Electronic Control of a Four Stroke Internal Combustion Engine

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Abstract: - This paper describes the development of the control system for the electronic ignition and injection of a 4-stroke mono-cylinder internal combustion engine. It is pretended to control the ignition advance and the injection time and period. The fuel mass flow rate is controlled using the air mass flow rate into the cylinder.

Key-Words: - Engine Control, Power Electronics, Electronic injection and ignition, Pollutants reduction, Experimental Characteristics.

1 Introduction

The traditional carburetor has difficulties to obey the new pollutants emission directives. With the new electronic injection and ignition systems it is possible to reduce the pollutants emission and the fuel consumption [1].

In the present work it is intended to develop a control system for the ignition and the injection and to apply them to a four-stroke mono-cylinder internal combustion engine.

2 Proposes solutions for the ignition and injection

In the nowadays cars is used high voltage systems for the ignition. For the here under study and control engine (Honda GX22) the ignition is made using a magnet. For that the construction is very simple and inexpensive. The ignition circuit is composed by a primary low voltage circuit and a secondary high voltage circuit.

Proposed solution for the ignition system

The proposed ignition system is divided into two blocks: the control block and the power block. The control block is separated of the power block by an photocoupler, in order to isolate that two blocks.

A structure was built, to allow the synchronisation of a Hall sensor signal with the crankshaft movement and also to manually adjust the injection and ignition times.

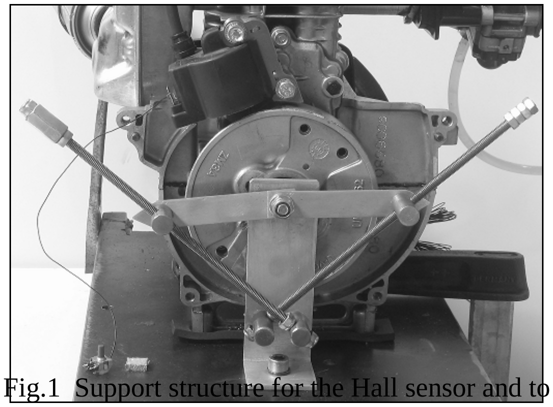


Fig.1 Support structure for the Hall sensor and to adjust of the ignition and injection times

The fuel burning time is not instantaneous, but progressive. Accordingly, there is need of an ignition advance in order to obtain the maximum cylinder pressure when the cylinder arrives to the TDC (Top Dead Center). That way, the maximum work is obtained from the fuel injected into the cylinder. For an optimum set-point, the ignition advance should not be constant, but a function of the crankshaft rotation. The structure presented in Fig. 1 allows adjusting the ignition advance, permitting to discover the optimum set-point for all the circumstances. The Hall sensor provides negative voltage pulses, which are translated into a square wave of 5V amplitude. The signal is then inverted to easier electronic manipulation.

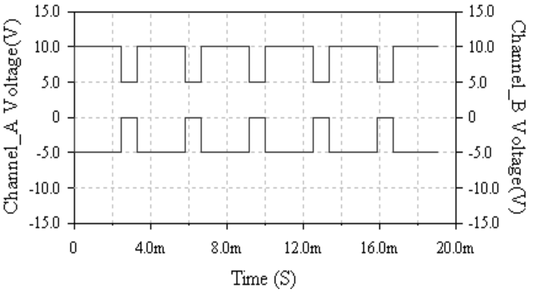


Fig.2 Original Hall sensor signal and inverted one

Four a four-stroke engine, the crankshaft rotates twice per cycle and the sensor signal has to be divided by two, being here adopted for that purpose a JK Flip-Flop (Fig. 3).

