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Sensors & Controls

Everything you wanted to know about gas engine ignition technology but were too afraid to ask.

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1. Introducing Electronic Ignition



Before electronic ignition systems were developed ignition control was undertaken using mechanical distributors. The distributor directed the output from a single high-tension (HT) ignition coil to the relevant spark plug.

Control over the timing of ignition was done through a cam operated contact breaker, centrifugal weights, springs and cams, with load mapping achieved using a vacuum advance unit.

Distributor based systems are prone to mechanical wear, insulation break down and contact failure. To keep the ignition timing correct these systems required a periodic tune-up to keep them working correctly.

Modern electronic ignition systems do not require a distributor. A single small HT coil is used for each spark plug and the igniter operates each coil separately in the correct sequence.

Engine position information is provided by position sensors and timing disks that are accurately attached to one or two of the main engine shafts, such as the camshaft. The firing sequence and variable spark advance is computed accurately from the pattern of teeth or pegs on the timing disk. If load mapping is required, this can be achieved by adding a manifold pressure sensor or a throttle angle sensor to the system. A variety of extra features are available on such systems, which can be accessed and adjusted by a computer.

Electronic Ignition systems provide extremely accurate spark timings, leading to improved combustion and emissions control. As there is no mechanical contact there is no wear therefore the accuracy is maintained. These reasons are why electronic ignition is used as standard throughout the industry.



2. Inductive Ignition



Inductive ignition systems have existed since 1908, developed by Charles Kettering.

Improved over the years, the significant recent development has been the introduction of Insulated Gate Bipolar Transistors (IGBT); these have allowed the design of extremely accurate, high spark energy inductive ignition systems.

A single operation is carried out by a transistor turning on the ignition coils primary winding current. This charging stores energy in the coils magnetic circuit. Current is then switched off. As the magnetic field begins to collapse the coil tries to resist the drop in current causing the voltage in the secondary winding to rise rapidly, this high voltage breaks down the air/fuel mixture in the spark gap allowing a spark to pass, causing ignition of the air/fuel mixture.

The advantage of inductive ignition systems is that inductive coils are generally more efficient than capacitive discharge coils as they provide longer spark duration that can ensure complete combustion, especially on lean burn and turbo charged engines. The longer spark duration is because inductive coils only provide enough energy to cross the spark gap; the remaining energy from the ignition coil is used to maintain the spark. Capacitive discharge coils release almost all of their energy instantaneously, considerably reducing the amount of energy available to maintain the spark.

With inductive ignition systems more energy can be delivered to the secondary winding of the coil than in a capacitive ignition system. With the same power supply current draw, up to five times more energy can be delivered to the secondary winding of an inductive coil than to a capacitive coil. Typically a capacitive discharge system will deliver a maximum of 10 millijoules of energy compared to an inductive ignition system delivering more like 50 millijoules of energy and potentially in excess of 100 millijoules. This difference in supplied energies will mean an inductive system can provide spark duration of 2000 microseconds or more in a single spark, compared to 600 microseconds for a capacitive system.

The time taken to charge the ignition coil of inductive ignition systems is called the Dwell, which can be increased or decreased for differing engine applications. For longer spark duration, improving combustion of lean mixtures or engines with large cylinders, the dwell time is increased, putting more energy into the primary coil. Dwell time is decreased when there is enough spark energy to combust the mixture, this decrease will reduce spark plug wear, increasing spark plug life.

The high energy and long, programmable spark durations are a considerable advantage since they provide better ignition of lean or non-homogenous air/fuel mixtures. In many cases engines that are unable to meet emission standards with capacitive discharge systems can be brought into compliance with electronic inductive ignition systems.



3. Capacitor Discharge Ignition (CDI)



Electronic capacitor discharge ignition (CDI) systems have been common on large industrial engines because the technology has been in use since the 1960's.

An advantage of the capacitor discharge ignition system is that the energy storage and the voltage step up functions are accomplished by separate circuit elements allowing each one to be optimised for its job.

