THE STUDY OF ELECTRICAL PARAMETERS AND THE EXHAUST GAS ANALYSIS FOR A DOUBLE SPARK PLUG

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Abstract – **The spark produced by a classical spark-plug does not always assure a fast and complete combustion of an air/fuel mixture into the combustion chamber of a thermal engine. This is the reason why we have done a long series of studies on this subject and a new type of spark plug with three electrodes has been proposed, using two different simultaneous electrical discharges generated by a high voltage power supply. The new type of spark plug should produce a larger and more homogeneous volume of plasma into the engine's combustion chamber that can assure a faster and complete combustion of the air/fuel mixture. To validate the functionality of the proposed ignition system physical, mechanical, electrical and chemical analysis have been done in order to reveal its benefits comparing with a classical ignition system.**

In this paper we present a comparison between the electrical parameters, respectively the exhaust gas parameters, when using in a single cylinder engine a classical spark plug and a double spark plug. The electrical parameters of the discharges have been measured in air, at atmospheric pressure and temperature and also when the spark plug was mounted into the cylinder heads. The exhaust gases were analyzed using a ROTRONICS CMR101 air/fuel acquisition system that allows the measurement of the oxygen ratio in the exhaust gas of the thermal engines.

Keywords: *spark plug, ignition, combustion engine*

1. INTRODUCTION

This paper aims to study and test the possibility of implementing the proposed double ignition system on a combustion engine, in order to increase the quality of combustion and, in consequence, to obtain a less pollutant and more economically engine.

Previous studies have demonstrated that to obtain a more ecological engine a combustion mixture with a lower concentration in hydrocarbons should be used [1], [2], but in the same time a higher energy should be injected into the ignition spark [3]. Using a poorest air/fuel mixture we can also obtain a more economically engine. Between the founded solutions we 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. The studies done by Nakamura [5], which involved the analysis of the influence of different ignition points on the combustion quality, using a cylinder equipped with several classical spark plugs have demonstrated that the combustion cycle evolves faster and a poorest air/fuel mixture can be used which leads to a reduction of the fuel consumption and also may decrease the concentration of some pollutants from the exhaust gases.

Considering the principles presented above, a new type of spark plug has been proposed (see Figure 1) [6], [7].

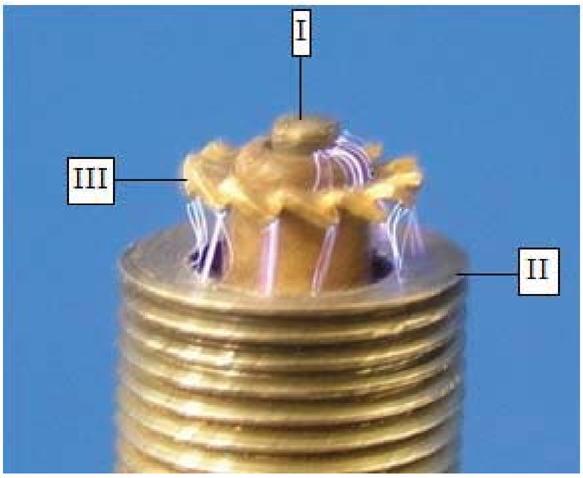

Figure 1: Photo of a double spark plug.

The new type of spark plug consists into a three electrodes ignition system: *I* – the central electrode, connected to a pulse high voltage source (usually a controlled ignition coil), *II* – the ground electrode and electrode *III* – free of potential. When the spark plug is supplied, two different, almost simultaneous, electrical discharges are produced: one between the central electrode *I* and the free potential electrode and the second one between the electrode *III* and the ground electrode *II*.

2. EXPERIMENTAL SET-UP

Both the double spark plug and the classical spark plug (Figure 2) have been tested on a multi-disciplinary teaching bench Deltalab EX1000 type [8] that allows complete studies of a single cylinder petrol engine with fuel injection and electronic ignition system.

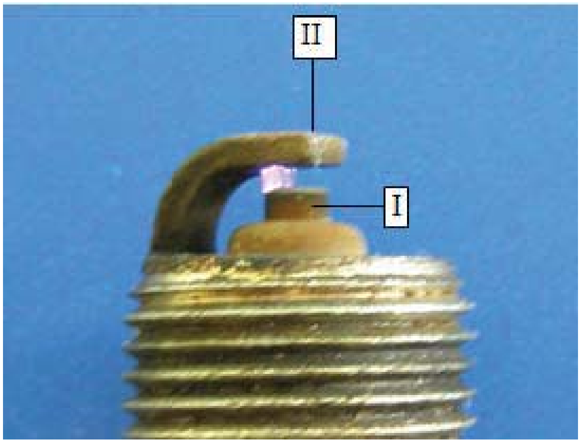

Figure 2: Photo of a classical spark plug.

