

# Ignition Coils

## Application Note

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## Requirements of an Ignition System

In a petrol engine, the combustion of an air/fuel mixture is initiated by an electrical spark. Accurate and reliable ignition is essential for optimum performance and minimal emission. Misfires reduce the engine's power output and can lead to damage in the exhaust ports, exhaust pipes and catalytic converter.

The spark, needed to ignite the air/fuel mixture in the combustion chamber, is generated by applying a high voltage to the electrodes of a spark plug. The voltage required to generate a suitable spark depends on the compression ratio of the engine, the quality and ratio of the air/fuel mixture and the spark plug construction.

More than 12kV is usually needed to ignite a mixture. In special cases, a few kV may be sufficient, whilst a highly compressed or lean mixture may require more than 30kV. As a rule of thumb, approximately 25kV should suit most applications.

As soon as the spark is generated, a conductive plasma is established between the electrodes of the spark plug and a reduced voltage of about 100V is all that is needed to maintain the spark. The duration or "burn time" of the spark, and its related energy, depend mainly on air/fuel ratio and the mixture preparation, which in turn is dependent on the inlet design, the air flow velocity and the type of fuel.

As in all systems, not all of the available electrical energy is passed into the spark/plasma - a significant amount is lost as heat.

It is difficult to measure the available energy in the spark/plasma. No commonly accepted industry standard exists, which makes the comparison of energy data almost impossible.

The maximum electrical energy available at the beginning of the ignition process can be easily measured, but this value can vary from approximately 25mJ to several hundred mJ and means very little in terms of the overall performance of the ignition coil. Comparing this maximum available energy with the energy required to ignite a mixture (1mJ or even less) indicates how much care must be taken in interpreting energy levels. McLaren Electronics has defined a measurement method which allows comparison between the different coils that we make, but we do not imply that this is the only possible method of measurement.

## Types of Ignition System

Petrol (and alcohol) engines mainly use one of two ignition types:

- Capacitor Discharge Ignition (CDI)
- Transistorised Ignition (TSI)

Both ignition systems have advantages and disadvantages, which should be carefully considered in each application. Both technologies were introduced many years ago, but continuous refinement has ensured that they are still suitable for the most sophisticated road and motorsport engines.

## Capacitor Discharge Ignition

In a CDI system, the energy for the spark is generated by an electronic circuit which stores energy at several hundred volts in a capacitor. At the moment of ignition, this energy is transferred from the capacitor to the ignition coil. Because the combustion chamber is under pressure at the moment of ignition, the coil has to transform the capacitor voltage up to several thousand volts in order to generate a spark. This requires a coil with a winding ratio of approximately 500:1 and good magnetic coupling between the primary and secondary windings. The inductance of the coil can be low as the CDI coil does not store energy.

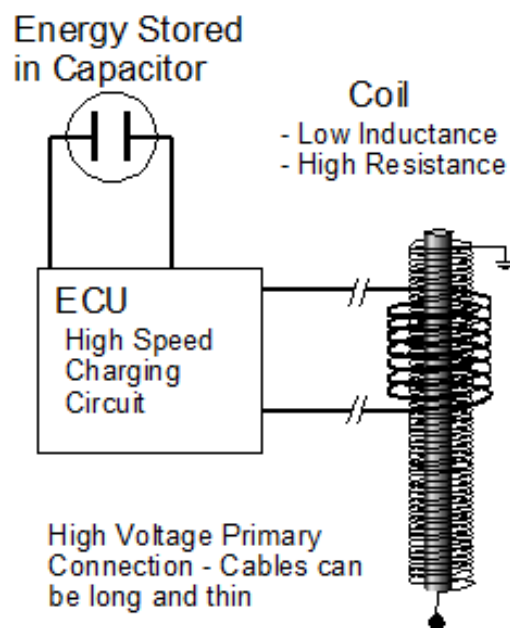
Most CDI systems charge a capacitor up to approximately 400V, resulting in a stored energy of approximately 50mJ. This historical value of 400V is based on the typical voltage capability of the storage capacitors available when CDI systems were first introduced. The TAG CDI system operates at up to 600V, which reduces the size of the capacitor required to achieve the same stored energy ( $\text{Energy} = \frac{1}{2} CV^2$ ). This higher operating voltage also allows coils to be smaller, as the step up ratio can be lower.

