

Electronic Ignition And Fuel Injection Systems

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Abstract

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Introduction

Firstly individual research as well taught lectures will be carried out to correctly understand the systems in use. Then working in groups we will carry out a few live tests of two separate engines. One a 2 Litre Vauxhall Motronic engine, the other a non motronic engine . to test the different systems a multi-meter and oscilloscope will be used to look for resistance and voltage patterns. With data from the workshop session individually we can then complete the following tasks.

- 1) Explain using data provided by the workshop session how injection on time is reached for each of the following conditions.

Ignition on, engine off

Engine cranking (cold start)

Engine Warm up phase

Acceleration

Deceleration

Idle Speed

- 2) Once this is done a report will be constructed individually to review data collected, methodology used and safety requirements. I will specifically look at:

The procedure used to carry out the test

Comparing data to manufacturers specification

Equipment used

Safety requirements followed during test

Comparison of NTC2 graphs

- 3) Then the two engines will be compared by looking at signal waveforms collected by the oscilloscope as well as other raw data.
- 4) Once this is completed I will chose two modifications to the ignition or fuelling control systems that will enhance both systems.

Research

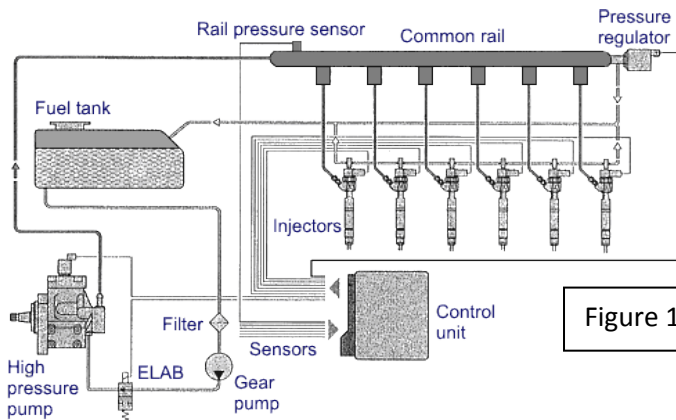


Figure 1

Fuelling

In its basic form The purpose of the fuelling system is to provide clean, filtered fuel to its point of delivery. In most modern fuel systems fuel injection is used over conventional carburettors. In a fuel injection system the fuel will also need to arrive at its point of delivery at a certain pressure so that the fuel becomes atomised there by increasing the surface area of the fuel speeding up the combustion process. The fuel

also needs to arrive at the correct time and the proper amount. “many cars are now being fitted with fuel-injected engines where the fuel is delivered in precise bursts. Engines so equipped are usually more efficient and more powerful than carburetted ones” (no author, 2019)

Ignition

The purpose of the ignition system is to provide a high voltage spark which can ignite the air/fuel mixture within the cylinder. The ignition system is also required to provide this spark at the correct time which will change drastically throughout the operation of the engine. According to an article on crankshaft (jaukkonen, 2013) The Electronic ignition system as we know it today was invented in 1948 by a Mr Delco Remy. “Although Alessandro Volta demonstrated how an electric spark could be used to drive what essentially amounted to a piston, two major components had to be invented before the ignition system could be developed. The first component was the magneto, which is a device that uses magnets to generate an electric current. Faraday first demonstrated how a moving magnetic field could generate a current in 1831, but the first magneto ignition system didn’t appear until the 1890s. Another watershed moment in the history of the ignition system was invention of the spark plug in 1860. This component, which is ubiquitous in modern spark-ignited internal combustion engines, was developed by Belgian engineer Etienne Lenoir for his gasoline engine.”(jaukkonen, 2013)

Methodology

To ensure safe working practices during testing many steps were taken before the testing was started. Firstly it is important that the engine is thoroughly checked over by checking all fluid levels such as coolant and oil as well as a brief visual inspection looking for any cracks or build-up of oil that would indicate a leak. To inspect the coolant level check that the coolant level match that of the levels imprinted on the container. The oil level can be checked using the dip stick, ensure the engine has been off for at least 10 minutes. Remove the dipstick and clean it with a rag. Insert the dipstick again and remove it once more and check the indicator usually located at the bottom of the dipstick.