The stand consists from: Honda petrol engine (31 cm^3 capacity, max power 1.5 hp, max speed 7000 rpm), microprocessor controlled fuel injection, DC electric motor, frequency generator, dynamic load adjustment (Figure 3). The engine is connected to a DC electric motor to provide starting, control and braking effort.

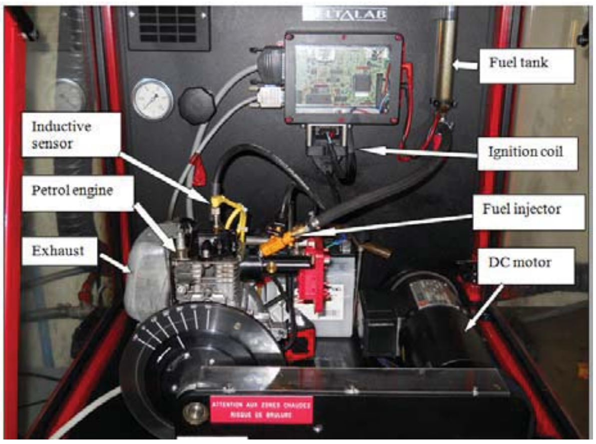

Figure 3: Deltalab EX1000 stand.

The stand performs under specialized software which permits the acquisition of different parameters related to its mechanical characteristics such: the fuel consumption, the engine speed, the temperature, the load or the position of the air regulator. Using the software we can also adjust the firing angle and also the injection timing and duration. The control settings for the injection and the ignition are transferred in real time from a computer connected to the apparatus using a user-friendly data interface. The engine operates on the basis of the ignition and fuel injection characteristics given by the user.

3. RESULTS. ELECTRICAL PARAMETERS

In order to determine the energy consumed by the discharges produced by the double spark plug and by a classical spark plug and also to identify the life-time of the sparks in both the cases, the current and the voltage of the discharge have been measured for two cases: when the sparks are produced in air, at atmospheric pressure and also when the sparks are produced inside the engine cylinder, at high pressure into a air/hydrocarbon mixture. To measure the current a LEM current transducer CT 0.1-P has been used. The transducer can measure a current up to 100 mA, and we can measure an output voltage proportional with the measured current. As an example, for a current of 50 mA, the transducer output voltage is 2.5 V considering an output resistance of 10 kΩ.
For voltage measuring a voltage divider with a rapport of transformation 1/2000 has been used.

3.1. Discharge produced in air

In the case of using a classical spark plug, in the first moment of the control pulse given by the ignition coil, just before the beginning of the discharge, the voltage is 16 kV and when the spark ignites, the voltage decreases to the value of 1 kV. This voltage represents the supplying values of the discharge.

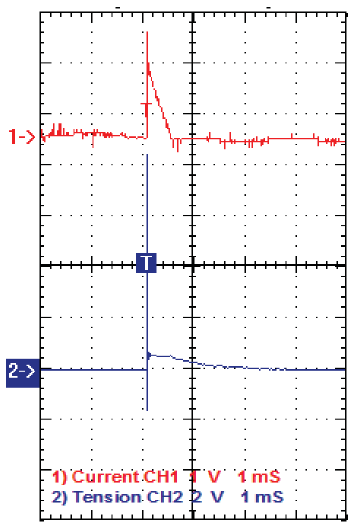

Figure 4: Classical spark plug electrical parameters – discharge produced in air.

The current has a maximum of 40 mA before the beginning of the spark and after that the amplitude of

the current is decreasing. The current pulse has a width of 0.45 msec. The spark life time is equal with the width of the current pulse. Both the voltage and the current waveforms of a discharge produced by a classical spark plug are presented in Figure 4. Using the values measured of the current and the voltage we can calculate an approximate value of the electric energy consumed to produce the spark. So, the energy consumed by a spark produced in air, at atmospheric pressure, using a classical spark plug is W≈ 7 mJ.
The double spark plug requires a higher voltage to produce the discharge because the distance between the electrodes is higher than the distance between the classical spark plug electrodes. The waveforms of the current and the voltage of the discharge in this case are presented in Figure 5.