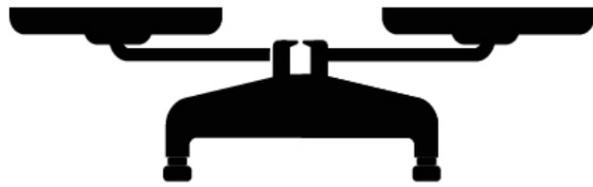
Capacitive discharge ignition systems work by storing energy in an external capacitor, which is then discharged into the ignition coil primary winding when required. This rate of discharge is much higher than that found in inductive systems, and causes a corresponding increase in the rate of voltage rise in the secondary coil winding. This faster voltage rise in the secondary winding creates a spark that can allow combustion in an engine that has excess oil or an over rich fuel air mixture in the combustion chamber. The high initial spark voltage avoids leakage across the spark plug insulator and electrodes caused by fouling, but leaves much less energy available for a sufficiently long spark duration; this may not be sufficient for complete combustion in a lean burn turbocharged engine resulting in misfiring and high exhaust emissions.

The high voltage power supply required for a capacitor discharge system can be a disadvantage, as this supply provides the power for all ignition firings and is liable to failure.

Ignition in lean fuel mixtures by capacitor discharge systems can sometimes only be accomplished by the use of multi-spark ignition, where the ignition system duplicates the prolonged spark of inductive spark systems by sparking a number of times during the cycle. This adds greater stress onto the high-tension leads and can cause considerable spark plug wear and possible failure.



4. CDI vs Inductive Ignition Systems

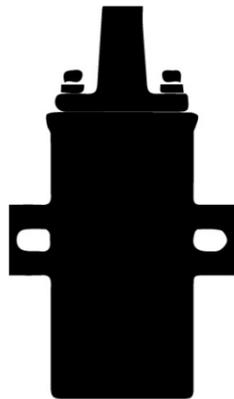


The term 'CDI' is often, incorrectly, used to describe electronic ignition systems. Most modern ignition systems are actually Inductive Ignition systems for good reason, especially when using lean burn fuel mixtures. Inductive ignition systems can provide prolonged spark duration; resulting in more reliable and a cleaner burn in modern lean burn engines.

Capacitive discharge systems may have advantage in older 4-stroke engines, an engine running beyond its service life, or a cheap 2-stroke engine. These engines will be running an oil rich / fuel rich mixture, which may cause fouling of the spark plug gap. The higher initial discharge of a CDI system may be able to 'burn' off these deposits better than a comparative inductive ignition system.



5. Ignition Coils



Ignition coils are used to step up the voltage of the engines primary circuit of the 12 - 24 volt range to 20,000 to 40,000 volt range. The increased voltage is required for the current to jump the spark gap in spark plugs, producing the ignition of the air/fuel mixture. The increase of the voltage is matched by a proportionate decrease in current.

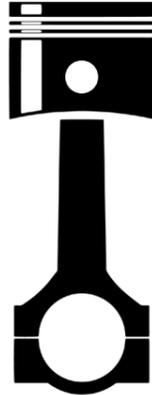
At its most basic an ignition coil is made up of a primary winding, a secondary winding and a laminated core.

The secondary winding is wound with considerably more turns than the primary winding. The resulting difference in number of turns is proportional to the step up in voltage. An inductive ignition system will charge the primary winding with generally 12 volts; when the current is removed a large EMF is generated in the secondary winding of up to 40,000 Volts, more than enough to jump across a spark gap.

In practice, ignition coils will have some extra components but are in operation practically the same.



6. 4-Stroke Engine Basic Operation



Before we continue any further with electronic ignition systems, it would be worth a quick revision of the basic operation of the four-stroke engine commonly in use today.

The operation is as follows -

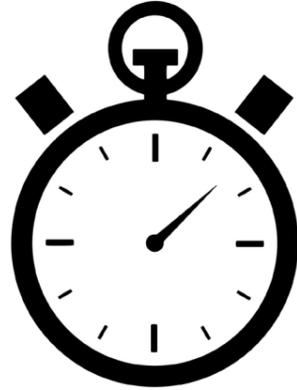
1. Intake Stroke - The inlet valve is opened and the fuel/air mixture is drawn in as the piston travels down.
2. Compression Stroke - The inlet valve is closed and the piston travels back up the cylinder compressing the fuel/air mixture. Just before the piston reaches the top of its compression stroke a spark plug emits a spark to combust the fuel/air mixture. The number of degrees before the top of its stroke is the ignition advance. When the piston is at the top of its travel, it is at top dead centre (TDC).
3. Combustion Stroke - The piston is now forced down by the pressure wave of the combustion of the fuel air mixture. The engines power is derived from this stroke.
4. Exhaust Stroke - The exhaust valve is opened and the piston travels back up expelling the exhaust gases through the exhaust valve. At the top of this stroke the exhaust valve is closed. This process is then repeated.