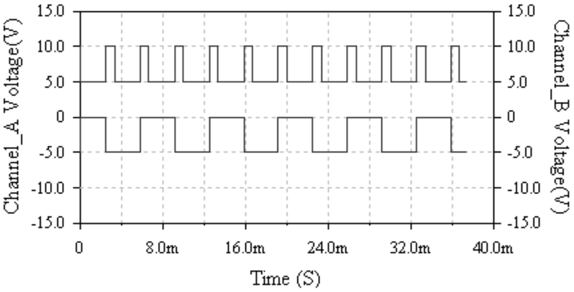


Fig.3 Hall sensor signal inverted and divided by two

For the control of the ignition advance the signal obtained from the frequency divider has also to be treated. For that, a 555 timer in the mono-stable mode [5,6] was used and the pulse width was then controlled. The obtained signal has, this way, a pulse width dependant of the crankshaft angular speed.

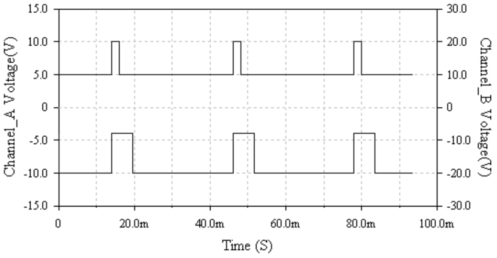


Fig.4 Timer 555 input and output signals

The key member of the control block is a MOSFET, since it allows a fast commutation [2,3]. Any time the signal level coming from the timer changes, the MOSFET starts conducting.

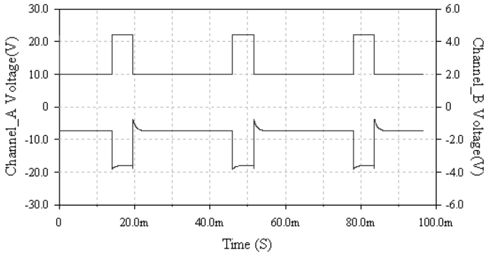


Fig.5 Output signals from Timer 555 and MOSFET

When the gate receives the commutation order, the MOSFET stops conducting, stopping the current in the primary and consequently the secondary flux tends to zero. The high voltage inducted in the secondary is responsible by the spark production.

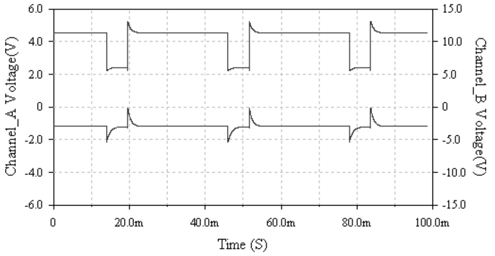


Fig.6 MOSFET signals in the turn off commutation and coil induced voltage

One important factor in all system is the coil energizing time. The timer pulse width must be adjusted to the current needed by the coil, which has an internal resistance and can be treated as a RL circuit. When MOSFET commutation occurs, the current in the circuit is given by (1):

$$i(t)=\frac{V}{R}\times\left(1-e^{-\frac{R}{L}t}\right) \tag{1}$$

The coil reacts producing a voltage given by (2),

$$V_L = Ri + L\frac{di}{dt} \tag{2}$$

Using equation (2), the minimum time needed to obtain the needed value of current for proper coil behaviour can be calculated. An excessive time can damage the power circuit. Knowing the needed time, the timer output signal can be changed accordingly, changing the timer capacitor and resistance [5,6].

B. Proposed solution for the injection system

The proposed solution described for the injection control is similar to the previous one. This likeness allows the use of a single circuit for both control systems. Nevertheless, due to the system development causes, two separated circuits were built. The injection control circuit can also be divided in two blocks: the control block and the power block.

As in the ignition control the first signal acquired is the Hall sensor signal. The inverted signal frequency has also to be divided by two, being this way used the gate $\overline{Q}$ of the JK Flip-Flop. Note that this signal is the same as the one used in the ignition control circuit, except being inverted.

For a four stroke engine, the ignition time (during compression stroke) is separated from the injection time (during admission stroke) around 180°. The signal modulation is analogous to the one described for the ignition system. The power block has a transistor, since the injection circuit currents are small. Nevertheless, the commutations time is also high. The transistor controls the injection time and period, starting conducting in the output signal positive ramp and ending in the negative ramp. The pulse width is very important, since it corresponds to the fuel injection time.