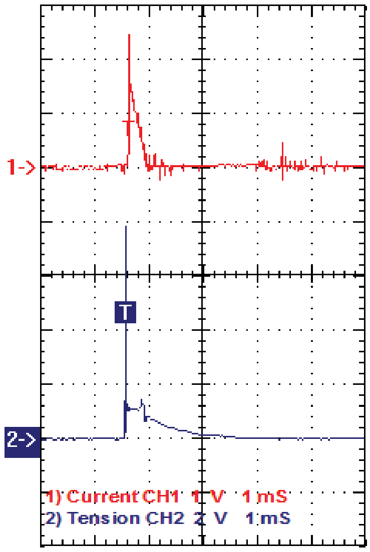

Figure 5: Double spark plug electrical parameters – discharge produced in air.

The values of the electrical parameters of the discharges produced in air using the two spark plugs are presented in Table 1.

Spark plug type	Classical	Double
Maximum current [mA]	40	50
Discharge lifetime [msec]	0.45	0.3
Maximum voltage [kV]	16	16
Discharge voltage [kV]	1	2.2
Energy consumed [mJ]	7	10

Table 1: The electrical parameters of the discharges produced in air.

In the case of using the double spark plug, the maximum voltage is 16 kV, the voltage of the discharge is 2.2 kV and the maximum current is 50 mA. The lifetime of the discharge produced in air using a double spark plug is almost 0.3 msec. Based on the recorded parameters the energy consumed by the discharge was determined: W≈ 10 mJ.

3.2. Discharge produced in engine cylinder

Because the pressure is much higher in the combustion chamber, the voltage required to ignite the discharge is higher than the voltage used in air. The difference between the two voltages is actually not very big as we can see by comparing the values obtained for the two mentioned cases (see Table 1 and Table 2).
In this case, for the classical spark plug, we have measure a maximum current of 50 mA and a discharge voltage of 1.2 kV (see Figure 6).

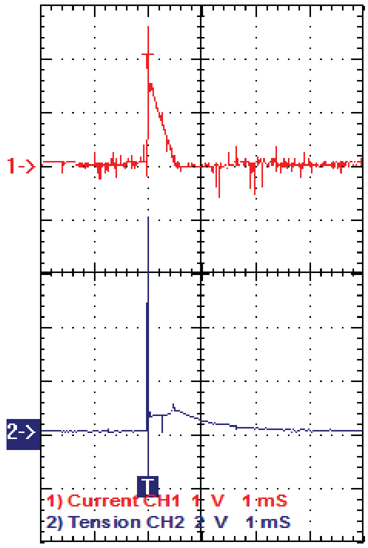

Figure 6: Classical spark plug electrical parameters – discharge produced in the combustion chamber.

The discharge lifetime is 0.5 msec and the value of energy consumed by the discharge is around 9 mJ.
The values of the electrical parameters of the discharges produced in engine combustion chamber using the two spark plugs are presented in Table 2.

Spark plug type	Classical	Double
Maximum current [mA]	50	55
Discharge lifetime [msec]	0.5	0.4
Maximum voltage [kV]	16	16
Discharge voltage [kV]	1.2	2.4
Energy consumed [mJ]	9	19

Table 2: The electrical parameters of the discharges produced in engine combustion chamber.

For the double spark plug, the maximum measured voltage is 16 kV, the maximum current is 55 mA and the discharge voltage is 2.4 kV (see Figure 7). The discharge lifetime is around 0.4 msec and the energy consumed by the discharge is 19 mJ.

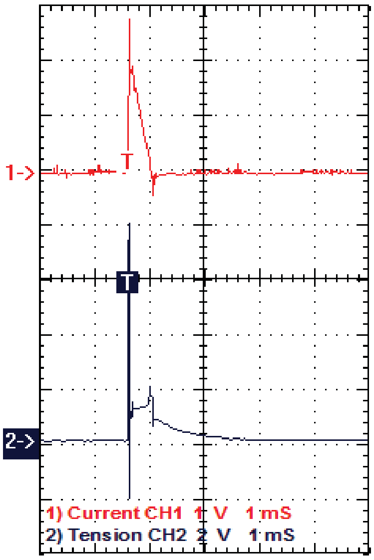

Figure 7: Double spark plug electrical parameters – discharge produced in combustion chamber.