The above is the cycle of operation of one cylinder of a 4-stroke engine. Generally engines have 2 or more cylinders acting in concert with each other to produce the engine power.

It is interesting to note that one complete engine cycle takes two revolutions but that individual valves and spark plugs only operate once in this time. Hence their timing needs to be taken from a half engine speed signal, which is the camshaft speed.



7. Ignition Timing



All ignition systems need to know at what position the engine is in its cycle to be able to perform accurate spark timing calculations. This information is generally provided by a timing disc attached either to the crankshaft (engine speed) or camshaft (half engine speed) and an electronic sensor mounted close by. Timing discs either have teeth or magnets arrayed around the circumference, which the electronic sensor can see. To enable the igniter to know when the first cylinder is at top dead centre, the timing disc either has an additional tooth or magnet or one missing.

If the timing disc is attached to the crankshaft, there is a need in some engine configurations to have a sensor on the camshaft so that the igniter knows which ½ of the four-stroke cycle the engine is in.



8. Wasted & Non-Wasted Spark Ignition



A non-wasted spark system only provides a spark on the compression cycle of each cylinder of a four-stroke engine. Each cylinder requires an ignition coil, and the timing disc for the ignition system needs to rotate at half engine speed (cam shaft speed).

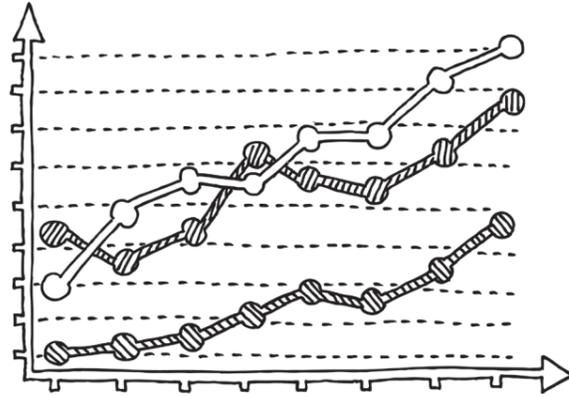
A wasted spark system produces a spark for the compression and exhaust stroke of each cylinder in a four-stroke engine. The reason this system is called wasted spark is that only the spark on the compression cycle is useful, the spark on the exhaust stroke is wasted as there is no combustible mixture in the cylinder.

Depending on the engine configuration it may be possible to use one dual-output ignition coil to operate two cylinders in wasted spark mode. A benefit of wasted spark systems is that the timing disc is attached to the crankshaft, which is generally more accessible.

Wasted spark ignition systems are commonly found in motorcycles but are not recommended for use in industrial or alternative fuelled applications.



9. Ignition Advance & Speed Mapping



Ignition advance is the number of degrees before top-dead-centre (TDC) that a spark occurs. The reason for ignition advance is that the spark to combust the fuel/air mixture needs to be timed so that the point of peak combustion pressure is when the piston is just beyond TDC. If the point of peak combustion pressure is too early and before TDC the pressure wave will slow down the speed of the piston travelling up towards it, and may cause detonation (knocking) which is very damaging to the engine. If the point of peak combustion pressure is too late, the pressure wave will chase the piston as it travels back down the cylinder in the combustion stroke and most of the energy will be lost.

As the speed of the engine rises, the ignition advance angle needs to increase. This is because the time to combust an unchanging air/fuel mixture is approximately constant. If the ignition advance angle were kept the same, the point of peak combustion pressure would move further and further into the combustion stroke losing more and more power. Therefore the ignition advance needs to be increased to bring the point of peak combustion to just beyond TDC.

Basic mapping varies the amount of ignition advance in relation to engine speed, this is called speed mapping.

The optimum amount of ignition advance varies from engine to engine and through different fuel types, timing maps of different engines using different fuels will be different. It is not possible to calculate the best map for your engine; you need to test the engine on appropriate test equipment to generate the engine maps.