A bulky and heavy electronic package is required to charge the necessary 50mJ into the storage capacitor in the short time between successive ignitions. However, McLaren Electronics CDI system makes use of an advanced, fast, switch-mode power supply to generate 600V in the very short time of 500µs. As a result, we are able to integrate CDI

electronics into the same small space envelope that is used for TSI. The transfer of energy from the storage capacitor to the CDI transformer coil happens very quickly - typically 30 to 50A flow between the capacitor and the coil. Because of the high charging voltage of at least 400V, this current can be achieved with thin inter-connection wires without any major performance loss.

The voltage generated and fed to the spark plug (the secondary voltage) follows this fast energy transfer. This results in a very rapid voltage increase (approx 10kV/ $\mu$ s) making CDI insensitive to shunt resistance (e.g. wet spark plugs).

Furthermore, the interaction of the magnetic field of the CDI coil with the surrounding engine metal (the Eddy Current Effect) is also limited as the secondary voltage generation does not (primarily) depend on the flux change in the magnetic field. However, this fast energy transfer limits the burn time to approximately 50-80 $\mu$ s. With CDI, burn time is very difficult to extend; neither an increase of energy stored in the capacitor nor higher inductance coils will extend the burn time by any significant margin. To overcome these limitations, experimental systems have been developed in which an initial "fast" spark is generated by a CDI and the burn time is extended by feeding energy to the plasma from a separate voltage source. Such a system allows very long burn time combined with the advantage of insensitivity to shunt resistance. However, the resulting system is complex and is not commercially available.



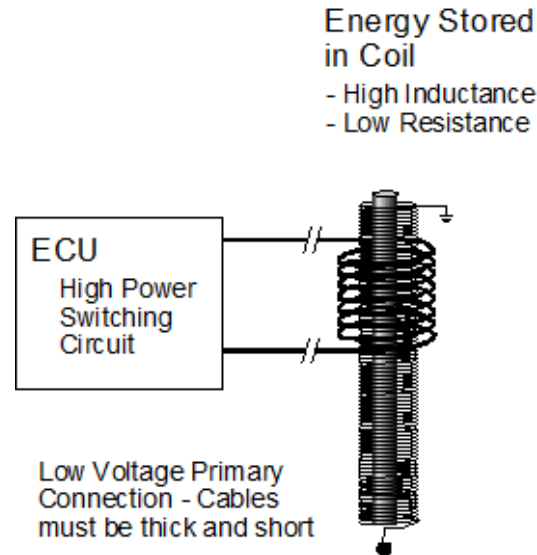
### Transistorised Ignition

The working principle of a TSI system is very simple. Voltage is connected to an ignition coil which results in a current flow and magnetic energy storage in the coil. When the current is switched off, the collapse of the magnetic field in the primary coil induces a voltage in the secondary coil. The ratio of the number of turns in the primary and secondary coils means that the output voltage is much higher than the input voltage. The resulting spark has an extended burn time (approximately 500 $\mu$ s to 1ms) as induction keeps the current flowing for as long as possible.

TSI, in its original form, was used long before CDI. Initially it used a mechanical contact breaker to switch off the current. This mechanical switch placed a limit on the voltage generation within the coil as the current had to be limited. In addition an ignition condenser (capacitor) had to be used to slow down the switch off process to prevent unacceptably short life span of the contact breaker. The seemingly simple task of replacing the contact breaker with a transistor was a major technical challenge. The transistor had to pass 6 to 8A but it also had to withstand approximately 400V. Fifteen years ago, this was such a major challenge for the semiconductor industry that only a few companies could reliably manufacture these parts, and then at a very high cost. Today, transistors are readily available which will withstand 25A at 600Volts and more.

