Implementation and tests of a variable control system of spark time ignition and injection time, using Digital Signal Processor – DSP.

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Abstract. *Electronic management system applied to Automotive Engineering is able to optimize the operation parameters for an Internal Combustion Engine (ICE) increasing their efficiency. The development of those systems is a multidisciplinary task that involves specialists from different areas that use, among other resources, high performance digital computers. The objective of this work is to present the implementation of a new electronic engine control unit, controlled by computer, using a Digital Signal Processor (DSP) to optimize the spark advance, the dwell and injection time curves of ICE's during the development in engine test beds. This work presents the implementation of the variable spark time ignition system and the comparative results, obtained during the development tests in dynamometer, between the implemented system and the original engine management used in the tests.*

1. Introduction

Electronic management system applied at Automotive Engineering is able to optimize the operation parameters for an Internal Combustion Engine (ICE) increasing their efficient and reducing the environment impact. The development of those systems is a multidisciplinary task that involves specialists of different areas that use, among other resources, high performance digital computers.

Those tools are largely used to allow the optimization due the high speed processing information and the great flexibility of system controller implementation. The use of Digital Microprocessor Signal (DSP) allows the system to control the spark time ignition, the dwell time and the injection time to be executed through the pulse wide modulation (PWM) from the DSP outputs.

This work present the implementation of those system and the comparative results, obtained during the development tests in engine test beds, between the implemented system and the original engine management unit. During the comparative tests, a commercial 4 in line cylinders small block engine (994 cm^3), 4 strokes, 8 valves and fueled with gasoline (E25) was used.

2. Objective

The objective of this work is to present the implementation of a new electronic engine control unit, controlled by computer, using a Digital Signal Processor (DSP) to optimize the spark advance, the dwell and injection time curves of ICE's during the development in engine test beds. This new system is being developed in partnership with members (from different institutions) involved with this paper to create a new tools applied to internal combustion engines research.

3. Methodology

The system is composed by a micro-controller (DSP) that receives a signal speed and position from crankshaft through the inductive sensor (1) and a sensed steel disc (2), as show on Figure 01.

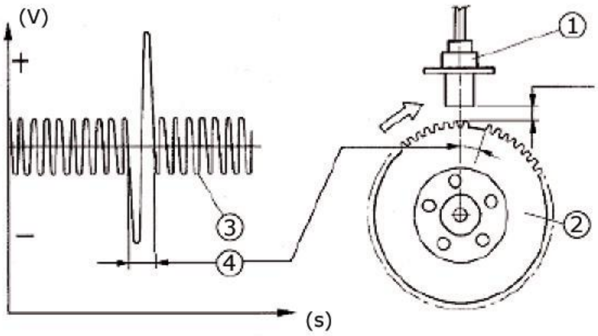

Figure 01: Speed and position crankshaft measurement [4].

Two power switch drivers was assembly to allow the 2 ignition coils and four injection fuel valves are actionated by the output PWM signal from DSP, as shown in Figure 02.

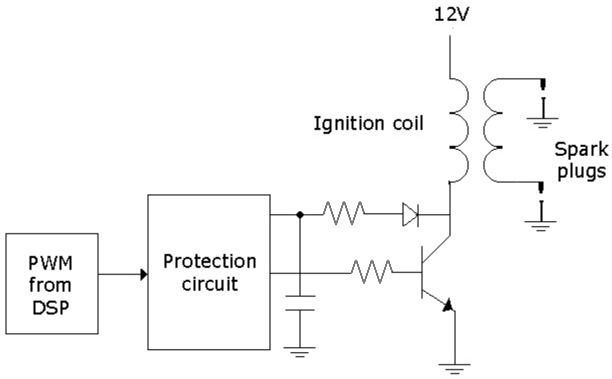

Figure 02: Power switch driver for ignition coil.

The micro-controller chosen is manufactured by Texas Instruments Inc. 2407A family. The 240xA devices offer the enhanced TMS320DSP architectural design of the C2xx core CPU for low-cost, low-power, and high-performance processing capabilities. Several advanced peripherals, optimized for digital motor and motion control applications, have been integrated to provide a true single-chip DSP controller [1].

They offer an array of memory sizes and different peripherals tailored to meet the specific price/performance points required by various applications. Flash devices of up to 32K words offer a cost-effective reprogrammable solution for volume production. All 240xA devices offer at least one event manager module, which has been optimized for digital motor control and power conversion applications. Capabilities of this module include center- and/or edge-aligned PWM generation, programmable dead band to prevent shoot-through faults, and synchronized analog-to-digital conversion [1].