In our case it was important that we tested the engine as it warmed up from cold start to operating temperature. However in most engine test procedures such as a sweep test performed on an engine dynamometer or a power run performed on a chassis dynamometer it is extremely important that the engine is at operating temperature before putting any major load on the engine. This is because the engine was designed to run at a certain temperature and putting excessive amounts of load when the engine isn't warm can reduce the life of the engine. According to an anonymous author (no author, 2018) when the engine is cold the oil is also cold causing the oil to be relatively thick and viscous. This causes extra strain on pumps as well as lubrication not being optimal. This combined with cold rubber hoses can lead to cracks in extreme cases.

Test Equipment

Multimeter

A multi-meter is essential in gathering data from a vehicle. A piece of diagnostic equipment that is mainly an ohmmeter, voltmeter and ammeter. It has other uses such as a continuity test etc but its ability to measure current, resistance and voltage make it one of if not the most important piece of test equipment.

Oscilloscope

Although a multimeter can provide lots of data about each system An oscilloscope is a piece of electronic test equipment that provides a much more thorough analysis of a circuit. An oscilloscope allows for resistance, current and voltage to be plotted against time to allow for waveforms to be produced. The oscilloscope also allows for precise measurement of certain timeframes such as the injector time width. According to Ditet "When checking circuits, power supplies and grounding, the signals often change too rapidly to check with a Multimeter. Often there are no trouble codes saved in the ECU but the problem exists because a trouble code is only recorded when there is a broken or short to the positive or the negative power supply or the sensor/actuator is faulty." (no author, no date)

Safety

Safe working practices were carried out throughout the procurement of data from the engine. Firstly when in the workshop area PPE is crucial. Steel toe cap boots, appropriate clothing such as overalls or lab coat and some eye protection. It is also important to remove any loose jewellery such as a watch or bracelet. Extra pre caution was taken by working from an engine rig with guard rails attached around any area with moving parts or an excess of heat.

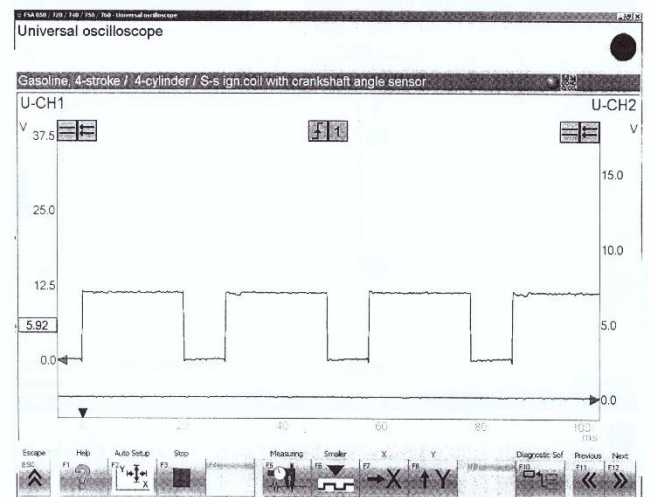
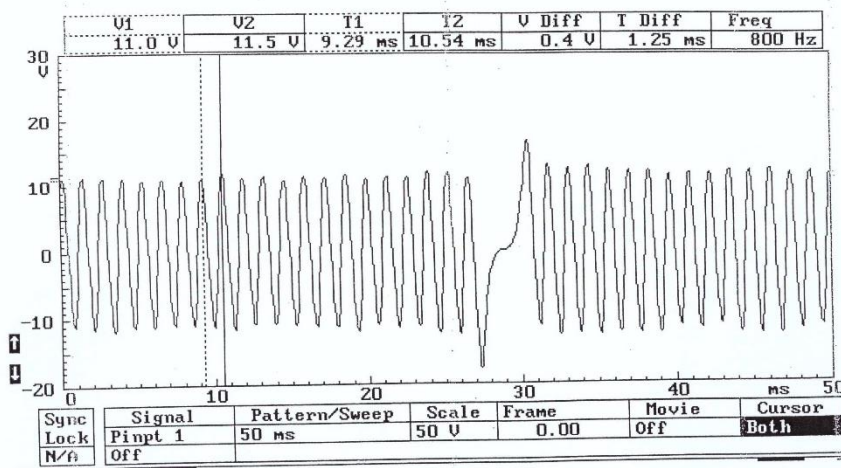
Analysis

Each of the phases discussed below are conditions that have been decided by the ECU that require special attention to be able to operate correctly. In order for the ECU to understand what the driver is doing it uses a plethora of sensors. Most of the sensors discussed below are there to decipher speed and load. There are lots of other sensors on vehicle such as parking sensors, tyre pressures etc but are not involved in the running of the engine so won't be discussed here.

