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# Performance of Fuel Electronic Injection Engine Systems

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## ABSTRACT

Electronic Fuel Injection systems are very important components in today's automotive industry. Its use on modern engines allows manufactures to develop new engine designs while increasing engine efficiency and lowering fuel consumption and exhaust gas emissions. EFI systems also increased engine reliability by providing a smooth start and run under most weather conditions. This paper presents the state-of-the-art of direct fuel injection in spark-ignition (SI) engines, the current technology to make possible its accomplishment, the characteristics of the engines using this system and a comparative experimental study between this system.

***Keywords:*** *injector, ECU, Sensor, Ignition Coil*

## 1. Introduction

The car's engine is the beating heart, which drives the car according to the driver's will and the driving conditions. The energy which operates the engine is received from air and fuel mixture, which is compressed inside the cylinder and then ignited. Three main systems determine the efficient and intact operation of the engine: The fuel system, the air system, the ignition system.

Before the advance of electronic injection system, the use of direct injection system had been in operation. In 1931, Taylor *et al*. accomplished tests with direct injection in a SI engine in order to compare the results with those obtained from carburetor system. They had as a result an increase from 7 to 11% in the maximum power and a significant improvement in the specific fuel consumption.

In 1957, Dolza *et al*., on a single-cylinder unit, accomplished tests with direct injection with the intention of comparing this system and that of conventional carburetor in the different conditions of speed, load and temperature of the engine.
Davis *et al*. (1961), of Texaco Research Center - Beacon, developed a engine with high thermodynamic efficiency associated with combustion of lean mixtures (economy), using direct injection into the cylinder. This process, called TCP (Texaco Combustion Process), had as main characteristic the swirl of the mixture air-fuel in the combustion chamber. The swirl happened due to the angle between the fuel injector and the wall of the cylinder. The objectives of these researches were reached, however the production of engines that used this process was not possible due to the high cost of production.

In 1963, Hussmann *et al*. tested a direct injection system to analyze the behavior of the engine during the operation with stratified charge and the effect of the variation of the lag of time between injection of fuel and ignition of the mixture.

Since its creation, the internal combustion engine has undergone constant changes on its design. The introduction of electronic systems inside of the engine allowed manufacturers a have bigger control over the engine and achieve lower emissions of polluting agents while increase the performance and efficiency (Zhao *et al*., 1997).

Today's electronic fuel injection systems provide smooth engine start and operation even in extreme cold and extreme heat conditions. In motorsport, electronic fuel injection systems allow engineers to adapt the cars to the demands of the circuit whether it demands a greater response at low engine speed or greater top speed. (Kowalewicz, A., 1984)

Advanced electronic engine management systems allow users to fine tune nearly every aspect of the engine's operation. And later high-end products can be used in Variable Valve Timing (VVT) engine, work with multispark systems (multiple sparks are created in rapid succession to improve fuel combustion at low engine speed and cold engine temperatures) and adapt to new types of engine and manifold designs. (Lenz, H. P., 1992).

New types of sensors can be connected to the ECU. Knock sensors correct ignition timing and prevent the fuel's premature ignition, sensors placed on turbocharged engines help control turbo boost. Some ECU's can also store the data collected from their sensors in rates from 20 to 200 times per second and even add GPS data for later analysis.

## 2. Electronic Fuel Injection

Due to the growing concern of fuel economy and lower emissions, Electronic Fuel Injection (EFI) systems can be seen on most of the cars being sold today. EFI systems provide comfort and reliability to the driver by ensuring a perfect engine start under most conditions while lessening the impact on the environment by lowering exhaust gas emissions and providing a perfect combustion of the air-fuel mixture.

In order to ensure the efficient operation of the engine, the EFI system must collect information from a range of sensors located inside the engine, process the information in the ECU and make the necessary adjustments to the quantity of fuel injected and the ignition timing. With this information the ECU can determine the load set upon the engine and make the necessary adjustments in the fuel injection to ensure a smooth and quick response to the load applied. In order to better understand how the EFI system works, it can be separated in three parts: the sensors, the ECU and the actuators. Figure 2.1 represents how these parts are connected.

