1$ at 357.5 nm, P3 : $\Delta\nu = -2$ at 380.4 nm, P4 : $\Delta\nu = -3$ at 405.94 nm and P5 : $\Delta\nu = -4$ at 434.36 nm, Figure 13. The determination of the Boltzmann diagram in order to obtain the rotational and vibration temperature of the species will be also taking into account.

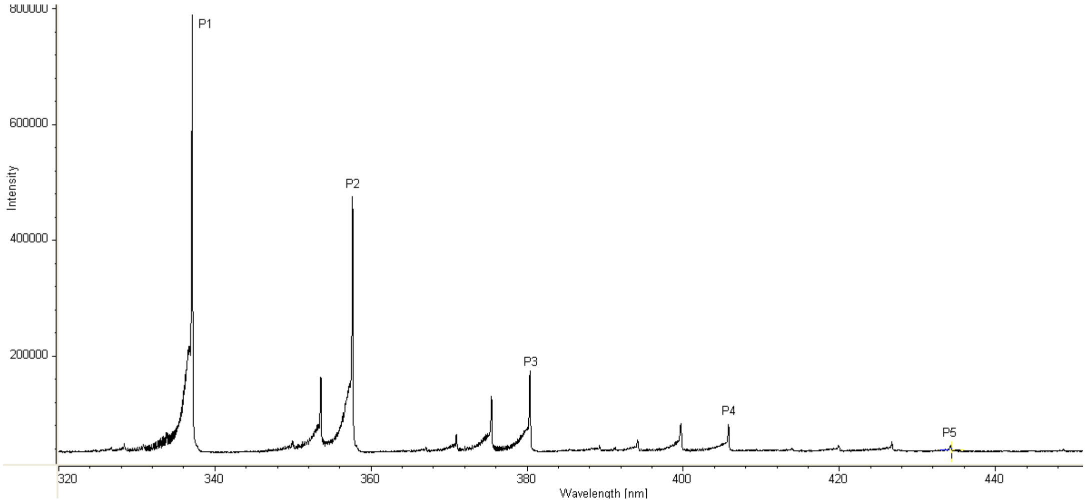


Figure 13 – The identification of the N_2molecular species

5. Annex 1

In order to extend our collaboration the French partner had manufactured a high pressure chamber, Figure 14.

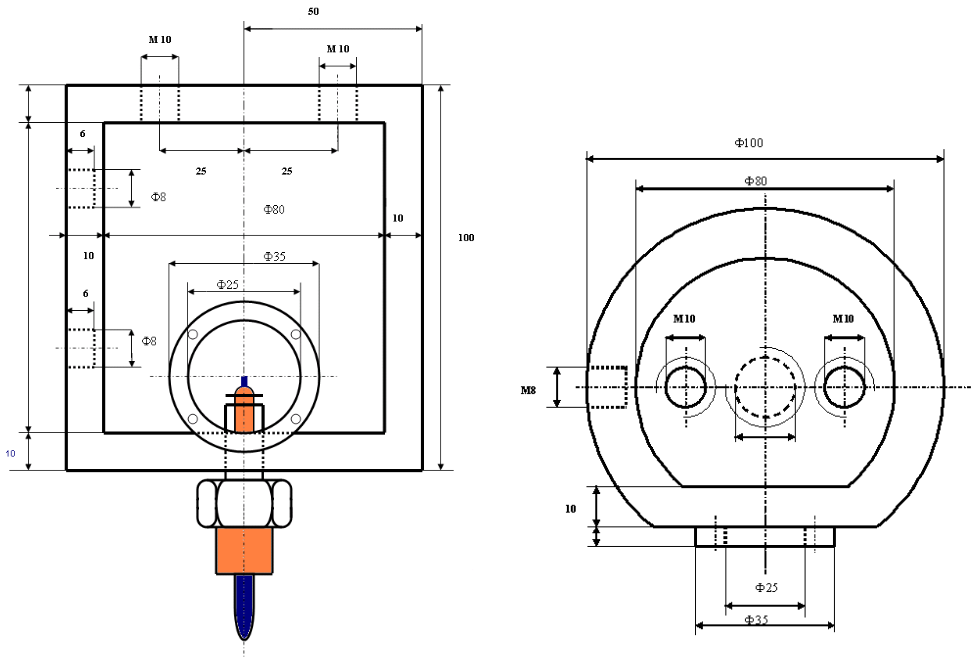


Figure 14 –The high pressure chamber

With the high pressure chamber a spectroscopic study of a combustion mixture and a chromatographic analyze of the exhausted gases is possible to be performed.

6. Conclusions

The novelty of the research project consists in the technical solution proposed, double-spark plug, and also the spectroscopic diagnostic along the spark length that was performed.

The experiments performed on the motor test stand have demonstrated the applicability in real condition of the double spark plug. This new type of spark plug provides a longer and a bigger volume of the plasma that assures a better combustion process.

The physical and chemical investigations that have to be done on the high pressure chamber by the partners involved in the project must confirm the quality of the combustion, main by chromatography analyze of the exhausted gases.

Up to now, the same fuel consumption and the same exhausted gases composition of a one cylinder motor for both classical and double-spark plugs have been demonstrated. Never the less, the spectroscopic analyze emphasized differences in the nature of the species formed in plasma (identification on the light length of the spectra) but also in their energy (by comparison of the amplitude of elements).

On the experimental results, after the data will be processed, two more paper will be published having the subject the plasma diagnosis. This diagnostic consists in the rotational and vibration temperature of the particles of the plasma and also their density. First will analyze the influence of the region where the signal is taken on the plasma characteristics and the second one will study the influence on the plasma of the waveform and the pulses duration.

The two partners involved in this project have establishd a schedule for the further activities, in which two French students will be involved. A Romanian graduate student (Technical University "Gh. Asachi" Iasi, Romania) already working on the project that will start a phd. thesis in cooperation with University of Orleans in 2011.

In January - February 2011 the project director will make a visit at University of Orleans (Bourges) as an invited professor where he will coordinate the experiments concerning the physical and chemical analyze of the combustion in the high pressure chamber, equipped with all the measurement systems. The future phd student will participate in February next year in the Laboratory GREMI - Site de Bourges under an ERASMUS fellowship. The results he will obtain in this research activity will be the basis of his dissertation thesis.

In the same time the PI of the two research teams will apply for a European Project FP7, in which 2 more partners will be involved, from Czech Republic and Poland. The discussion will be finalized up to the end of the year.

7. References

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