F E A T U R E

Car Electronic Ignition Systems

The different methods of implementing electronic ignition.

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The following article sets out to explain the theory behind the system that generates the high voltage at your car's spark plugs, a handy thing for the Saturday mechanic to know, because there are very few cars made these days with standard ignition systems. Let's start at the beginning.

Inductance

If you apply a voltage to an inductor, the current doesn't instantaneously rise to a maximum but grows relatively slowly. The actual rate of growth is dependent on the applied voltage and the resistance and inductance of the circuit.

What happens is that the growth of current is resisted by a voltage (called *back EMF*) which is induced in the inductor. Similarly when a steady current is switched off the inductor opposes that change by producing an EMF which tries to maintain the flow of current.

Now EMFs are voltages, so by getting current to flow through a coil and then switching the current off we can generate a voltage. Which if the inductance is large the resistance low and the rate of switch-off quick can be quite a high voltage.

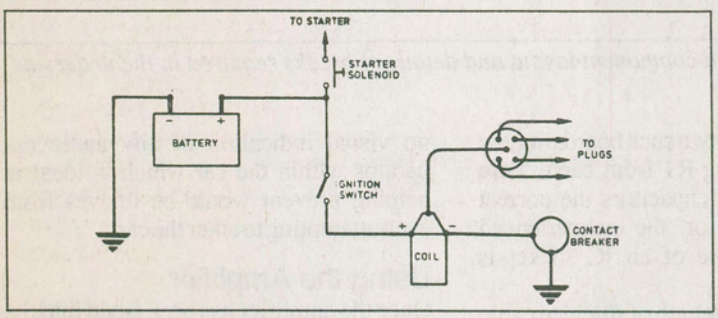


Fig. 1b. Conventional system with an in-circuit current-limiting ballast resistor.

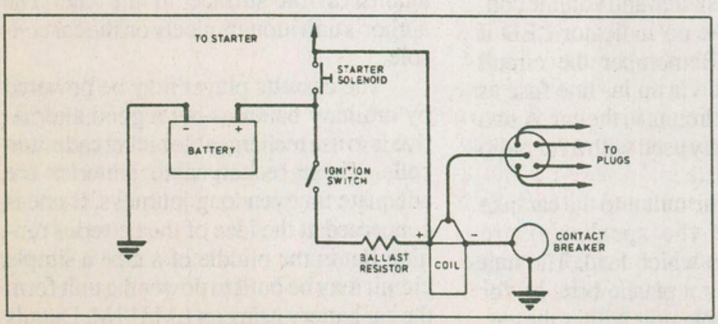


Fig. 1a. A conventional breaker ignition system.

Transformers

This high voltage can be stepped up to say 40kV if we use the transformer action by winding another coil of many turns around the inductor. This is essentially the action of a *coil* in a conventional ignition system.

The current is switched on and off by the contact breaker points in the distributor. The rotor arm and distributor cap are used to direct the high voltage to the correct spark plug. See Fig. 1.

How It Works

Let's just go over the circuit in case we have to find any faults in it. The source of supply is the car battery which, by a heavy duty cable, normally connects to the starter solenoid. The solenoid terminal is used to feed current to the ignition switch, which in turn feeds the coil positive (+) terminal.

Current flows to ground (car chassis) through the coil if the contact breaker points are closed. When the points open a high voltage is induced and there is a capacitor connected across the points to reduce arcing and enhance the effect.

High voltages leave the coil by the thick lead (lots of insulation) which goes to the distributor. Typical coil primary resistance is three ohms and maximum current in the region of four amps.

This system is called the *Kettering* system after Charles Kettering who invented it. It works OK, provided that the spark is made to occur when the respective cylinder is just before-top-dead- center (BTDC). This can usually be adjusted by rotating the distributor in its mounting and is called *timing* the ignition.

Spark Advance Systems

Unfortunately there are some mechanical add-ons to enhance performance (anything mechanical is unfortunate). One of these add-ons is to advance the spark so that it occurs earlier at high engine revolutions.

This is known as the *centrifugal advance system* and is a quaint collection of bob weights and springs buried in the bottom of the distributor. As the revs increase it rotates the cam of the contact breaker points a few degrees in the direction of rotation, and so the spark occurs earlier.

Similarly the base plate is rotated by another system which advances the spark only on light throttle openings. This is an economy device which is activated by a vacuum capsule on the side of the distributor.

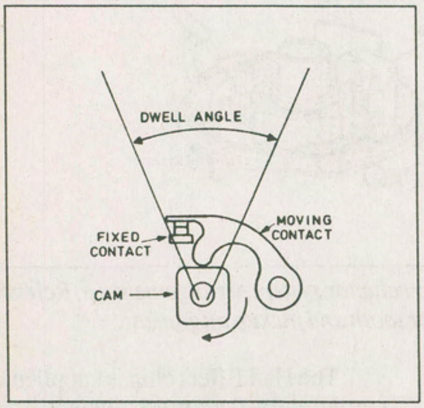


Fig. 2. Dwell angle or dwell time is the period that the contacts are closed.

