DESING AND TESTS OF A TORCH IGNITION SYSTEM WITH HOMOGENEOUS CHARGE FOR OTTO CYCLE ENGINE

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Abstract. *This work aims at the development of a torch ignition system adapted for an Otto Cycle, with the objective of obtaining fuel economy. The use of torch ignition systems may reduce pollutants emission, and specific fuel consumption. The engine used is a commercial flexible, eight valves and four cylinders in-line. First of all, performance reference data were determined on the standard engine. In the next step it was obtained data about the modified engine, using the torch ignition system. In both cases the results collected will contains information about the performance on engine functioning, and both systems will be compared to each other, to quantify the differences. The torch ignition system presents a single fix geometry of torch cell in each cylinder, being fed with non stratified mixtures, through the engine's indirect fuel injection system, while spark advance and injection time being controlled by a re-programmable ECU. The results obtained indicates that the torch ignition system works and got a good potential to be developed, needing more testing in different running conditions. It is possible to foresee with these results that the torch ignition system can work with leaner mixtures and smaller spark ignition advance, as a result of the higher turbulence and faster burning speed inside the cylinder.*

Keywords: internal combustion engines, fuel consumption, pre-chamber, torch ignition, turbulence

1. INTRODUCTION

The prediction of a short availability of petrol in the world, and more restricted environment laws obligates engine manufacturers to develop cleaner engines. Based on this scenario, this work aims the development of an ignition system for Otto cycle engines, intended to reduce fuel consumption and also pollutant emissions. This new system works with leaner mixtures, reducing fuel consumption and carbon dioxide emission. The system developed in this work is a modification of the conventional ignition system to a pre-chamber torch ignition system, using non-stratified charges.

One of the torch ignition system's objectives is to generate turbulence inside the main chamber, trough a jet of flames projected from it. There are pre-chambers that work with and without auxiliary fuel injection. Figure 1 show a pre-chamber without auxiliary fuel injection, also known as turbulence cell, which is cavity located in the main combustion chamber.

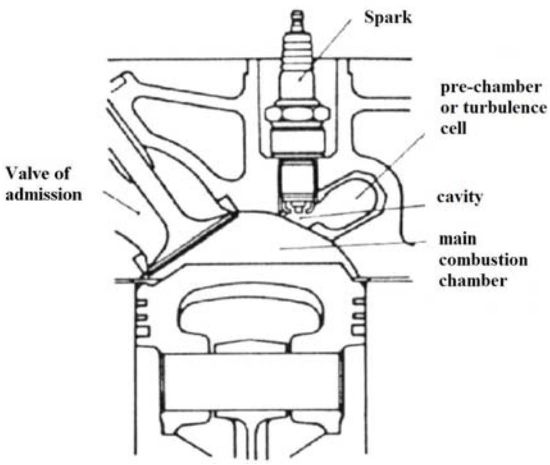

Figure 1. Turbulence Cell, HEYWOOD (1988)

During compression, the turbulence cell is filled up with mixture from the main chamber. Spark ignition, located in the entrance of the cell initiates the burning of the mixture, raising internal pressure and thus generating a located swirl which is expelled back to the main chamber, in the form of a flame thrower directed towards the remaining mixture, increasing turbulence inside the main chamber. The turbulence generation in the pre-chamber results in flame jets with high superficial areas, allowing the burning of leaner mixtures, without stratified charges. The function of this pre-chamber is only to generate a greater turbulence in the main chamber after the spark ignition.

2. OBJECTIVES AND RELEVANCE

This work aims for reducing fuel consumption on na Otto Cycle engine, not compromising the Mean Effective Pressure. For this it is proposed and tested, in a dynamometric bench, an torch ignition system adapted on a commercial Otto Cycle engine, evaluating the performance parameters and functioning of the engine. The torch ignition system associated with electronic fuel injection and electronic ignition represents an interesting research subject dealing with the search of more efficient engines, which lower pollutant emissions and low fuel consumption.

3. METODOLOGY

In the present work it has been used only a single pre-chamber geometry, with non-stratified charge, in the four cylinders of the engine. The pre-chamber is fixed into the original slot of the spark plug, to reduce the need of modifications in the original cylinder head.