The high-performance, 10-bit analog-to-digital converter (ADC) has a minimum conversion time of 375 *ns* and offers up to 16 channels of analog input. The auto sequencing capability of the ADC allows a maximum of 16 conversions to take place in a single conversion session without any CPU overhead. A serial communications interface (SCI) is integrated on all devices to provide asynchronous communication to other devices in the system [1].

Trying to facilitate the use of the implemented system, the same sensors and actuators present in the original electronic management system had chosen. The Figure 03 shown the real prototype assembly used during the tests.

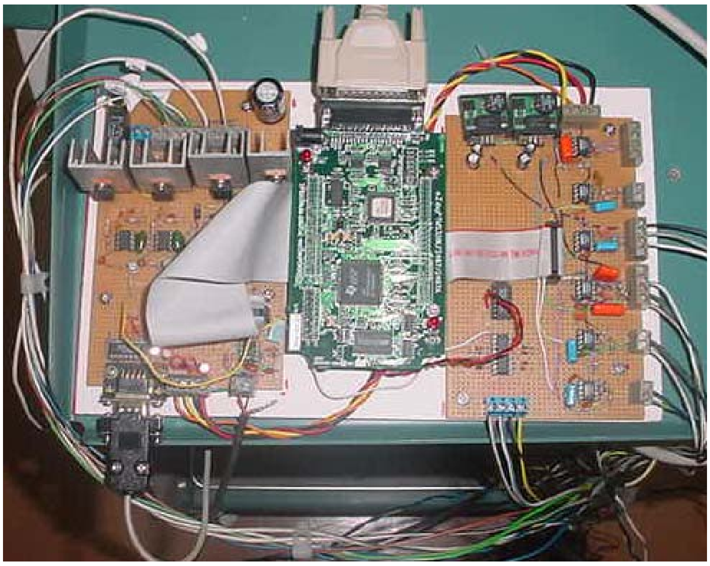

Figure 03: Electronic Control Unit.

The measurement of the engine speed is possible through an inductive sensor composed by a magnet and an inductor (coil) incorporated. This sensor supplies an alternate voltage with frequency and magnitude proportional to the engine speed (Figure 01).

Through this signal it is possible to synchronize the ignition pulses with the alternative movement of the pistons engine due to the presence of an equivalent fail up to 2 teeth at the sensed steel disc. That fails is positioned at the 20 teeth before the Top Dead Center (TDC) of cylinders 1 and 4 [2]. This signal is sent to a conditioning circuit that uses a voltage comparator to transform the speed sensor signal in a square wave, as shown in the Figure 04.

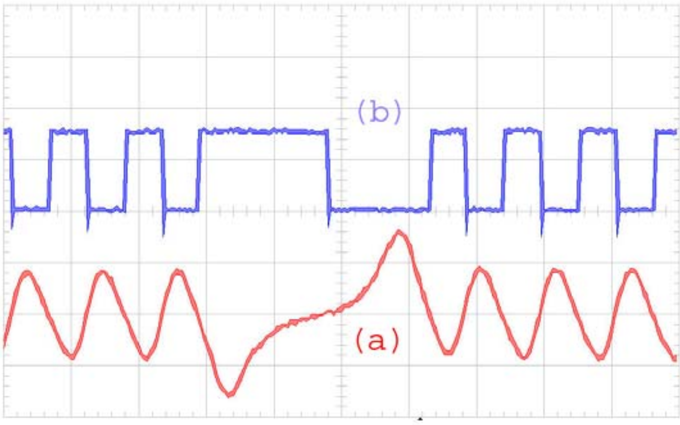

Figure 04: (a) Speed sensor signal (b) Output square wave.

The output signal from voltage comparator had 58 pulses with the same period and a pulse with a larger period (Figure 01). That variation in the period represents the fail equivalent to 2 teeth in sensed steel disc. This signal, conditioned with maximum width of 3,3 V, is sent to DSP.

Each teeth of the sensed steel disc identified for DSP generates an interruption to enable an internal counter (COUNT 2). This counter determine the time between two consecutive interruptions and it determines the time spend for each tooth to pass in front of sensor. The Figure 05 presents a flowchart of software implemented.