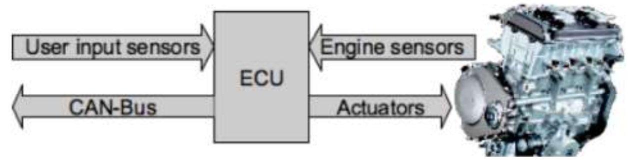



Fig. 2.1 Electronic flow injector system diagram

The sensors are used to monitor the status of the engine are Engine Speed, Camshaft Position, Throttle Position, Manifold Absolute Pressure (MAP), Engine Coolant Temperature and Intake Air Temperature. The actuators are comprised of the injectors and ignition coils.

### 2.1 Sensors

For the ECU to respond correctly to the engine's condition it must rely on an array of sensors. These sensors provide information on temperatures, speed and position. Figure 2.2 shows the flow of information from the sensors to the ECU.

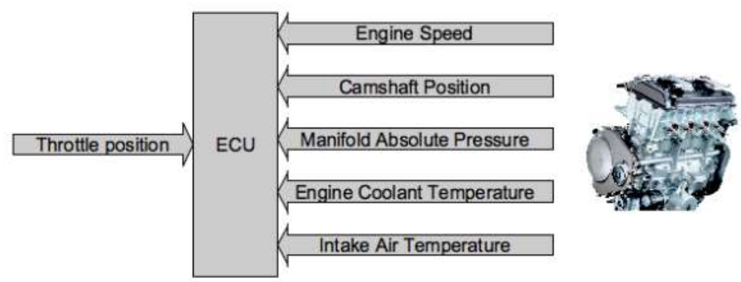



Fig. 2.2 Sensor flow of data

#### 2.1.1 Engine Speed Sensor

The Engine Speed Sensor relays the engine's current angular speed, in revolutions per minute (RPM), to the ECU. It uses a magnetized cog with 12 teeth attached to the engine's crankshaft (Figure 2.3) and a Hall Effect sensor. When one of the cog's teeth passes near the near the sensor it creates a magnetic field (B) perpendicular to the sensor's surface (Figure 2.4).

Fig. 2.3 Engine Speed Sensor

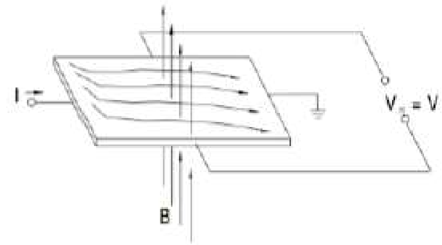
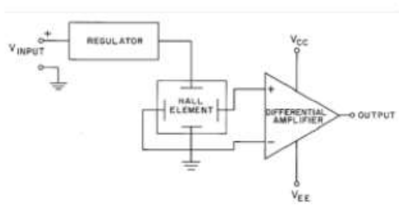



Fig. 2.4 Hall Effect sensor's surface [8].

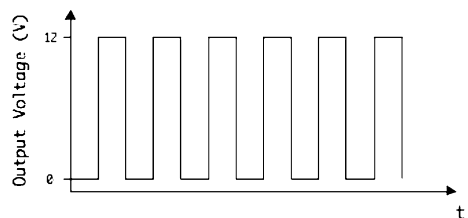
This magnetic field causes a voltage difference across the sensors surface known as the Hall voltage (VH). This voltage is proportional to the current passing through the sensors surface (I) times the magnetic field (B) (Equation 1) [8].

$$V_H \ \alpha \ I \times B \ \ldots\ldots\ldots\ldots\ldots\ldots \ (1)$$

The Hall voltage is then amplified and sent through a comparator (Figure 3.5) so that we obtain a pulse at the sensor's output pin every time one of the cog's teeth passes near the sensor's surface (Figure 3.6).




Engine speed sensor internal conditioning circuit.




Engine speed sensor output.

When reaching the ECU, the voltage output of the sensor is too high to be placed directly on the dsPIC's pins and therefore must be lowered to a range between 0 and 5 Volts. In order to do this the signal is connected to a zener diode and lowered from 12 Volts to 4.7 Volts.