3.1.Engine Selection

The engine selected allows easy acces to the cylinder head as well as the spark plugs, where the new components are implanted. It is Flexible, which allows the use of gasoline and ethanol, which avoids further modifications to use different fuels. It is a 1.8 dm³, 8 valves, 4 in-line engine. Table 1 shows the parameters of the selected engine.

Table 1. Engine's Parameters

Cycle/Strokes	Otto / 4 Strokes
Aspiration	Natural
Number of cilinders	4 in line
Bore (mm)	80,5
Stroke (mm)	88,2
Connecting Rod Lenght (mm)	130
Cylinder Volume Total/Single (cm³)	1796/449
Compression Ratio	10,5+/-0,3 :1
Power ABNT (cv/kW) (gasoline E22) Power ABNT (cv/kW) (ethanol E100)	112,0/82,4 a 5600 rpm 114,0/83,9 a 5600 rpm
Torque ABNT (kgm/Nm)	17,8/174,6 (gasoline E22) @ 2800 rpm 18,5/181,5 (ethanol E100) @ 2800 rpm
Combustion Chamber Volume (cm³) (cylinder head only)	33,3+/-0,5
Number of Valves per Cylinder	2

3.2. Main Parameters of the Combustion Pre-Chamber

3.2.1. Volume

Many researches correlated the volume of the pré-chamber with the main combustion chamber, mosto f them experimentally, DATE (1974). The best results were obtained by HONDA with the CVCC system, using a proportion of 7,3% of total volume. The test setup was chosen because of its proximity with the HONDA system. In the present work the pre-chamber volume is 3,816 cm³, representing 7,47% of the total volume. With this pre-chamber volume, the compression rate turns to 9,8:1, instead of the 10,5:1 of the original engine.

3.2.2. Geometry

The pré-chamber's shape was studied and the best results were obtained with cylindrical bodies, which tend to form homogenous mixtures in its interior, due to the high formation of vortexes in it.

3.2.3. Positioning

RYU (1987) studied the positioning of the pré-chamber related to the piston's face, and found that the vertical position (90º) resulted in the fastest burn of the mixture, due to the high turbulence formed, while in parallel positioning (180º) the vortexes generation inside the main chamber is reduced, creating little turbulence.

The pre-chamber substitutes the spark plug, with a 45,15º inclination toward the piston's face. N this configuration, the pressures within the system won't be as big as a perpendicular jet on the piston face.

3.2.4. Ducts and intercommunication orifices

The pre-chamber is physically separated from the main chamber by intercommunication orifices, which generates great turbulence when the burning mixture passes thru it, FAVRAT (2002). The orifice's diameter must allow the passage of the flame without making it fade. There is a critical value, which is the smallest diameter allowed, considering pressures and the air/fuel ratio. The developed nozzle, calculated with ADAMS (1978) methodology, is shown on Fig. 2. This nozzle have a 5 millimeters wide cylindrical duct, with conical shapes in both end, built to act as a small rocket engine, with an entry angle of 45º and an exit angle of 15º.

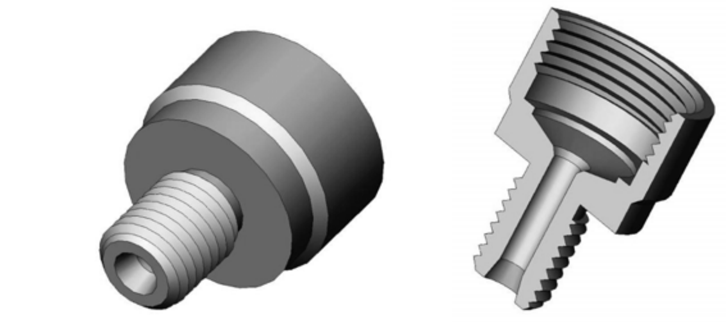

Figure 2. Pre-chamber geometry

3.2.5. Spark Plug Positioning

The spark plug position inside the pre-chamber was studied by MAVINAHALLY (1994). He concludes that the it can not be too far from the intercommunication orifices, for this tends to gather more remaining gases inside the pre-chamber's body, causing variations on engine cycles. In this work, the spark plug is located in the top of the pre-chamber, opposed to the intercommunication orifices, due to adaptation problems of the spark plug in a different position within the pre-chamber. High thermal spark plugs, colder ones, were needed. The chosen spark plugs were the NGK BR9ES, with a thermal degree of 9. This is a resistive spark plug, to avoid noise in the eletronics envolved. The pre-chamber body is inserted in the spark plug slot, located in the cylinder head, wich is an innovation of the proposed system.