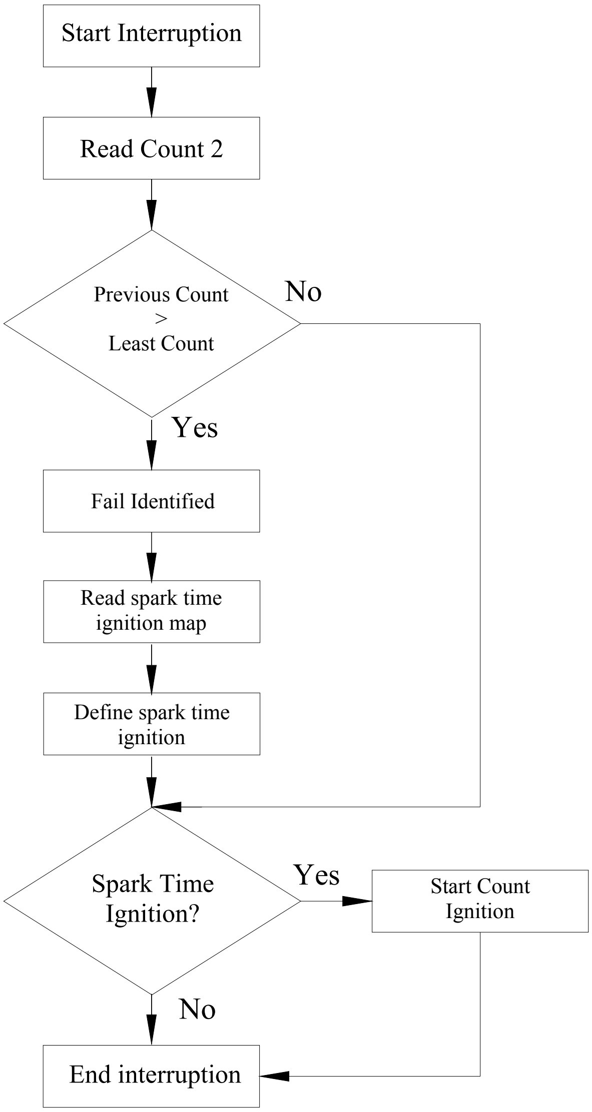

Figure 05: Software flowchart implementation.

The software implemented compares the period of each teeth and identifies the fail when the period measured was larger then before. DSP uses the period of the square wave generated to measure the speed engine and use this parameter to define a spark time ignition.

Determined the period of the square wave, DSP makes calculations, in *ms*, the instant of piston 1-4 will be in TDC, synchronizing the pulse of time ignition. The Figure 06 presents the output signal from PWM of DSP sent to coil switch driver of primary 1 and 4 cylinders coil, with 36º before the Top Dead Center (BTDC), at 2000 RPM.

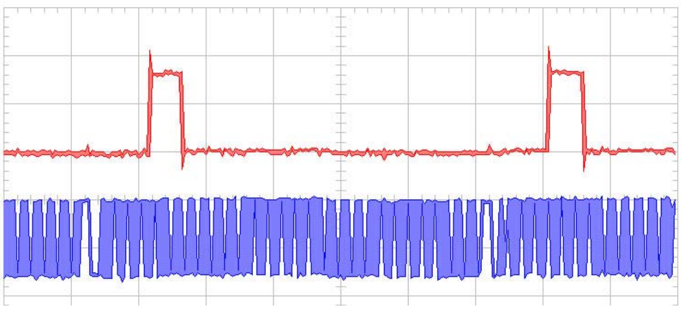

Figure 06: PWM signal output to coil switch driver (ignition coil 1–4 / 36º BTDC / 2000 RPM).

The spark time ignition maps were implemented with the initial values in function of the speed and of the load (throttle position) of the engine. Those maps establish the advance angle in agreement with the strategy of ignition system. This map was determinate at all nominal engine speed range, from idle up to 6500 RPM, with a step of 250 RPM. Intermediary speed values are obtained through interpolation of those maps [3].

The computer is used in the system as the interface of process, through implemented communication software, in Delphi platform, who communicate with DSP by serial communication port (RS 232 – COM1). Through this protocol it is established a serial communication is receive from DSP the system parameters, as engine speed, water temperature, air temperature, intake manifold pressure, battery voltage and throttle position. Simultaneously, the serial protocol is able to send to the DSP commands to increase or decrease the spark time ignition, the dwell and the injection time. The Figure 07 shown the interface of calibration tool (IHM), implemented using Delphi 5.0.