The signal is then monitored by the ECU that determines the signal's frequency (fs) by counting the time interval between pulses. The engine's speed in RPM is obtained using Equation 2.

$$RPN \ = 5 \times f_s \ \ldots\ldots\ldots\ldots\ldots\ldots \ (2)$$

### 2.1.2 Camshaft Position Sensor

The Camshaft Position Sensor works the same way as the Engine Speed Sensor as it also uses a cog and a Hall effect sensor. The main difference between the sensors is the cog used. The cog used by the Camshaft Position Sensor is attached to the engines camshaft (Figure 2.5) and only has 3 teeth designated by Top Dead Center (TDC), Bottom Dead Center (BDC)\ and reference
(Figure 2.6).

Fig. 2.5 Camshaft Position sensor cog


Fig.2.6 Camshaft Position sensor's cog detail

TDC occurs when cylinders 1 and 4 reach the highest point inside the combustion chamber (Figure 2.7a) and cylinders 2 and 3 are at their lowest point (Figure 2.7b). BDC occurs 180□□after TDC and represents the opposite point of TDC. In BDC cylinders 2 and 3 are at the highest point and 1 and 4 are at the lowest. Finally, the reference pulse occurs slightly after BDC to allow the ECU to distinguish between TDC and BDC pulses. The reference pulse also provides the ECU with a way to determine the camshaft's position at engine start. The Camshaft Position Sensor output is shown in Figure 2.8.

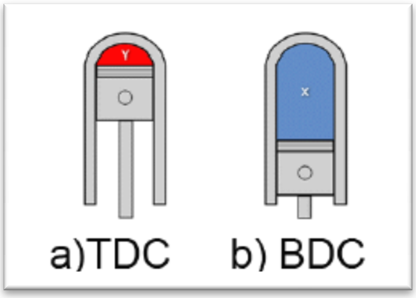



Fig.2.7 Cylinder position: a) TDC b) BDC.

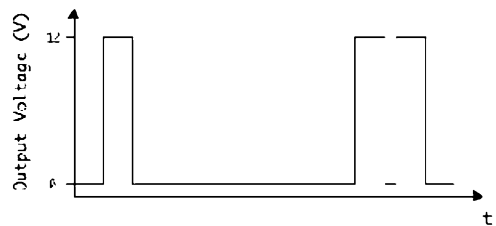



Fig.2.8 Camshaft Position sensor output.

The Camshaft Position Sensor uses the same signal conditioning circuit as the Engine Speed Sensor (Figure 3.5) and the ECU requires a full camshaft revolution to determine its position during engine start. Since the camshaft and the crankshaft are mechanically connected and 1 revolution of the crankshaft equals 1 revolution of the camshaft, it is possible to determinate the camshaft's position by comparing the time between impulses of both sensors (Figure 2.9).

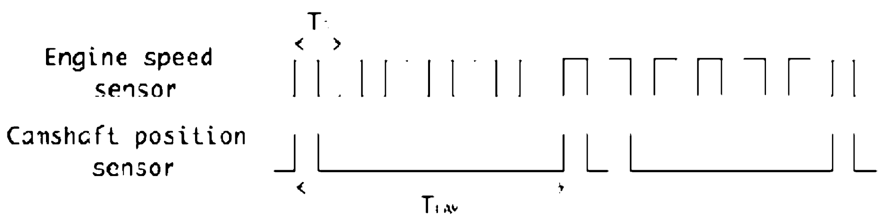



Fig. 2.9 – Engine Speed and Camshaft Position signals.

If we ignore, for now, the presence of the reference pulse it is possible to see that TDC and BDC pulses occur every 6 pulses from the Engine Speed Sensor, in other words, the camshaft's sensor period is 6 times the period of the crankshaft's sensor (Equation 3).

$$T_{CAM} = 6 \times Y_S \quad \text{..........................} \quad (3)$$

Taking the reference pulse back into consideration, the pulse sequence outputted during the first camshaft revolution can have 3 distinct orders (Figure 2.10).