For an engine there will usually only be one speed reference and that is the crankshaft position sensor or CPS. The CPS works by having a reluctor ring on the crankshaft that has teeth. As the teeth pass the sensor a voltage is induced within the sensor. One of teeth will be missing and this is used as a position reference and is often placed at the point when all the pistons are at either TDC or BDC. one of the engines features a hall effect sensor and one is inductive. An inductive sensor works by having a magnet on one side of the reluctor ring which then induces the voltage in the sensor producing an analogue signal. A hall effect sensor produces a digital signal. A hall effect sensor also needs voltage supplied to it as it does not generate its own signal. It is for this reason an inductive type sensor needs 2 wires (signal and earth) because it generates its own signal whilst a hall effect

needs 3 wires (signal, live and earth).

Hall effect sensor to the left and inductive type sensor on the right.



According to an article by advance auto parts. "The engine speed sensor actually measures the rotational speed of the crankshaft itself in RPMs. It's a Hall effect sensor, with a serrated disk and magnetic coil; as the crank spins, a current and magnetic field are set up around the coil, and the disk disrupts the field. These disruptions serve as a "count" of RPMs" (Renshaw, 2018)

To find out what the load is an ECU will utilise many sensors to figure out the engine load. Sensors such as the throttle position sensor, maf or map sensors. However There is no single sensor which determines the load of the engine and which sensors which are prioritised vary constantly depending on what is required of the vehicle. For this reason each phase of the engine shall be discussed to better understand how injection on time is achieved below.

Ignition on, engine off

During this phase not many components are in use. to talk about this, data from the motronic engine test session will be used.

Pin Number	What it does	Engine off (V)	Ignition on (V)
36	Control circuit for supply to auxiliaries and ECU	12.06	0.3
18	Permanent live (memory)	12.38	12.01

Apart from pin 36 and pin 18 no other pins that we tested show any voltage. This is to be expected as nothing is in use except for auxiliary electronics such stereo, lights etc. this is why pin 36 and pin 18 shows approximately battery voltage. Also pin 18 which is permanent live has a lower voltage supply then the control circuit. This is due to the permanent live powering some of the components such as the memory. Inside the car somewhere the vehicle will have some sort of memory device which will need a permanent live for the data to be stored. If the memory were to lose power then any data such as fault codes will be lost.

In reference to injection on-time It is expected also that during this phase the fuel pump will draw power from the permanent live as it needs to prime in order for fuel pressure to be available immediately within the fuelling system. It does this so that soon as the engine is cranked fuel will pressure will already be there ready for the cranking phase.

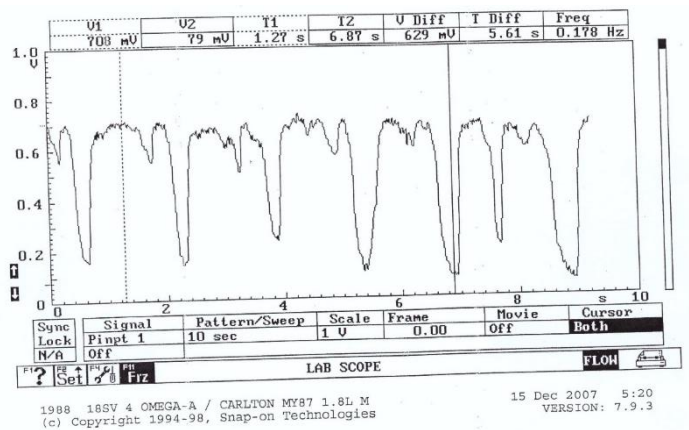
Engine Warm up phase and idle speed

In the case of the motronic system during the lower temperatures during engine warm up phase the engine will be in an open loop configuration. This basically means the lambda sensor is off and the engine will determine the amount of fuel that should be injected into the engine each cycle from the MAP or MAF sensor only. The amount of time the injectors will be open for will be higher than when the car is at operating temperature as the more fuel that's burnt the quicker the engine will warm up. As the temperature increases the ECU will decrease the amount of fuel injected and increase the amount of air to create a more lean air/fuel mixture. In the case of the motronic engine we saw that at 20C the injector bank is open for 3.5 milliseconds whilst between 50C and operating temperature (80C) the injector bank is open for 3 milliseconds.