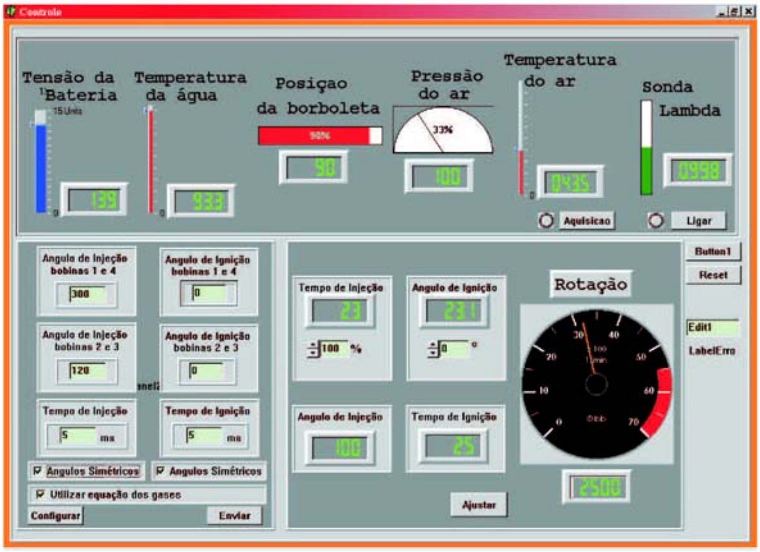

Figure 07: Interface of Calibration Tool (IHM).

Through the adjustment of the spark time ignition and the injection time is possible to optimize the time ignition and the injection time maps used by DSP to obtain a better engine efficiency in all of engine speed range. The map is optimized in agreement with the strategy adopted by the operator that, usually, increase the spark time ignition until obtaining of the Maximum Brake Torque (MBT) or in the value where the self-ignition phenomenon (Lower Detonation Limit) and knock (pinking) happens [9].

With the parameters and defined strategies for the operator, DSP generates a command signal for ignition coil (1-4 and 2-3) and to fuel injection valves synchronized with the alternative engine pistons movement. The output signal from DSP is sent for the ignition coil and to fuel injection drivers whose purpose is to supply current for the coil ignition so that enough potency is supplied for the correct spark ignition and the necessary fuel mass. The Figure 08 shown the Block Diagram from the software implemented.

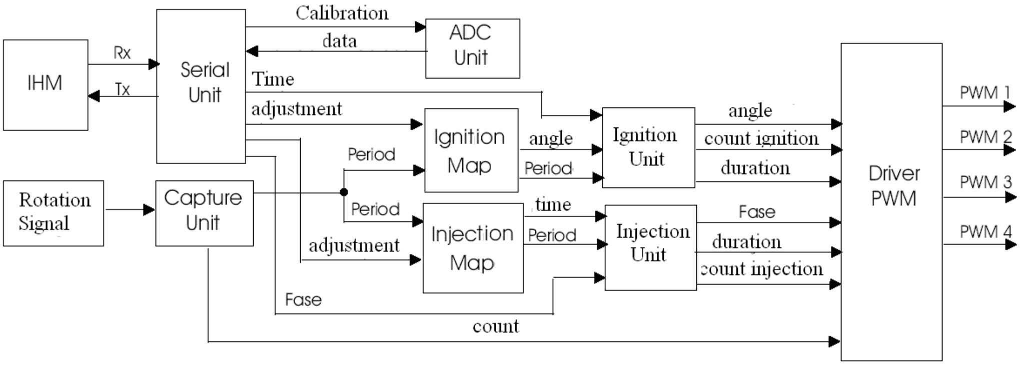

Figure 08: Block Diagram.

The module Capture Unit (Figure 08) calculates the engine frequency and identifies the crankshaft position from the signal that is provided by the speed sensor. This block sends the calculated period to the ignition and injection time maps, tables that provide the ignition and the injection time depending of the speed and throttle position engine. These parameters can be set and adjusted through the calibration tool that allows the user, as the dwell time, the injection phase, for example.

The ignition unit block receives the spark time ignition from the map and the dwell time through the calibration tool and the period from the capture unit. Simultaneously the fuel injection block receives injection phase signal from the serial unit, the injection time from the map and period from the capture unit.