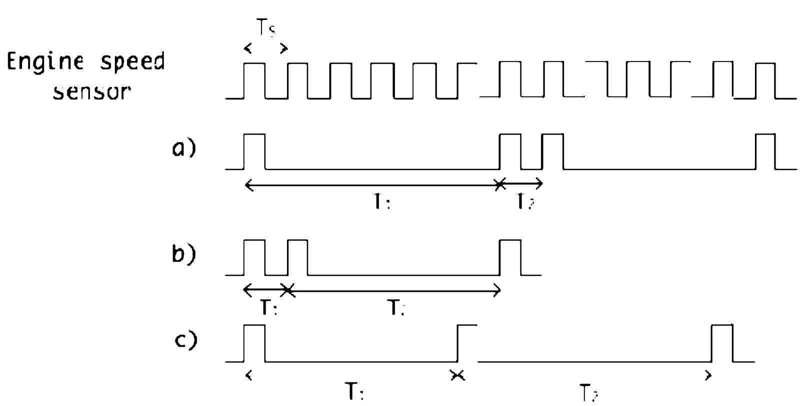



Fig.2.10 possible sequences during start with T1 and T2 and comparisons

If T1 is equal to the camshaft period (without reference pulse) determined from the Engine Speed sensor output, then the last pulse registered will be the reference and will be followed by the TDC pulse (Figure 2.10a). In the event that T1 does not match the camshaft's period, the ECU compares T2. If T2 matches, the last pulse of the revolution will be BDC and will be followed by the reference pulse (Figure 2.10b).

If none of the time intervals match the camshaft's period, the last pulse in the revolution will be TDC (Figure 2.10c). After determining the camshafts position the ECU can start the correct injection and ignition timings for each of the cylinders.

### 2.1.3 Throttle Position Sensor

The Throttle Position Sensor (TPS) is attached to the throttle valve (Figure 2.11) and relays the current throttle pedal position to the ECU.

Fig. 2.11 Throttle Position Sensor

The TPS sensor is composed by a potentiometer connected to the valve's axis. When the driver accelerates, the valve is opened and the potentiometer's wiper arm moves along the resistor changing the output voltage of the sensor (Figure 2.12). The throttle position is determined by measuring the voltage difference between the wiper arm and ground. The TPS sensor output voltage varies linearly, between Ground and VCC, with the throttle pedal's position (Figure 2.13).

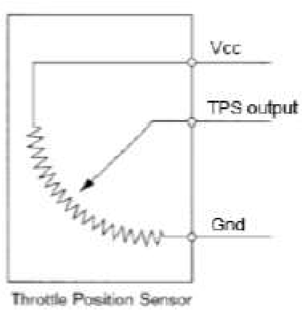



Figure 2.12 – TPS sensor's internal view[2].

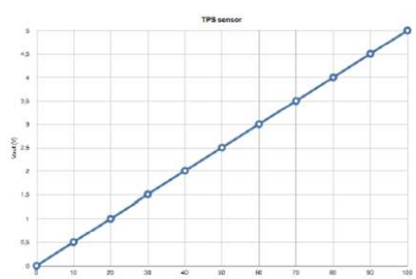



Figure 2.13 – TPS output.

Before converting the TPS voltage to a digital value, there is a low-pass filter to remove any noise that could prevent the Analog-to-Digital Converter (ADC) from making an accurate reading. The throttle pedal's position is then transformed into a percentage representing how much throttle is being applied.

## 3. Manifold Absolute Pressure

The Manifold Absolute Pressure (MAP) sensor (Figure 3.1) is responsible for measuring the air pressure inside the intake manifold and providing the ECU with the load currently being applied on the engine. With the increase of the engine's load, the volume of air entering the engine through the intake manifold causes a rise of air pressure that is registered by the MAP sensor.

Inside the MAP sensor is a small silicon chip (Figure 3.2) placed between a vacuum chamber and a line leading to the intake manifold.

Fig. 3.1 – MAP sensor.

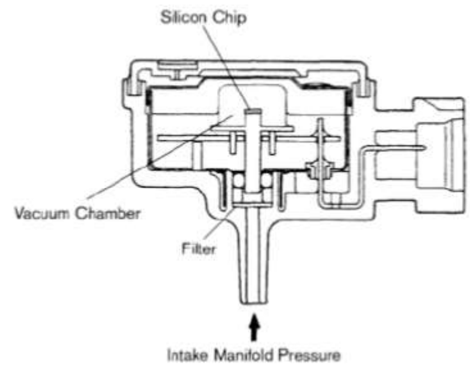



Fig. 3.2 – internal views of the sensor [3]

As the pressure increases inside the manifold, the silicon chip flexes (Figure 3.3), acting like a strain gauge and changing its resistance.