For the mono-stable timer, the pulse width can be controlled by an external capacitor and resistance [5,6], or using a control voltage in timer pin 5. The advantage of this function is enormous, since the injection time can this way be controlled accurately. The pulse width of the timer output signal is proportional to the injection period, which can be obtained using a relation between the control timer voltage and a rheostat voltage. The rheostat voltage is by its time proportional to the accelerator position. Several experiments were conducted to determine the relation between the crankshaft angular speed and the rheostat voltage. With the knowledge of the accelerator position, the fuel injection period can be calculated for each crankshaft angular speed. For that, a plot of the injector fuel delivery rate as a function of time was used [5,6]. To have a timer control voltage proportional to the rheostat voltage, it is necessary to use an amplifier similar to the one in Fig. 7, which is ruled by (3),

$$V_o = \left(1 + \frac{R_1}{R_2}\right) \times V_i \tag{3}$$

Where V_o represents the timer control voltage and V_i the accelerator rheostat voltage and $\left(1 + \frac{R_1}{R_2}\right)$ the gain of the amplifier for proportionality between the two voltages.

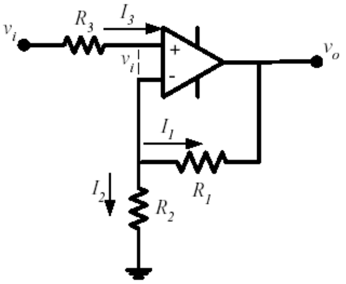


Fig.7 Non inverter amplifier topology

3 Experimental results

A. Ignition system control results

Several trial and error experiments allowed the optimization of the control circuits. The control boards allow the control of the ignition and injection times. Another important factor is the coil energizing current, which was experimentally determined. Considering the coil as an RL circuit [5,6], the current value is calculated using the equation (3), being the time constant calculated using equation (4).

$$\tau = \frac{L}{R} = 7{,}07 \times 10^{-4} s \tag{4}$$

The time to obtain different current values can be obtained. The equation (3) gives those values for arbitrary chosen times. The current measured values are presented in Fig. 8, where can be seen a stabilization in current value, after some time. The spark occurs with coil energy dissipation at turn off time. The minimum spark current needed is around 5A and for higher value; losses by Joule effect can be considerable, which can damage the coil.

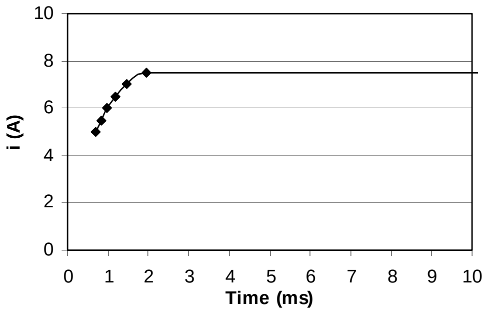


Fig.8 Coil current versus charging time

B. Injection system control results

The first tests performed were used to determine the parameters for the injection control. The first parameter was the relation between the pin 5 control voltage and the timer pulse width. For that, a variable voltage was applied to this pin and the pulse width was measured. For small voltage values, the pulse width was constant [5,6] and for voltages around 1.5 V the changes started. The representation of the experimental values can be seen in Fig. 9. It can be observed that the relation between the control voltage and the pulse width is almost linear and can be fitted by the straight line presented in the figure. It can be concluded that the timer pulse width increases with the increase of the control voltage. A second test was performed to obtain the relation between the accelerator rheostat voltage and the crankshaft angular speed. The obtained results [5,6] show that the rheostat voltage increases with the engine angular speed.