These two blocks defines the engine work parameters and the PWM output driver provides the command signal to the injection and ignition engine actuators.

In order to compare the new electronic engine control unit, a commercial system, manufactured by Magneti Marelli, model IAW 1G7, applied the engines FIASA 1.0 m.p.i manufactured by FIAT Automóveis S/A was used.

4. Results

For the accomplishment of comparative tests with the proposed system, was make engine test beds in according to Brazilian Norm NBR ISO 1585, that specific to the conditions of engine test bed for a engines applied in road vehicles, the corrections factor in the measures and the forms of presentation of the Power, Torque and specific fuel consumption at Wide Open Throttle (WOT) in function of engine speed [5].

The corrections factor was applied to all the Torque and Brake Power data obtained, like specific in NBR ISO 1585 [1]. The correction factors were calculated in the conditions environmental measures during each test. The dry pressure was calculated according to expression of NBR 5484, using the temperatures of humid and dry bulbs measures [6].

During those tests, the same engine was stabilized in WOT condition at the engine test bed and measured the Torque observed value in all point of speed range from 1500 to 6500 RPM, with an increment of 250 RPM.

The hydraulic dynamometer used is the D210-1e model, manufactured by SCHENCK S/A. The data were acquired through the data acquisition board (DAQ) with a 16 bits ADC installed in an IBM-PC Pentium III. The acquisition program was developed in PC-Assembler and Delphi 5.0. The data acquisition frequency used was 2.5 Hz [7].

The first tests were realized with IAW 1G7 engine management system, manufactured by Magneti Marelli. All the sensor and actuators, beside the original spark time ignition and injection time maps were maintained.

Finished the tests with the IAW 1G7 system, all of the sensors and actuators were disconnected from the original system and reconnected into the new electronic engine control unit controlled by DSP.

Done the modifications, a new dynamometric tests at WOT was realized, using the spark time ignition system being varied (increasing and decreasing) the spark time ignition in each point of engine operation. The injection time was changed to maintain the Air/Fuel ratio as the same as the IAW 1G7 system. The criteria used for the optimization of the engine are the Maximum Brake Torque (MBT) without the self-ignition of air/fuel mixture appeared and, consequently the knock (pinking). The Air/Fuel Ratio and the Lambda (λ) factor were measured by the HORIBA A/F Analyzer, model MEXA 110H.

The detection of the knock was accomplished through the additive method, being used a piezoelectric accelerometer fixed at the engine block. The criteria used were reaching the maximum spark time ignition before the knock occurrence (LDI). The fact of the spark time ignition influence directly on the catalytic temperature, at each speed it was observed, always respecting the maximum value of 750 ºC, recommended by the engine manufacturer.

The Figure 09 presents a comparative Torque curves, according to NBR ISO 1585, obtained at WOT with the original ignition (Default) and with the system in development using a micro-controller DSP (Optimized).

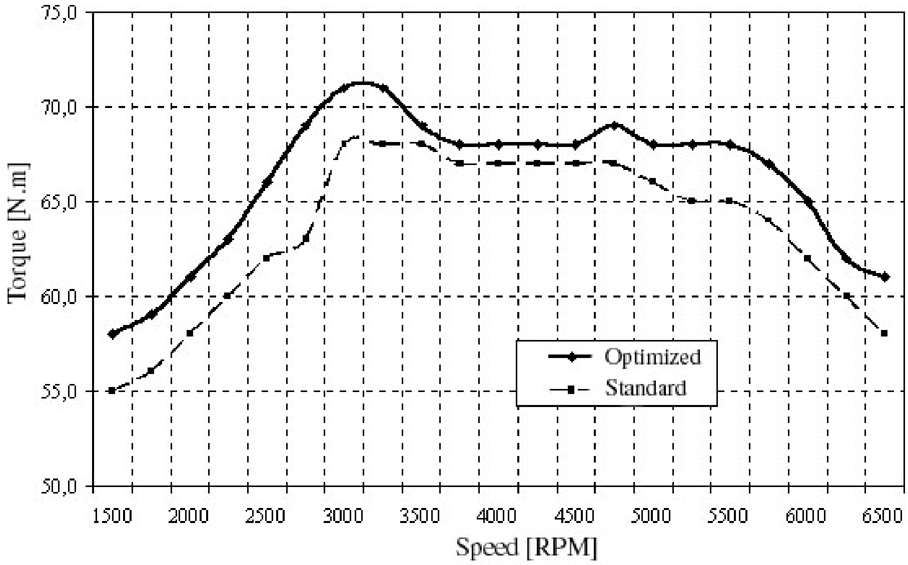

Figure 09: Torque results at WOT for Default system (IAW 1G7) and Optimized system (DSP).