3.2.6. Cooling System

The system's cooling is provided by the original water galleries built in the cylinder head, shown on Fig. 3, which stands close to the spark plug slot, on the original setup. The spark plug slot is enlarged to provide room for the pre-chambers and to reduce the distance between the water galleries and the pre-chambers bodies, thus cooling the system.

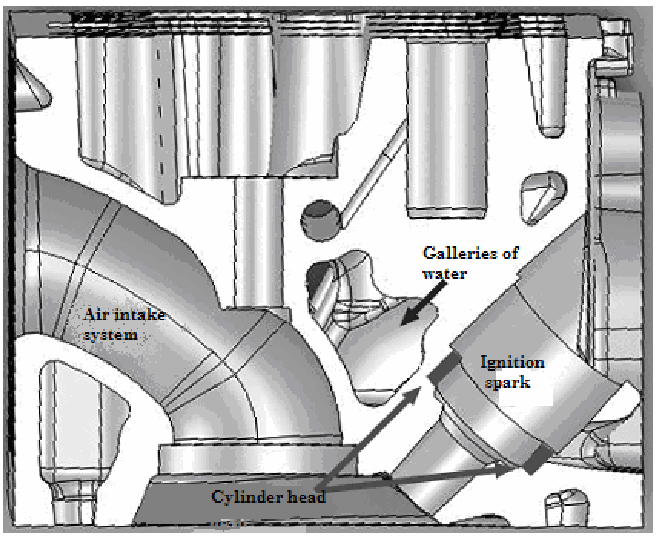

Figure 3. Cylinder head water galleries and spark plug slot

3.3. Electronic Fuel Injection System

The original engine's ECU is replaced by an experimental development ECU, designed at UFMG, which allows to program the engine main parameters, such as spark ignition timing, injection timing and others.

3.4. Pre-chambers Final Setup

Figure 4 shows the pre-chambers used on the engine. This geometry provides an easy access to the spark plugs and facilitates the installation of the pre-chambers bodies on the cylinder head with a torquimeter.

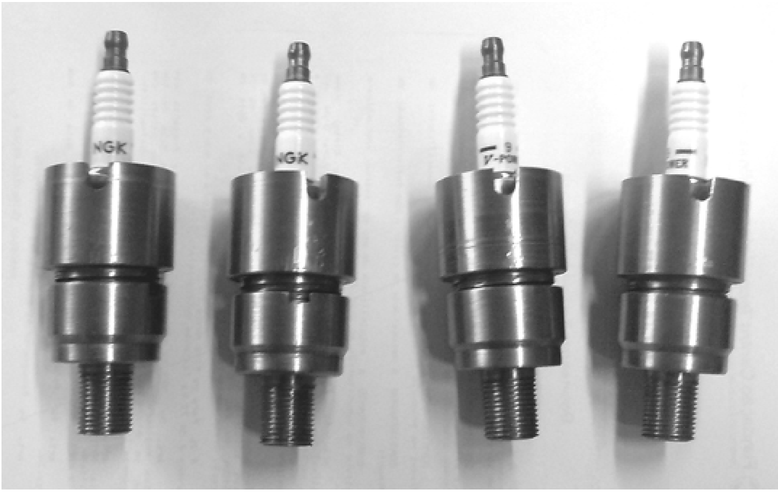

Figure 4. Pre-Chamber final setup

3.5. Engine testing using Torch Ignition System

Reference data of torque, power and fuel consumption were provided by testing the original setup of the engine, and then the results using the torch ignition system. All the dinamometric bench testing were executed following the NBR-ISO-1585 procedures.