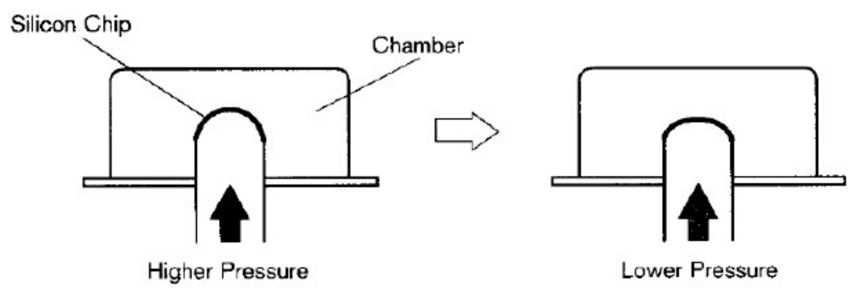



Figure 3.3 – chip flexing under pressure [3].

Before engine start, the MAP sensor registers the Barometric Atmosphere Pressure (BAP) to provide a reference point for calculating engine load. Figure 3.4 shows the sensor's voltage output for different altitudes.

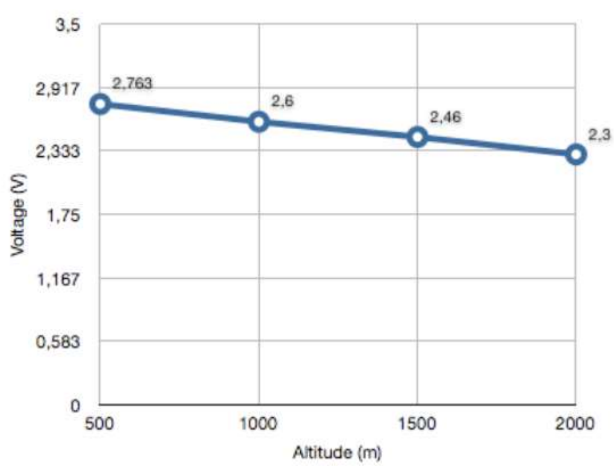



Fig. 3.4 MAP sensor voltage output for different altitude [13]

Engine load is determined by comparing the MAP sensor's value before engine start and the values obtained during engine operation. The value registered for the atmospheric pressure is the same that is registered during Wide Open Throttle (WOT) periods, in other works, 100% engine load. Knowing this, and the fact the output voltage is 0 when the intake manifold is in perfect vacuum, it is possible to calculate the engine's load (Equation 3).

$$Load = \frac{MAP \times 100}{BAP} \quad ,,,,,,,,,,,,,,, (3)$$

The MAP sensor's voltage output undergoes the same conditioning as the TPS sensor and is filtered by a low-pass filter prior to conversion.

**4. Engine Coolant Temperature**

The coolant temperature has a considerable influence on fuel consumption. Knowing the Engine Coolant Temperature (ECT) is a good way for the ECU to assess the engine's overall temperature. Elevated engine temperatures can lead to premature damage to the engine's internal components. The ECT sensor is located near the engine where the coolant exits the engine to cool down in the radiator and is composed by a Negative Temperature Coefficient (NTC) thermistor (Figure 4.1) immersed in the coolant. Due to the Negative temperature coefficient, the resistor's value will decrease with the increase of the coolant's temperature (Figure 4.2).

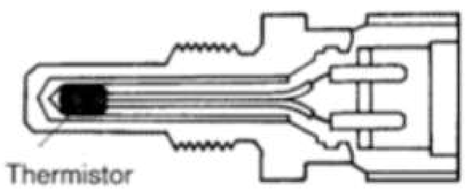



Fig.4.1 Sensor Internal View

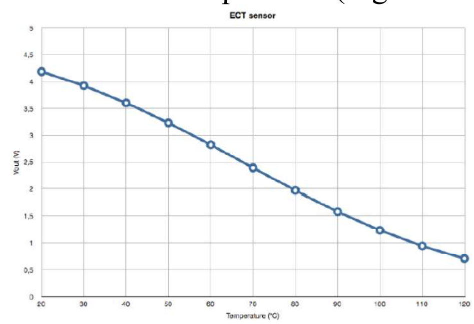



Fig. 4.2 ECT Sensor's voltage output

Engine temperature readings are used by the ECU to make small corrections to the amount of fuel injected and ignition advance resulting in faster engine warm-up during cold starts and helping to lower engine temperature when needed [9].