As mentioned more air is let in through to make a leaner mixture the engine does this by opening the idle air control valve to allow more air. From 45% at 20C to 48% at 80C. The Idle air control valve or IAC valve is a valve that allows air to bypass the main throttle butterfly and allow the exact right amount of air through for idle. It will be dynamically adjusted by the ECU constantly to achieve the best idle speed for the situation.

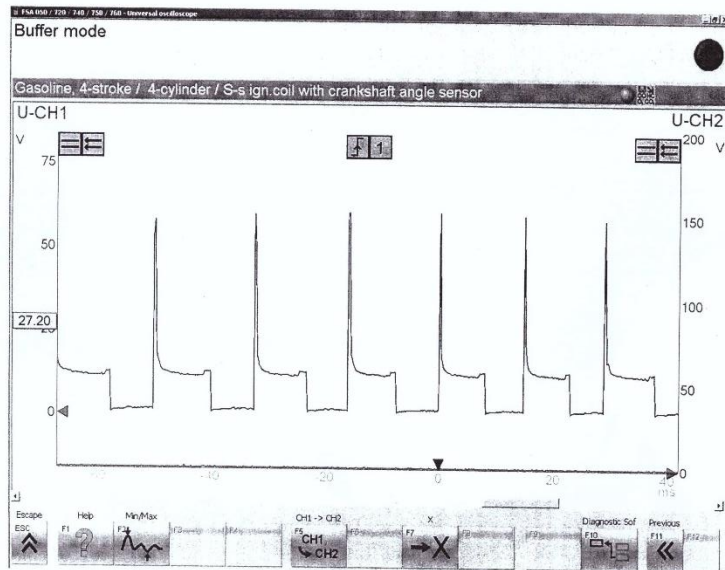
Once the engine reaches a certain temperature the lambda sensor will now be at its own operating temperature in our case approximately 30°C (table below). Once the lambda sensor is on, through the use of an oscilloscope (diagram below), we can see the lambda sensor will begin switching. From this data the ECU can determine if the exhaust gases are too lean or too rich. When the exhaust gas becomes too lean more fuel will be injected and when the gases are rich the fuelling will be reduced. This is an example of a closed loop system and is the first example of an active feedback loop.

Temperature (C°)	Injector Bank ms (pin 16)	Rotary Idle % (pin 4)	Tank Valve (pin 5)	Lambda (pin 28)
20	3.5	45	off	off
30	3.2	46	off	on
40	2.9	44	off	on
50	2.9	45	on	on
60	3.1	47	on	on
70	2.9	46	on	on
80	3.1	48	on	on