The original engine's setup is used as reference data to map the system, from 0 to 100% of throttle, and engine's speeds from 1500 to 6250 rpm.

The calibration of the ECU, during the tests, is made for a non-stratified, homogenous mixture to obtain data about torque, power and fuel consumption relative to both configurations tested. With the torch ignition system, test were made with 10 and 20% of throttle, with engine speeds as specified before. Spar ignition timing is mapped bases on LDI (Knock Lower Limit). When knocking is detected during calibration, the spark advance is reduced in 1 degree. A second parameter is also used to map the system, wich is the MBT (Maximum Brake Torque). If found before the LDI, the current advance value is used in the spark timing map.

4. RESULTS AND DISCUSSION

Here are presented the results obtained from the preliminary test with the torch ignition system, in comparison to the original system. In both cases, results were obtained only to 10 and 20% of trhottle, to avoid overheating of the torch ignition system. All the test were executed using the experimental ECU. The results are presented on the following figures, from Fig. 6 to 11, referencing the results as follows in Fig. 5:

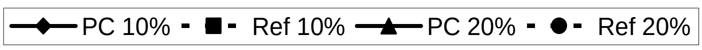

Figure 5 – Graphics legend

In order: Pre-chamber with 10% of trhottle, Reference data with 10% of trhottle, Pre-chamber with 20% of trhottle and Reference data with 20% of trhottle.

4.1. Torque

Figure 6 shows the results obtained with both 10 and 20% of trhottle, relative to torque. It is observed that, with the torch ignition system, the torque results are smaller compared to the original system. The lower results are due to the lower compression ratio resulted from the enlargement of volume of the combustion chamber, which turns from 10,5:1 to 9,8:1, and it is possible to happen due to the fact that the torch ignition works with lean mixtures. It is noticed that, for a higher throttle position, the torch ignition tends to get closer to the original system, increasing torque. This is a result of the higher and better turbulence inside the main chamber.

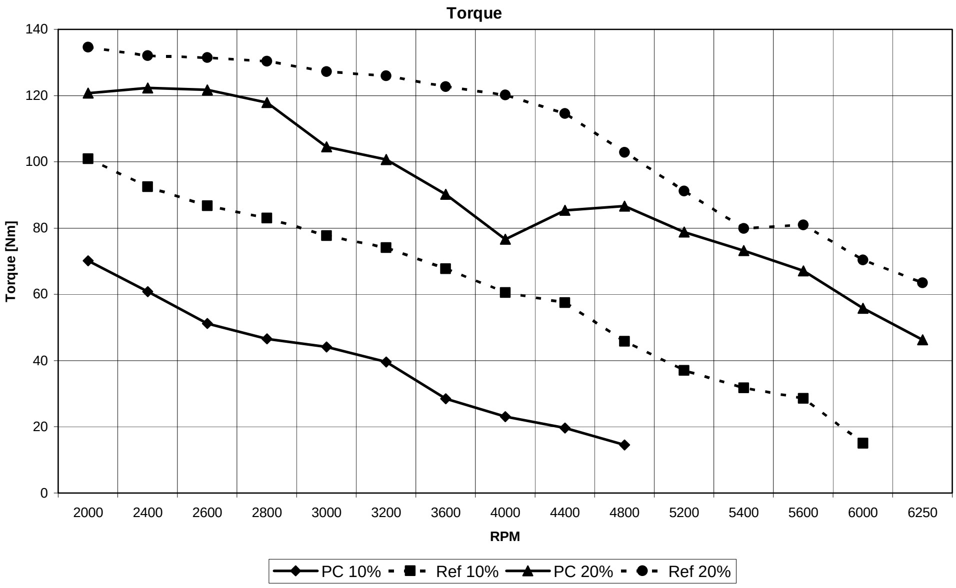

Figure 6. Torque

4.2. Specific Fuel Consumption

In figure 7, the results of the torch ignition system are higher specific fuel consumption, compared to the original. This occurs because of the smaller torque and power produced during the tests. As discussed in torque results, the higher specific fuel consumption is connected to the lower compression ratio and possibly to the use of leaner mixtures. Here it is observed better results with 20% of throttle.