**4.1 Intake Air Temperature**

The intake-air density depends upon its temperature, The Intake Air Temperature (IAT) sensor is identical to the one used for ECT but instead of being immersed in coolant, the sensor is exposed to the outside air. The IAT sensor is located inside the air intake manifold measuring the temperature of the air being channelled into the cylinders.

The temperature of the air entering the engine is used to make small adjustments to the fuel injection and ignition advance to provide a more efficient combustion [9].

**5. Electronic Control Unit**

Once the ECU has collected all of the information from the sensors in the engine, it has to determine when and how much fuel to inject in the combustion chambers. Ideally the ECU tries to achieve the optimum air to fuel ratio of 14.7:1(stoichiometric ratio) but the changing operating conditions require small changes to the ratio. At lighter loads the ECU can use leaner air to fuel mixtures (higher air to fuel ratio) to save fuel and user richer air to fuel mixtures (lower air to fuel ratio) to help reduce engine temperature or warm up the engine. An air to fuel ratio of 12.6:1 (rich) provides maximum power while a ratio of 15.4:1 provides the best fuel economy. Figure 5.1. Shows the power and fuel consumption curves versus the air to fuel ratio [10].

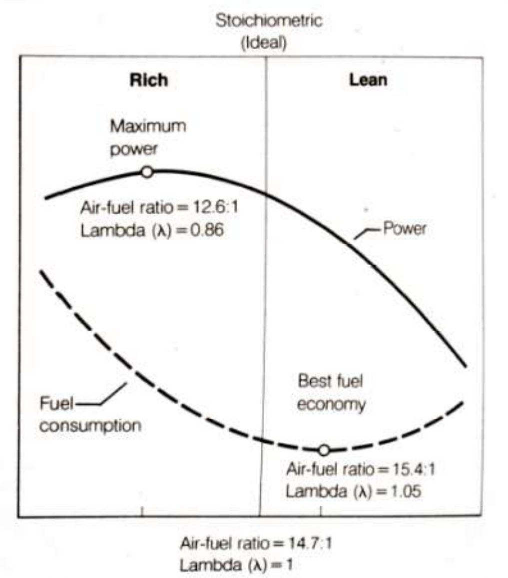



Figure 5.1 – Power and fuel consumption curves versus air to fuel ratio [10].

The stoichiometric ratio is a compromise between rich and lean mixtures with very little sacrifice of power or fuel economy and helps reduce emission of pollutant gases in the combustion process.

## 6. Actuators

After performing all the calculations the ECU must command the injectors and the ignition coils in order to inject and ignite the fuel inside the combustion chamber of each cylinder. Precise injection and ignition timing can provide the engine a greater power output and smooth operation while an incorrect timing setup can result in a significant loss of power and efficiency and subsequently cause severe damage to the engine.

### 6.1 Injectors

The delivery of fuel to the engine is made by a set of injectors (one per cylinder). The injectors (Figure 6.1) are small electronically controlled nozzles located in the air intake, upstream of each combustion chamber (Figure 6.2) that spray fuel into the chamber several times per second.

Fig. 6.1 Injector

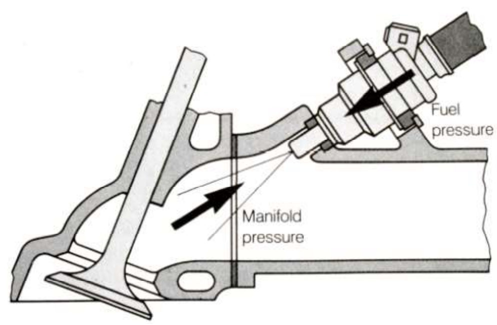



Fig. 6.2injector location

The injector comprises of an electric coil (Figure 6.3) that opens the valve allowing the flow of fuel into the combustion chamber. The high pressure of the fuel inside the fuel lines along with the small valve opening atomize the fuel (Figure 6.4) mixing it with the air inside the chamber providing a more efficient fuel combustion [10]