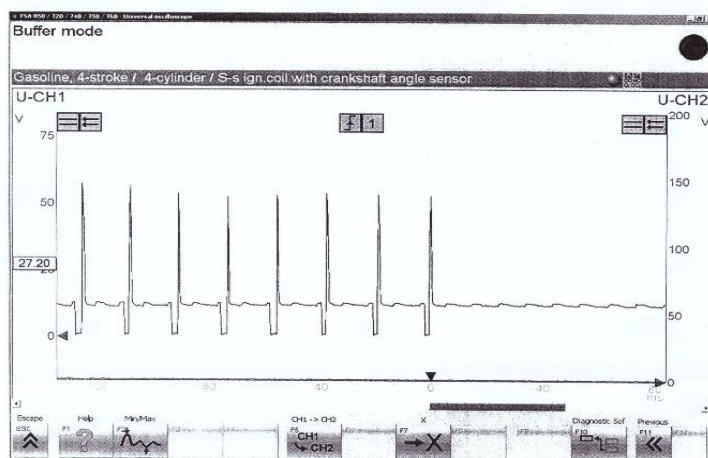


Lambda sensor pin 28

Acceleration And Deceleration



Injector pin 16
during
Acceleration



Injector pin 16
during
deceleration

During snap acceleration in order for the engine to accelerate more fuel is needed during each 4 stroke cycle of the engine. In order to do this the ECU will tell the injectors to increase the injection duration or pulse width to make a more rich air/fuel mixture to provide the energy needed for acceleration. The ECU can do this up to a point when Instead the ECU will decrease the time between each injection so that the injectors on average are open for longer over the duration of many cycles. It does this because in order for the fuel to more efficiently mix with the air, the fuel must arrive by being injected at high pressure. This high pressure is what atomises the fuel giving it a greater surface area allowing the combustion process to be as efficient as possible. If the ECU just increased the pulse width the valve would be open much more than it is closed causing the fuel behind the injector to lose pressure which will prohibit the engine from performing as well as possible.

During deceleration (foot off brake, foot off accelerator) the injection time will decrease rapidly by again decreasing the pulse width up to a point where the injectors are no longer injecting any fuel. It will do this up until no fuel is being injected. Once the engine speed starts to drop below a certain threshold the ECU will then begin firing the injectors again to go into idle.

Conclusion

System comparison

test readings compared to manufacturer's specifications

The motronic system shall be compared first and from the data gathered it has become evident there are more faults in the Motronic system than in the non motronic system.

Coolant Temp

Temperature°C	Manufacturer (ohms)	Tested (ohms)

0	4800 to 6600	
20	2200 to 2800	1587
40	1000 to 1400	717
80	270 to 360	256

It has been observed that the data from the coolant temperature doesn't match that of the manufacturers specification. This is possibly a fault from the sensor and it is recommended for the unit to be replaced.

TPS sensor

Throttle Position	Manufacturer	Tested
Throttle Closed	1900 to 2000	2107
Throttle Open	1000 to 2000	2702

it is also evident the data collected from the TPS or throttle position sensor is incorrect and this is because the sensor fitted isn't an original sensor that was fitted to the engine so faulty readings are expected.

HT Leads

High Tension leads	Resistance (ohms)
1	19600
2	18440
3	14950
4	21300
King lead	Faulty reading

it has been observed that both the 4th cylinder and king lead are faulty. The king lead is definitely faulty as an infinite amount of resistance was found. this means that there isn't a complete circuit inside the lead to resist voltage sent out by the ohmmeter. Also lead 4 appears to be faulty as it's the shortest lead. This means it should have the least resistance. similar to how the other HT leads increase in resistance as the length of the cable increases.

On the non - motronic system there is only one fault detectable from the data we collected which again can be found on the HT leads on lead 4.

HT Leads

High tension leads	Resistance (ohms)
1	8500
2	8720
3	7270

4	5420
King lead	5515

As we can see although the 4th lead is the second shortest cable the resistance value falls below that of the smallest cable, the king lead. This indicates this lead could be faulty.