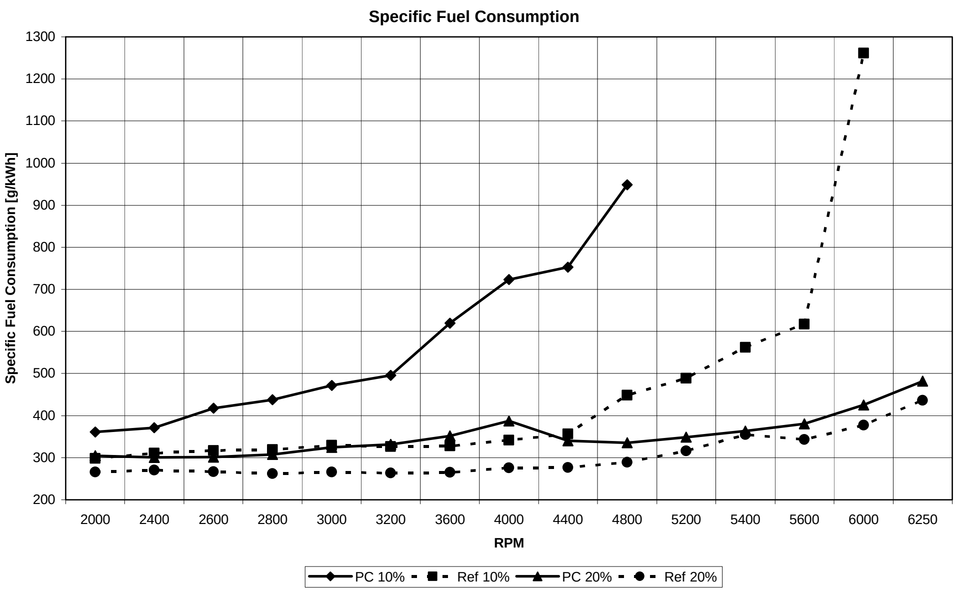

Figure 7. Specific Fuel Consumption

4.3. Effective Fuel Consumption

The effective fuel consumption, appart from the specific fuel consumption, presents better results for the torch ignition system. Working with leaner mixtures results in lower effective fuel consumption, and this is an advance compared to the original system.

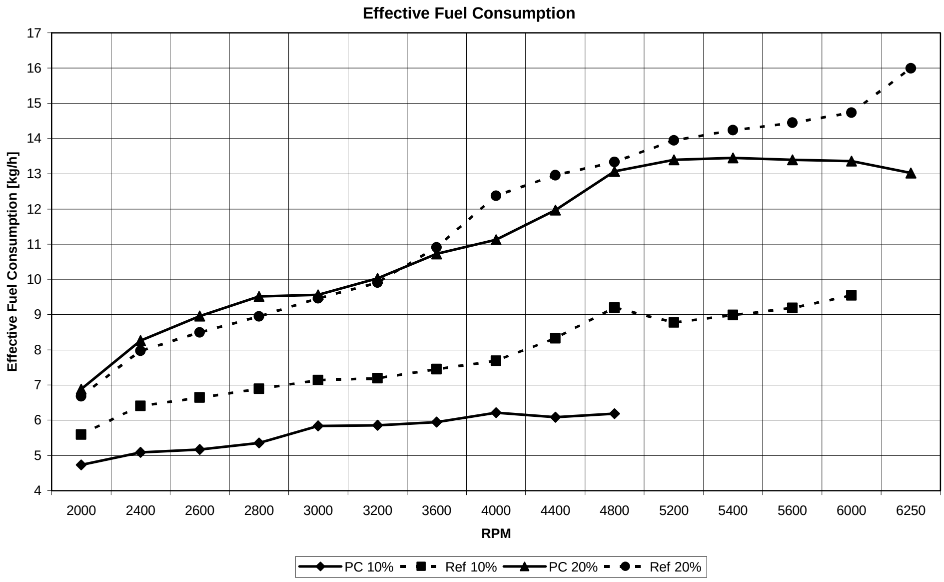

Figure 8. Effective Fuel Consumption

4.4. Control Parameters of the Engine

To better analyze the results of the dynamometric test it is necessary to analyze the control parameters of the engine obtained in the mapping, as spar ignition timing, injection timing and lambda values.