Ignoring the protection and diagnostic circuitry of transistorised ignition (which can be implemented on a single silicon chip for mass market applications) the circuitry is a single transistor. This means the electronic design is simple, but the design of the coil is much more complex. The maximum energy available to the spark (ignoring losses) is the energy that

can be stored in the coil at the moment of ignition. This energy equals  $\frac{1}{2} LI^2$  (where "L" is the inductance of the coil and "I" is the current flowing through it). Energy can be increased by increasing the inductance of the coil or by increasing the current or both. Inductance depends on the magnetic circuit and the number of turns of the coil winding. The current is limited by the resistance of the coil and the voltage available. Increasing the number of turns in the coil has two effects: it increases electrical resistance reducing the current and it increases inductance. A high inductance coil is very slow to charge which limits the number of sparks per minute. This is the reason that CDI was developed for high speed engines.



### Comparison of CDI and TSI

In a CDI system, the coil only acts as a voltage transformer - energy is stored in a capacitor in the drive electronics. This has the following implications:

- Coil inductance can be low
- Switching rate is very high
- Primary voltage is high so connecting cables can be thinner and longer
- Fast increase in secondary voltage and insensitivity to shunt resistance leads to a very precise and repetitive combustion
- Magnetic circuit design is not critical
- Burn time is short
- EMI is limited by low inductance and short burn time

Engines that do not need a long burn time, will usually show their best and most consistent power output when using a CDI system.

In a TSI system, the coil stores energy as well as acting as a voltage transformer. This has the following implications:

- Coil inductance must be relatively high
- Switching rate is limited by time to charge the inductance.
- Primary voltage is low and current is high so connecting cables must be thick and short
- Magnetic circuit design is critical and can be affected by location in the engine
- Burn time is long
- EMI is severe in high performance systems

The transient response of a racing engine may benefit from the long burn times available with TSI. Whilst it should always be possible to generate a good mixture at full engine load (characterised by high air flow and long injection pulses), this may not always be the case at part load. Part load is often considered to be of little interest to a racing engine, but valuable time is often lost if a driver cannot effectively change gears or stabilise the car with the throttle; both of which are heavily dependent on crisp engine response.

After thousands of hours of designing effective coils for both CDI and TSI systems, McLaren Electronics can offer similar sized coils for either application.

High voltage and insensitivity to shunt resistance are most easily achieved using CDI technology. If your engine does not rely on extended burn time, a CDI system will allow smaller coils, easier installation with potential longer lead length and faster voltage increase. Where the ECU demands the use of TSI, some of the potential gain of a CDI system can be recovered by fast, low inductance coils, running at higher current levels of approximately 25A (compared to mass market coils which usually operate at about 10A).

### **Electro-Magnetic Compatibility (EMC)**

In automotive technology, the ignition system is the major source of electro-magnetic compatibility problems. Any change in electrical charge causes radiation and the electrical spark, required for ignition, generates electro-magnetic noise. An ignition system, particularly one for fast burn racing engines, has very rapidly changing electrical charges so the radiation is high. Radiation suppression elements can be integrated into a coil, but they dissipate energy and reduce the effectiveness of the ignition system. To minimise the effects of radiated noise, care has to be taken in selection of ignition systems and the layout of the electrical wiring.

TSI systems, based on large and heavy ignition coils, common in mass market road car applications, are least demanding in this respect. Mass-market coils are usually high inductance and made for low current operation and normally include suppression resistance. As a result, the current and voltage build up is slow and the resulting electro magnetic radiation is limited. Very high engine speed cannot be achieved with these coils and power output may be below optimum.

CDI coils tend to radiate more energy than these mass market TSI coils as CDI coils are designed to allow very fast voltage increase. However, radiation is limited, as the coil acts as a voltage transformer and radiation only occurs during the short burn time.

The most demanding are the high current, low inductance TSI coils that radiate quite severely and for a relatively long time. They often demand a fully screened electrical wiring system and may require radiation suppression elements.

### **Custom Coil Construction**

McLaren Electronics can design and manufacture coils of all types, with and without integrated radiation suppression. Our design can be optimised to be used with our own ECUs or any third party control unit. We can supply coils for distributor and distributorless ignition systems, for on-plug or chassis installation.

Coils can be supplied with cable protection, using military specification sleeving and strain relief boots, or simply bare, insulated primary wire connections.

Supported by our in-house harness design and manufacture team, coils can also be assembled into a loom ready for installation. Several different types of spark plug or HT cable connections are available. The most common are: fixed connector, spring loaded plunger, spring loaded cap, M4 sawtooth and screw thread.