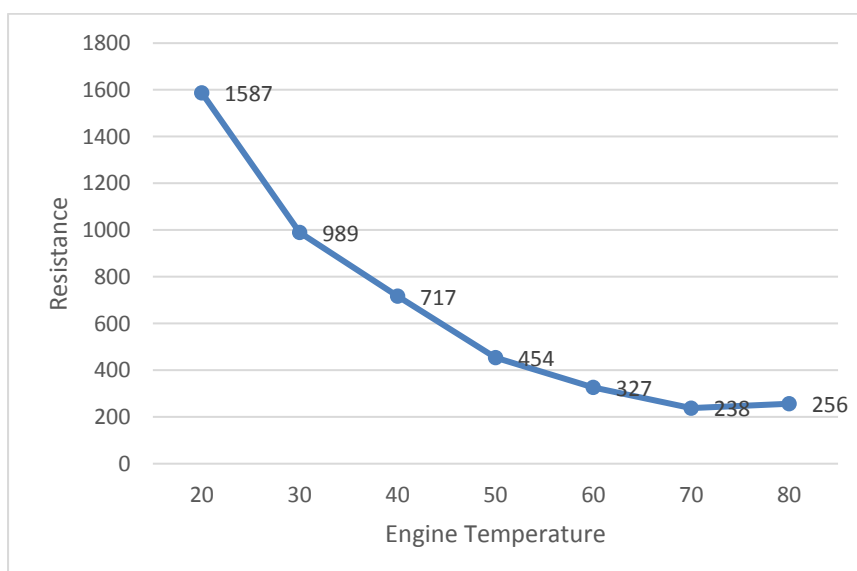
NTC2 Graph Comparison

A NTC or negative temperature coefficient sensor is a sensor that is used to determine the temperature of either the engine oil or coolant temperature. From this the ECU can determine the temperature in the engine. A NTC sensor does this by having a voltage supplied to it and as the temperature increases the resistance decreases allowing more voltage to pass through thus determining the engine temperature. The ECU can then determine the optimum amount of fuelling as a warm engine will require less fuel than a cold one as mentioned before.

data taken from the LE3 Motronic system

Temperature°C	NTC2 Res (ohms) (pin 45)
20	1587
30	989
40	717
50	454
60	327
70	238
80	256

Graph to demonstrate NTC2 resistance values at different temperatures for the **motronic** system.

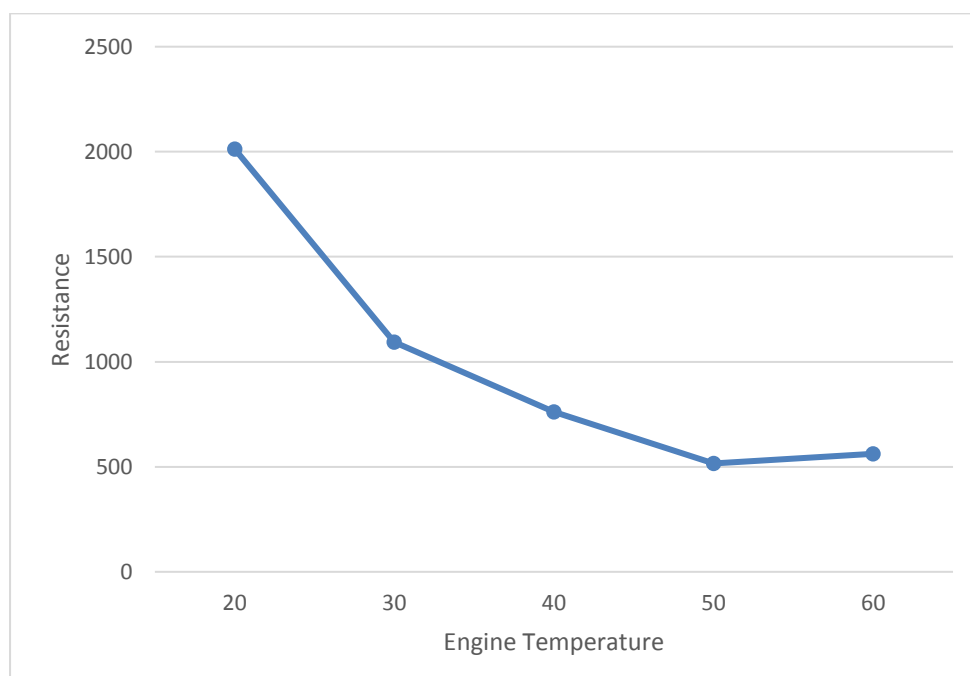


From this graph we can see a negative correlation between resistance and engine temperature. This is to be expected and the only real piece of data that wouldn't follow the expected trend is that at 80 °C the engine appears to get colder and this is from the fan being turned on.

data taken from the LE3 non - Motronic system.

Temperature °C	Resistance (ohms) pin 8
20	2013
30	1093
40	761
50	516
60	562

Graph to demonstrate NTC2 resistance values at different temperatures for the **non - motronic** system.



Again very similar to the Motronic system in that the sensor follows a negative correlation. Less data points were obtained however due to the lower operating temperature of 60°C as apposed to the motronic 80 °C operating temperature. Even so it is still visible at 60 °C of the fan being activated causing the coolant temperature to decrease. This in turn increases the resistance and sending a lower signal voltage.