The energy required to produce an electrical discharge (spark) using the double spark-plug is higher but also we should consider the distance between the electrodes. So, for the classical spark-plug, the distance between the electrodes is 0.7 mm and for the analyzed double spark-plug the sum of the distances between the electrodes is 2.3 mm.
If we consider that the discharge is in air, to produce a spark with a length of 0.7 mm using the classical spark-plug we use an electric energy of 7mJ. To produce 2 sparks having a total length of 2.3 mm using the double spark-plug we use 10 mJ. Apparently, the classical spark plug is more economical but actually it is not. If we compare the energy used to produce a discharge with a length of 1 mm (for example) we can see that using the double spark-plug we consume less energy.

4. RESULTS. THE EXHAUST GASES ANALYSIS

In order to compare the functioning of the double spark-plug and the classical one, the richness and the lambda parameters have been measured using an ROTRONICS CMR101 air/fuel acquisition system [9] that allows the measurement of the oxygen ratio in the thermal engines exhaust gases. The system consists in one unit CMR 101B that calculates the parameters based on the percentage of oxygen measured with one wide band lambda sensor (UEGO). From the oxygen rate, the system can calculate the following values: the richness, the lambda value, the air/fuel ratio according to the fuel used.

The mixture composition is not always the same, it depends of the engine's "size" and "needs" (the loading and the speed), but it begins from the ideal value, or stoichiometric value: 14.6 Kg of air for every liter of fuel consumed. This type of mixture (ideal), is clean, but not very often obtained. There are other proportions of air / fuel ratio required by the engine for different operating modes to obtain a complete combustion into the cylinders. Next to the ideal mixture (14.6:1 air : fuel by mass) we can find: *lean mixture* - 15.17 kg of air for every liter of fuel, *very lean mixture* - over 17 kg of air for every liter of fuel, *rich mixture* - less than 15, up to 12 kg of air for every liter of fuel and *very rich mixture* - less than 12 kg of air for every liter of fuel. For example, the starting regime requires a very rich mixture because a part of the fuel is being condensate and the vaporization of the fuel is more difficult because of the low engine temperature.
Using the mentioned air/fuel acquisition system both for the cases of the double and classical spark plugs the richness and the lambda parameters of the exhaust gases have been measured and using the Deltalab software. The engine speed and the cumulated fuel consumption have been measured for three distinct positions of the air regulator and for different loads of the engine. The air regulator is a valve which controls the volume of air entering into the engine, so the air – fuel mixture can be richer or poorer. The air regulator has nine positions, from 1 to 9. When the air regulator is in position number 1, the air access into the engine is blocked and when the air regulator is in position 9 the highest flux of air is allowed to enter into the combustion chamber. Also, the load of the engine can be set using an exterior potentiometer. To take the measurements we have considered three positions for the air regulator (4, 5 and 6) and for every of this position of the air regulator the engine was loaded with a load between 1 and 8.
The values of the parameters measured in the case of using the classical spark plug and for the air regulator positioned in 4th position are presented in Table 3.

Load	Richness	Lambda	Speed [rpm]	Fuel consumption [ml/min]
1	0.75	1.33	3060	0.8
2	0.8	1.28	3000	1
3	0.85	1.17	2880	1.2
4	0.9	1.12	2820	1.6
5	0.95	1.06	2760	1.8
6	1.01	0.98	2520	1.9
7	1.1	0.9	2460	2
8	1.19	0.86	2400	2.1

Table 3: Exhaust gas parameters for the 4th position of the air regulator when the classical spark plug is used.

As we can see in the table above, stoichiometric value is obtained when the engine is very loaded because the mixture used is a rich one. When the engine is not loaded (Load 1) the value of the lambda parameter is very big. This means that for burning all the quantity of fuel injected into the engine a much bigger volume of oxygen is required. In this case, a big quantity of unburned fuel (hydrocarbons particles) is evacuated in atmosphere.
The using of the double spark plug can offer a small improvement of the combustion as we can see comparing the values of the parameters measured for the case of using the classical spark plug and for the case of using the double spark plug (see Table 4).

Load	Richness	Lambda	Speed [rpm]	Fuel consumption [ml/min]
1	0.78	1.3	3060	0.8
2	0.81	1.27	3000	1.1
3	0.84	1.16	2880	1.2
4	0.9	1.12	2820	1.6
5	0.96	1.01	2760	1.7
6	1.02	0.96	2520	1.8
7	1.06	0.92	2460	1.9
8	1.18	0.86	2400	2

Table 3: Exhaust gas parameters for the 4th position of the air regulator when the double spark plug is used.