4.4.1. Spark Timing Ignition

Figure 9 shows the behavior of the original system using the experimental ECU. IN the torch ignition system, the burning speed is faster, due to the bigger turbulence inside the cylinder and because of the higher area of the flames during combustion, compared to the original system. This allows the use of smaller spark ignition advances, and it represents a benefict compared to the original system. Using smaller values, it is possible to raise the compression ratio of the engine, increasing torque and power.

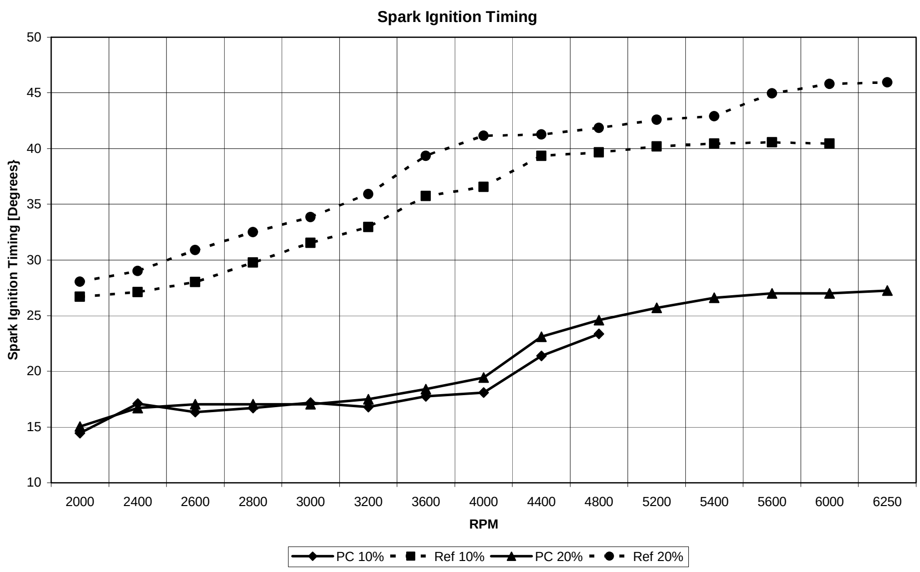

Figure 9. Spark Ignition Timming

4.4.2. Fuel Injection Timing

The fuel injection timing parameters are shown in Fig. 10. As in the spark timing, injection time tends to be smaller with the torch ignition system, once again tending to better results than the original system. The exception on this behavior occurs on the maximum torque, where the torch ignition works with stechiometric mixture and, since the volume of the combustion chamber is bigger than in the original system, more fuel is needed to fulfill it. The difference in the fuel injection timing is about 19% at 6250 rpm, while at 2000 rpm de difference is 6,3%.