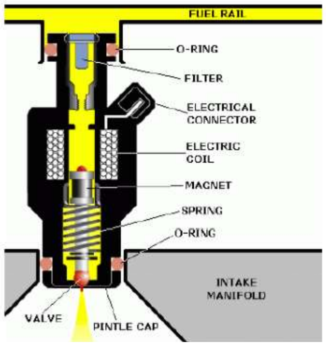



Fig. 6.3 Internal view of an injector

Fig.6.4 Injector spray

The injectors are controlled using the injector signals created by the ECU (Figure 6.5). This signal is sent to the injection driver that controls the opening and closing of the injector.

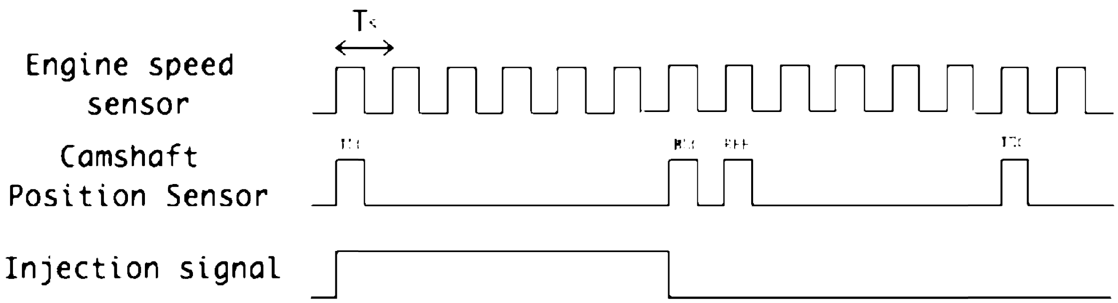



Fig. 6.5 Injector control signal

## 6.2 Ignition coils

After the fuel has been injected into the combustion chamber, the ECU must ignite the fuel efficiently. The optimum point of ignition occurs when the combustion chamber is at its maximum compression point (approximately 10° after TDC) [11]. The point of ignition can vary slightly from the optimum combustion point to help reduce the engine's temperature. Since the spark cannot be instantly created, the ignition coils (Figure 6.6) store an electromagnetic charge that is later discharged in the form of a spark at the tip of the sparkplug. The time taken for the spark to occur from the moment current starts passing through the coil is called dwell [12].

Fig. 6.6 Injector coil

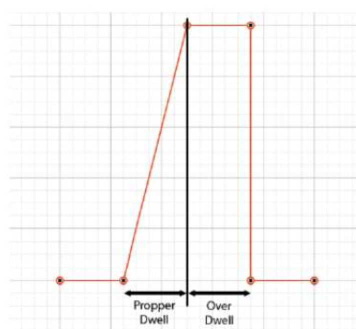



Fig. 6.7 Dwell

Dwell time (Figure 6.7) depends of the ignition coils used and, in this case, the dwell is equal to 3 milliseconds [13]. Increasing the dwell (over-dwell) will not provide additional energy to the combustion and overheats the coil shortening its life span.

## 6.3 Controller Area Network Bus

The Controller Area Network Bus (CAN-Bus) is a broadcast protocol bus mainly used in the automotive industry. Being a broadcast bus, all nodes connected to the bus receive the messages sent through it. It is up to the nodes to decide whether to keep or discard the message received. There are 4 different types of CAN messages: Data frame, remote frame, error frame or an overload frame.

The most common message used, and the one used by the ECU, is the data frame. The data frame can be split into 4 major fields: Arbitration field, data field, Cyclic Redundancy Check (CRC) field and the acknowledge slot (Figure 6.8) [14].