Apparently, there are no big differences between the parameters obtained for the two spark plugs studied. For a better comparison between the parameters, in the figures bellow the lambda and richness versus load characteristics are presented.

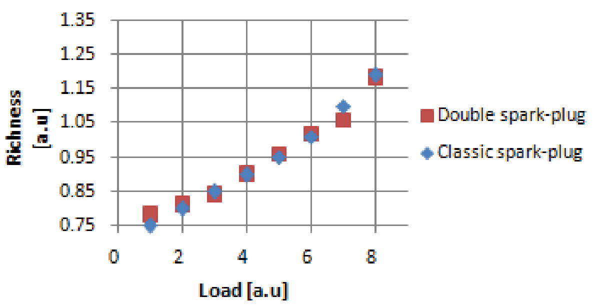

Figure 8: Richness characteristics depending on engine load.

As we can observe in Figure 8 there is a small difference between the values of richness parameter obtained for using the double and the classical spark plugs. The double spark plug offers a small improvement of the combustion, especially when the engine is not very loaded. The same aspect can be seen by comparing the lambda parameters obtained for the two ignition systems (Figure 9).

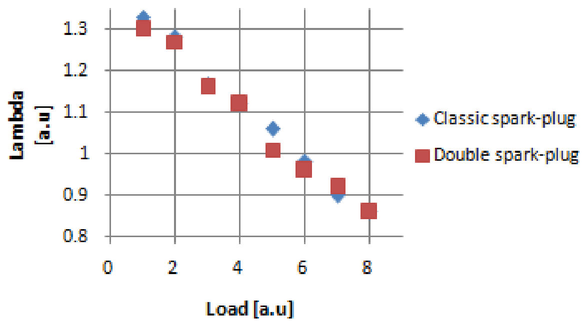

Figure 9: Lambda characteristics depending on engine load.

As can be observed comparing the tables 2 and 3, the engine speed is the same for both spark plugs, but there is a small difference for the fuel consumption. In Figure 10 the fuel consumption characteristics depending on engine speed are presented. The engine speed is decreasing with the load.

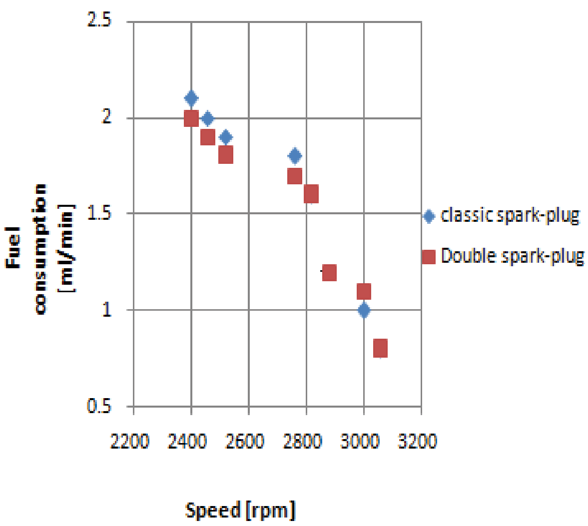

Figure 10: Fuel consumption characteristics depending on engine speed.

Similar values have been obtained also for the 5th and 6th positions of the air regulator.
Regarding the engine speed we can mention that the maximum engine speed is over 5200 rpm when the air regulator is in the position number 6 and only 3060 rpm when the air regulator is in position number 4. So, if we want to obtain high speed and the load of the engine is not very big we have to use lean fuel mixture. When the engine is very loaded a rich fuel mixture should be used.

5. CONCLUSIONS

The double spark plug needs a higher quantity of energy to produce the sparks but the length of the discharges is higher than the length of the discharge produced by the classical spark plug. Even if the energy consumed by a double spark plug is higher than the energy consumed by a classical spark plug, using the proposed ignition system we can assure a better combustion. This aspect has been demonstrated by the exhaust gas analysis.

The exhaust gases analysis has demonstrated also that using the double spark plug we can reduce the quantity of unburned hydrocarbons evacuated into the atmosphere.

Looking at the benefits of using the double spark plug we can also mention the reduction of the fuel consumption, given by the improved quality of the combustion.

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