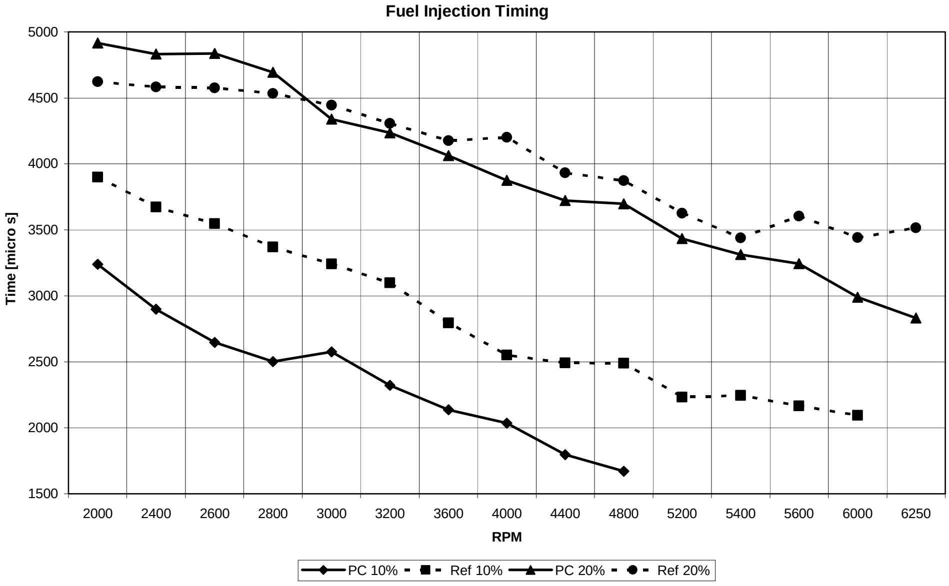

Figure 10. Fuel Injection Timing

4.4.3. Lambda

The lambda factor is shown only for the 20% of throttle, in Fig 11. The torch ignition system obtained a value of lambda of 1,17 at 4000 rpm, without misfiring. This system can work with even leaner mixtures, but there is a limitation which is the reducing of torque and, for even more leaner mixtures, the limitation is an elevation of the catalytic converter. Air/fuel ratios with the torch ignition system reached values over 15,0:1. The maximum difference between the systems is of 33% at 6250 rpm.

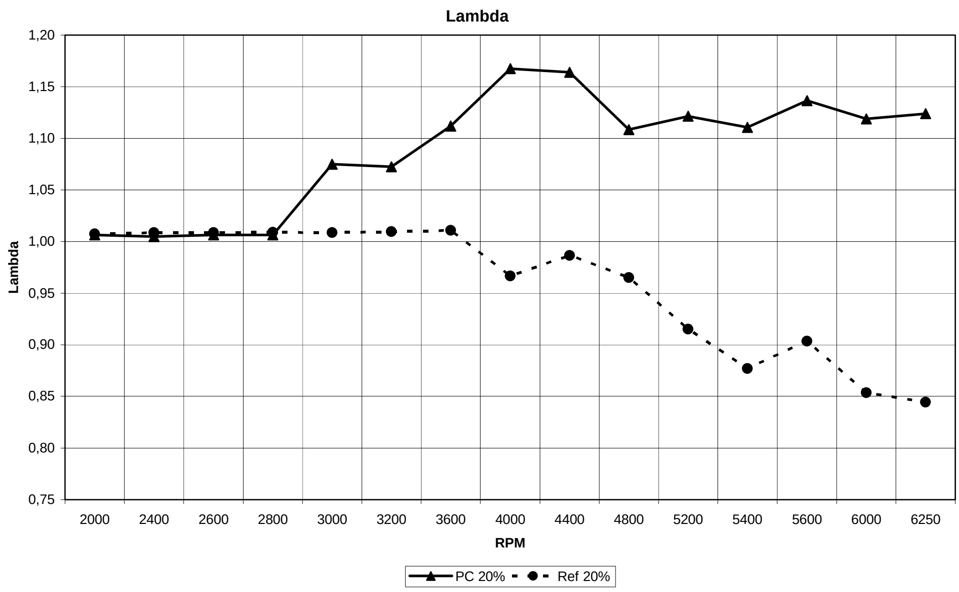

Figure 11. Lambda factor

5. CONCLUSION

The results obtained with the preliminary tests of the torch ignition system shows some of the tendencies expected, such as the leaner mixtures which leads to lower fuel consumption. To better analyze torque it is necessary to work with higher throttle positions, as it is possible to identify a raise in torque when throttle goes from 10% to 20%, with the torch ignition system.

The performance of the torch ignition system, with 20% of throttle is close to the original system, which is na expected result.

The loss of torque using torch ignition is linked to the lower compression ratio of the new engine's configuration, from 10,5:1 to 9,8:1, and higher lambda values, up to 1,17.

Two important caracterisitcs were noticed with the torch ignition system, proving that this is a promissor system to be developed, due to it's capacity to work with leaner mixtures and reduced spark ignition timing, both resulting from the higher turbulence inside the main combustion chamber and the faster burning speed of fuel. From these results, it concludes that the torch ignition system is viable and represents a great potential to future developments, and, for this, it is necessary more test using all the range of throttle and engine speeds.

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