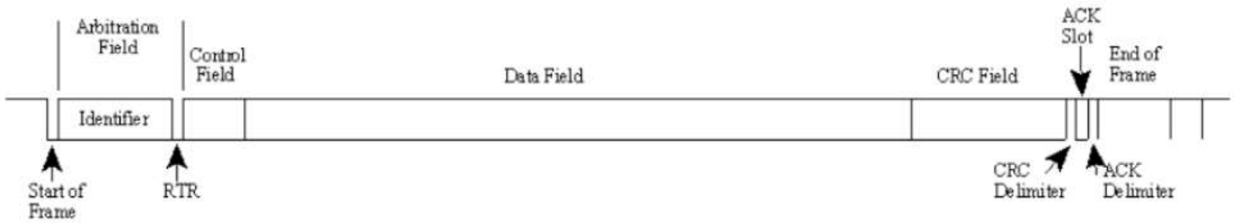



Fig. 6.8 Data frame message [14]

The arbitration field determines the priority of the message and its used by the nodes as a way to decide which messages to keep. The Arbitration field is 11 or 29 bits long depending on whether the message uses standard or extended CAN identifiers.

Highest priority is given to the lowest message identifier. The data field contains the message itself. It can take up to 8 bytes of data. The CRC field is part of an error detection mechanism used by the CAN-Bus protocol. It contains a 15 bit long checksum used to verify the integrity of the message. Finally, the acknowledgement (ACK) slot is a short interval were the listening nodes send confirmation of the correct arrival of the message. Since all nodes in the bus receive the message, it is impossible to use this slot to make sure that the intended receiving node has received the message sent. Other methods must be used to ensure the arrival of the message to the correct node. During operation, the ECU uses 3 different message identifiers (Table 3.1).

**Table 3.1 - CAN message identifiers.**

| Identifier | Function |
|---|---|
| 1 | Base Fuel Map value |
| 2 | Base Ignition Value |
| 3 | Acknowledge |

Of these identifiers, only 2 are accepted by the ECU in incoming messages. These identifiers correspond to the messages carrying Base Fuel Map or Base Ignition Map values. The third identifier is used by the ECU as an ACK message signaling, the correct arrival of the message.

## 7. CONCLUSION

As combustion depends on the homogeneity of the air-fuel mixture, the fall in power and torque, the low global efficiency and high specific consumption can be attributed to the excess of liquid fuel injected into the cylinder. The pulses generator, responsible for activating the injectors, supplied the cylinders with an extremely rich mixture at those speeds.

This paper presented the state-of-the-art of direct fuel injection technology. .For the conditions where a slight fall in the torque and power happened, the use of improved injectors and combining with an electronic injector controller, could allow for the possibility to improve the formation and homogenizing of the air-fuel mixture increasing the global thermal efficiency, torque and power.

## References

1) Taylor, et. al., 1931, Fuel injection with spark ignition in a Otto-cicle engine, SAE Transactions, vol. 26, pp. 346-351.
2) Dolza, J. et. al., 1957, The General Motors fuel injection system, SAE Transactions, vol. 65, pp. 739-746.
3) Davis, C. W. et. al., 1961, Fuel injection and positive ignition - a basis for improved efficiency and economy, SAE Transactions, vol. 69, pp. 120-134.
4) Hussmann, A. W. et. al., 1963, Charge stratification by fuel injection into swirling air, SAE Transactions, vol. 71, pp. 421-444.
5) Zhao, F. et. al., 1997, A review of mixture preparation and combustion control strategies for

spark-ignited direct-injection gasoline engines, SAE Technical Paper Series, n. 970627.

6) Kowalewicz, A., 1984, Combustion systems - of high-speed piston I. C. engines, Warszawa, Elsevier

7) Lenz, H. P., 1992, Misture formation in spark-ignition engine, New York, Springer-Verlag-Wien/SAE.

8) HoneyWell, *Hall effect sensing and application*, available from http://content.honeywell.com/sensing/proinfo/solidstate/technical/chapter2.pdf

9) Strader, Ben, *Building & Tuning High-Performance Electronic Fuel Injection*, Car Tech, ISBN 978-1-884089-79-4

10) Probst, Charles, October 1989, *Bosch Fuel Injection and Engine Management*, Bentley Publishers

11) Toyota university, *Position sensors*, Toyota Motor Sales, U.S.A., available from http://autoshop101.com/forms/h39.pdf

12) ] Motec, 2004, *Engine Management & Data Acquisition Systems*, Formula SAE seminar, Detroit

*13)* Honda Motor Company, 2003, *CBR600 F4i service manual*

*14)* Kvaser, *The CAN Bus*, available from http://www.kvaser.com/can/intro/index.htm