Modifications

Direct injection

There are many ways that each engine can be improved and one of the most important improvement of all for both engines would be to employ a direct injection system. Currently both systems feature a system where fuel is injected just before the intake valves, as part of the induction assembly. This isn't ideal as for fuel to burn efficiently the fuel must be atomised where it is

separated into small particles to increase the overall surface area of the fuel. If atomisation doesn't occur then the fuel won't mix with the air correctly, will be clumped together and form droplets. These droplets don't burn well meaning more unburnt fuel will leave the combustion chamber decreasing fuel efficiency as well as decreasing the force developed by the piston each cycle. In order for the fuel to be atomised it must be injected at high pressure. By giving it some distance to travel you are increasing the chance that these droplets due will form therefore mounting the injector within the cylinder will improve this system.

Sequential injection

Currently both systems use continuous injection. sequential injection improves upon continuous injection in the same way direct is better than indirect injection. Better atomisation of fuel. In a continuous injection system fuel is injected precisely twice every 360 degrees of camshaft rotation. This means that fuel will have a certain amount of time to wait before being sucked into the combustion chamber. This causes the fuel to lose pressure thus causing the fuel to no longer be atomised. Employing a sequential injection system means the fuel will be injected once every 180 degrees or once in line with the firing order. This means the fuel will burn much more efficiently allowing for more power and better fuel economy.

Knock sensor

Nearly every if not all modern engines are fitted with knock sensors however both engines tested don't feature a knock sensor. The introduction of the knock sensor would be a massive improvement for the engine as it adds a system where the ECU can dynamically adjust ignition timing depending on the operating conditions of the engine. Similar to the closed loop system incorporated by the lambda sensor the introduction of a knock sensor would mean both fuelling and ignition timing will be part of an active feedback loop. According to ASE certifications "This is because its function is to sense vibrations caused by engine knock or detonation. The PCM uses this signal to alter the ignition timing and prevent detonation. It will compare this information with its preset tables to identify a valid knock or ping. If a ping is sensed, it will *retard* the ignition timing to protect the engine from this damaging pre-ignition."

A knock sensor is used to detect pinking or pre ignition. Pre ignition is caused by the fuel being ignited at the wrong time which will cause lots of vibration within the engine as the combustion process is taking place while the piston is travelling up the cylinder. to counteract this the ECU will retard its ignition timing to counteract the pre ignition detected by the knock sensor thus improving the efficiency of the engine. The way a knock sensor detects vibration is through the use of a piezoelectric crystal. Piezoelectric crystals output a voltage when vibration occurs which when interpreted by the ECU provide a great adaptive control measure which brings me onto the next improvement.

Piezoelectric fuel injectors

Most passenger vehicles still use solenoid injectors as they are the most tried and tested method of achieving high pressure fuel delivery. However as more strict emission rules and regulations surface the push for higher injection pressures has caused manufactures to experiment with the use of piezoelectric injectors. The main advantage of piezoelectric injectors is that they have an increased amount of max possible switches per cycle. According to sharpautos (no author, 2013) typically a

solenoid injector can only have a maximum of 5 injection pulses per cycle whilst the later can perform 7 injection pulses per cycle. It is for this reason I have chosen to include this as an improvement.

References

No author, 2019, how a car works, How a Fuel injection system works, accessed 09/06/2019

<https://www.howacarworks.com/basics/how-a-fuel-injection-system-works>

JD Jaukkonen, 2013, Crankshift, What is an ignition system, accessed 09/05/2019

<http://www.crankshift.com/ignition-system/>

Jerry Renshaw, 2018, Advance Auto Parts, What are sensors and how do they work, Accessed 09/05/2019

<https://shop.advanceautoparts.com/r/advice/cars-101/car-sensors-what-are-car-sensors-and-how-do-they-work>

No author (username unitedbmwginnett), 2018, BMW of Gwinnet place, why warming up your car is important, accessed 09/05/2019

<https://www.bmwofgwinnetplace.com/blogdetail/2018/3/7/why-warming-up-your-car-is-important/>

no author, no date, Ditetex, how to chose an automotive oscilloscope, accessed 09/05/2019

<http://autoditex.com/page/how-to-choose-an-automotive-oscilloscope-61-1.html>

no author, no date, CSE Certifications, knock sensors, accessed 09/05/2019

<https://www.freeasestudyguides.com/knock-sensor-symptoms.html>