Emissions can be controlled via the use of ignition advance in addition to controlling the air/fuel mixture. Large ignition advances will promote the formation of oxides in the exhaust gases and increase engine power (to an extent), but will also decrease the engines fuel consumption.

If an engine is set up for maximum power the resultant carbon monoxide levels will be too high to meet current emissions legislation, so it is common practice to adjust the ignition timing at different load levels to suit. Generally the ignition timing is retarded somewhat to reduce CO and NOX emissions.

A trade-off between exhaust emissions, fuel consumption and engine power has to be taken by the application engineer during testing.



10. Load Map Benefits



The amount of time taken for a fuel/air mixture to combust mainly depends on the richness of the fuel mixture. When the engine is under low load with a lean air/fuel mixture the degree of ignition advance will need to be large to allow for the slow combustion of this mixture. Conversely when the engine is under load a richer air/fuel mixture is used to provide more power. This richer mixture has a faster combustion time so the degree of ignition advance needs to be reduced to keep the peak combustion pressure just beyond top dead centre.

To achieve this variation of ignition advance in modern engines load mapping is used. Information is sent from either a throttle sensor or a manifold pressure sensor to indicate how much load the engine is under. Therefore, load mapping varies the amount of ignition advance in relation to engine speed and load.

The precision that load mapping provides allows the engine to operate at its most efficient and clean throughout the range of load conditions.



11. Advanced Spark Diagnostics



Conditions such as faulty/worn spark plugs, leads and coils can be detected through a Laptop based interface with the ignition control modules.

This can also indicate internal cylinder faults or mismatch between cylinder performance highlighting problems such as burnt valves, localised air leaks and poor combustion.

With Advanced Spark Diagnostics, you can benefit from this technology if you are remote monitoring your engine. You can set maximum and minimum spark voltage and duration into the software, so when the measurements fall outside of the parameters, an error code can be transmitted to your remote monitoring equipment. This enables you to actively manage your engine service intervals, potentially reducing your service costs.

Figure 1 shows a spark trace from a correctly operating cylinder, the first part of the line (a) shows the start of the spark line. This is the point after the initial plug voltage has bridged the gap.

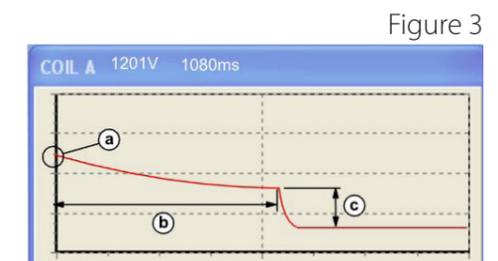
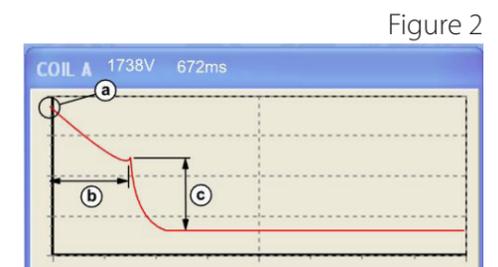
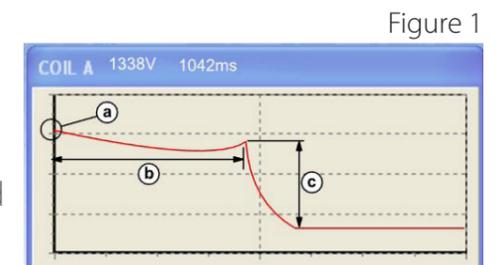
The length of line is the duration of the spark (b), known as burn time or spark duration. If the line is short (Figure 2) this shows insufficient spark energy exists to maintain the desired burn time. This can be caused by one of the following:

- Loss of spark energy through faulty plug lead (high resistance)
- Fouled/eroded spark plug
- Excessive boost levels
- Excessively lean/rich mixtures
- Insufficient dwell (coil on time)

If the line is too long (Figure 3) this can be caused by the following:

- Faulty spark plug/lead (short circuit)
- Lack of compression (burnt valves, holed pistons etc)
- Excessive dwell

The height of the spark line (c) is also monitored as an indication of healthy cylinder operation. A low spark line indicates a similar faults list for the long spark line above, this is due to the voltage required to maintain the spark across the gap being reduced, this may be shown as a combination of a low and long spark line.



Notes

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