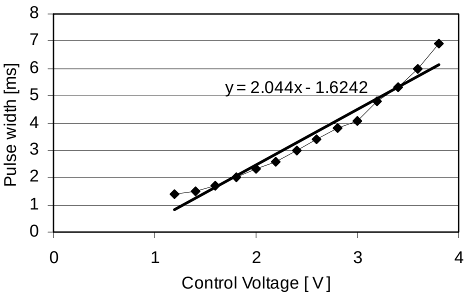
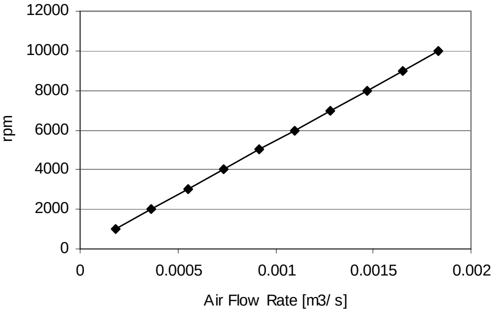


Fig. 9 Control voltage versus timer pulse width



With that knowledge the injection period can be estimated more precisely. Figure 10 shows that the relation between the rheostat voltage and the crankshaft angular speed is linear. This relation is also presented in Figure 10 and was used to calculate the accelerator position as function of the crankshaft angular speed.

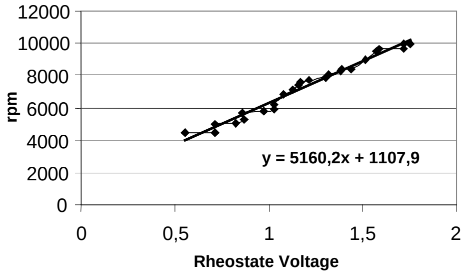


Fig. 10 Rheostat voltage versus crankshaft angular speed

To relate the rheostat voltage and the injection period, it is necessary to calculate the fuel mass flow rate for each crankshaft angular speed. First, the volumetric air flow rate was estimated, using (5),

$$V_{asp} = \frac{\dot{V}d \times nr}{nr \times 60 \times 10^3} \quad [m^3/s] \tag{5}$$

Where Vd corresponds to the engine displacement ($22\,cm^3$), nr is the number of crankshaft turns for engine cycle, being 2 for a four stroke engine.

After that, the air mass flow rate is determined using (6),

$$\dot{m}_{ar} = \frac{\dot{V}_{asp} \times 100 \times p_a}{0,297 \times T} \quad [kg/s] \tag{6}$$

Where p_a is the atmospheric air pressure (bar) and T the ambient temperature (K). It was considered a 303K. The stequiometric combustion air/fuel relation (7) was then used to estimate the fuel mass flow rate.

$$\left(\frac{A}{F}\right)_s = 14.6$$
$$\dot{m}_F = \frac{\dot{m}_a}{14.6} \quad [kg/s] \tag{7}$$

In Fig. 11 it is shown that the air flow rate increases with the increase of the crankshaft angular speed.

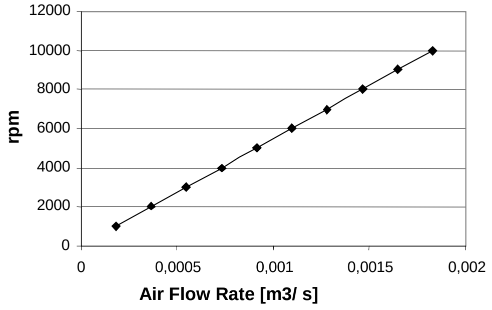


Fig. 11 Volumetric air flow rate versus engine angular speed

The knowledge of the air mass flow rate is needed to estimate the fuel to be injected. Figure 12 presents the relation between the air mass flow rate and the engine crankshaft speed. It can be seen a linear increase of the estimated values. Nevertheless, other parameters have influence in the air mass flow rate: ambient pressure, moisture and temperature. These parameters promote changes in the air mass flow rate and in the power produced by the engine. Several correction factors can be used to account for this influence. Figure 13 presents the relation between the fuel to inject and the crankshaft angular speed.