According to the Figure 09, one tendency of Torque increase can be observed in the Optimized curve in comparison with Default. The most expressive values were obtained in the range from 1500 to 3500 RPM (increase about 12%) and from 5000 to 6500 RPM (increase about 10%).

The Torque increase in both speed ranges can be due to the increase of spark time ignition until de occurrence of the knock.

Like happened with the Torque, the Figure 10 shows a comparative test results with the Power, corrected according to NBR ISO 1585, obtained at WOT with the original ignition (Default) and with the system in development using a micro-controller DSP (Optimized).

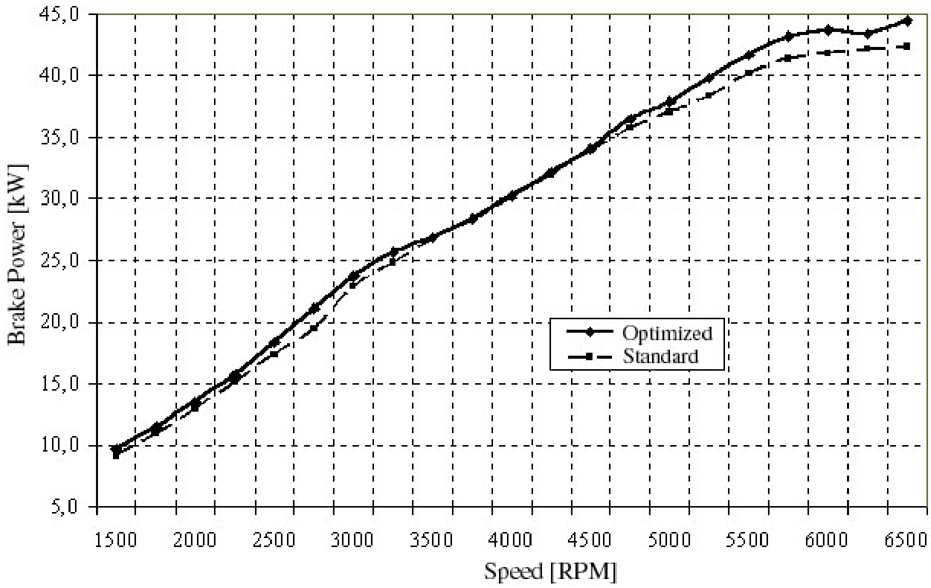

Figure 10: Brake Power results at WOT for Default system (IAW 1G7) and Optimized system (DSP).

The increase of the Torque measured during the engine tests contemplates directly with the Power increase, shown in the Figure 10. The increase tendency is observed in the Brake Power developed by engine in test, where the most expressive values were also obtained from 1500 to 3500 RPM (about 8% of increase) and from 5000 to 6500 RPM (about 4% of increase).

5. Conclusions

The dynamometer tests allow us to conclude that the variable spark time ignition system implemented makes possible that engine in development be optimized in way to find the ideal operation parameters in each speed and load.

The maps obtained can be applied in a specific memory address and the system it can adoptive the new obtained calibration and start to control the engine between the established points.

The whole engine speed range mentioned in this work was optimized. There was, however, only effective influence in the Torque and Power curves in two specific speed range (from 1500 to 3500 RPM and from 5000 to 6500 RPM).

During the dynamometric tests it can be noticed that the range from 3500 to 4500 RPM the increase of the spark time ignition didn't cause considerable Torque and Brake Power modifications (increase or decrease), being then maintained the largest obtained value, before the LDI condition be reached. That fact can be associated to the physical engine characteristics, where, in spite of the excessive spark time ignition increase, the self-ignition and the knock phenomenon don't happen.

About the operative conditions of the system developed, it can be concluded that the initials tests shows satisfactory results, motivating the continuity of studies and the development of electronic management system to control the air/fuel ratio in closed loop incorporate to system implemented.

In a next stage, the emission tests at dynamometer will be accomplished to verify the system performance, according to the Automotive Exhaust Limits described on the current legislations.

6. References

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