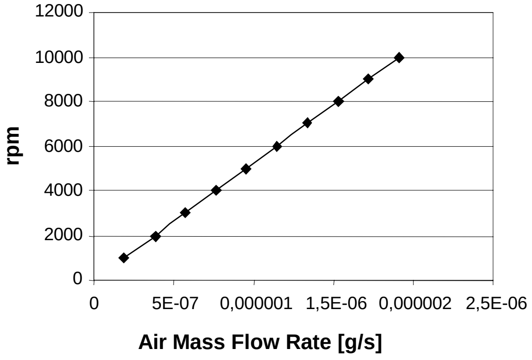


Fig.12 Air mass flow rate versus crankshaft speed

Theoretically, the ideal combustion should be stequiometric. A fuel rich mixture is not completely burned and showing high CO content. A fuel weak mixture is also not desirable, since ignition problems can occur.

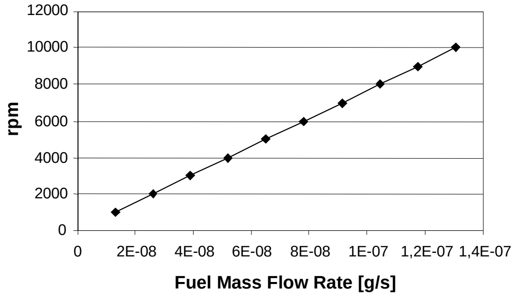


Fig.13 Fuel mass flow rate versus crankshaft speed

Figure 13 shows the relation between the theoretically estimated values of fuel mass flow rate and air mass flow rate.

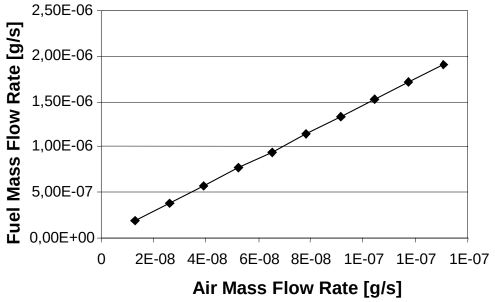


Fig.14 Air mass flow rate versus fuel mass flow rate

After determination of the fuel quantity to inject as a function of the crankshaft angular speed, it was required the determination of time for the injector to be open. That was done using the builded graphs [5,6], with values summarised in Table I. As an example, for 4000 rpm, the injection has a period of 4.25 ms; using Table I, the control voltage is around 3V. With this value, the relation between the control voltage and the rheostat voltage can be calculated.

Table I Fuel mass flow rate, injection period, turns of the crankshaft and position of the accelerator as funtion of the crankshaft speed.

Crankshaft Angular Speed [rpm]	**Fuel mass flow rate [g/ms]**	**Injection period [ms]**	**Crankshaft turns**	**Accelerator position [degrees]**
3000	0.39	3.5	0.175	63
4000	0.52	4.3	0.283	101
5000	0.65	5.0	0.417	150
6000	0.78	5.9	0.590	212
7000	0.91	6.7	0.782	281
8000	1.04	7.2	0.960	345
9000	1.17	8.2	1.230	442
10000	1.31	9.0	1.500	540

From Fig. 15 one can conclude that the fuel flow rate is proportional to the injection time, almost in a linear function.

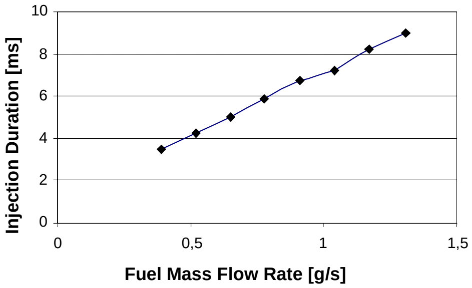


Fig.15 Fuel mass flow rate versus injection period

4 Conclusions

The electronic injection and ignition systems allow a better control of the combustion, which permit to use the energy contained in the fuel in a better manner and also permit to control the pollutants formation.

Beside all the tests already performed, many others have to be done in order to improve the liability of the control circuit. The implementation of the control systems in the engine and the synchronization between them is very important, allowing to ascertain the needed improvements. The substitution of part of the circuit by a microprocessor will be an important step, since the ignition advance and the injection time and period could be controlled more precisely. With the microprocessor and the acquisition sensors it will be possible to know in real time the engine parameters and change them accordingly to the use.

Acknowledgment

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