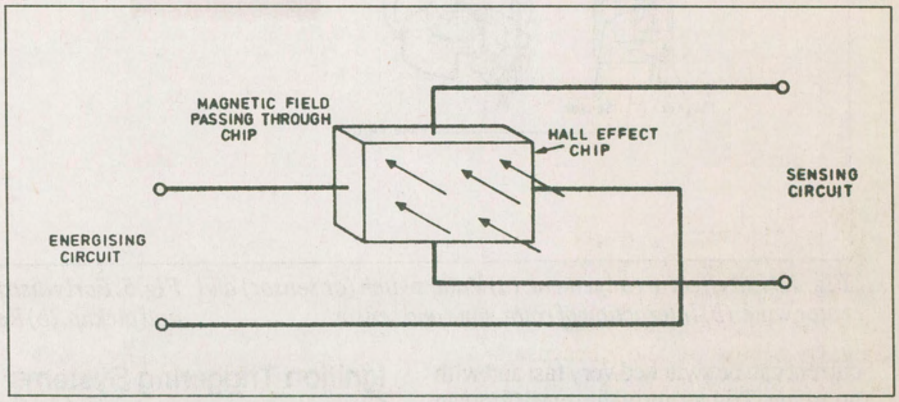


Fig. 3. Basic action of the Hall device. A magnetic field from a magnet is broken by a rotating disk and induces an energizing pulse in the device.

Limitations

The Contact Breaker systems was invented by Charles Kettering in 1908. Although he was undoubtedly a far-seeing man (he later became head of General Motors) it is not surprising that we are now able to improve on his invention.

The areas in most need of improvement are to be found in the low voltage section of the distributor.

Points

The points are a switch which when closed allows current to flow in the coil. The size of the voltage that is generated by the coil is directly proportional to the *speed* that the points open and the *amount* of current that the coil carries.

Both speed and amount of current are limited by the size of the points set. A large set could carry more current but would not open so quickly or alternatively a small set would open quickly but no be able to carry the current. A modern points set is a compromise.

Dwell

The time that the coil has to store energy is determined by the time the points are closed and is known as the *dwell time*. At high engine speeds the dwell time is very short and can become inadequate leading to misfiring and certainly to inadequate combustion and loss of power and economy. This occurs because the dwell time is controlled by a fixed dwell angle of cam rotation. See Fig. 2.

Maintenance

Arcing at the points surface erodes the metal and adjustment is lost. The cam follower also wears and contributes to loss of gap.

Adequate gap to prevent arcing and maintain dwell angle is gradually lost and needs to be restored every 5,000 miles or so. If emissions and economy are to be maintained even more frequently adjustment is called for.

Timing

All timing operations are controlled mechanically. They are therefore subject to friction, wear and general lack of accuracy. Low emission, high performance and good economy all rely upon accurate timing.

C.B. Ignition Enhancements

Ballast Resistor

The current carried by the coil is forced through by the voltage applied by the battery. Unfortunately, when cranking from cold the battery does not provide as high a voltage. A solution is to provide a coil which has a resistance of only 1.5ohm so that at the reduced voltage it will still draw about 4A of current.

However, when the engine is running, 12V to 14V will be available and so an extra resistance (*ballast resistor*) is connected into the circuit to limit the current to the 4A required. See Fig. 1b. This systems aids starting.

Sliding Points

When the points arc, they are eroded; if the arcing can be spread over a larger area it will take longer to erode the points and service intervals can be extended. The more recent Minis have an example of how to achieve this.

A *the points open the base plate and cam follower are arranged so that the points surfaces slide across each other and spread the erosion over a greater area. This is claimed to increase service intervals to 12,000 miles.

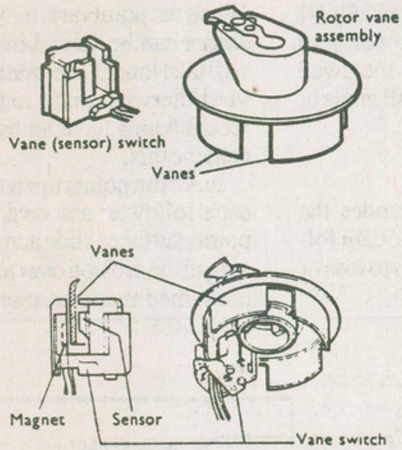
Transistor Assisted Ignition

So far in our view of ignition systems it's implied that the improvements have been to increase the maintenance period and improve economy. But now there is an even greater pressure on the manufacturers to reduce emissions. Rich mixtures of fuel and air produce a lot of nasty by-products but they do ignite easily. Modern engines run on lean mixtures — some very lean indeed.

To make sure the air/fuel mixture ignites properly it requires a high energy spark and a high voltage. The ordinary C.B. ignition systems are not always able to manage this, particularly at high engine speeds, so transistor assisted systems were introduced.

The energy stored in a coil is equal to $1/2LI^2$ where L = the inductance and I = current. It is clear that if the current is doubled the energy available is four fold. Unfortunately the points are already over burdened — if they were made larger to carry more current they would have too much inertia to handle the revs.

But by the use of transistors (usually a Darlington Pair) large currents can be controlled quite easily and additionally the



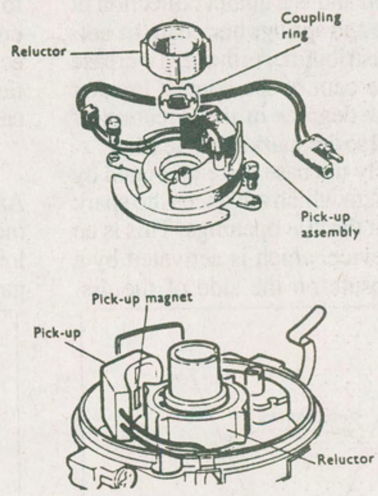


Fig. 4. Hall effect arrangement. (a) Vane switch (or sensor) and rotor vane. (b) Interaction of rotor vane and sensor.

Fig. 5. Early distributor reluctor system arrangement. (a) Releuctor and pickup, (b) Reluctor tooth and pickup alignment.

current can be switched very fast and with no arcing. Triggering of the transistors can be by contact breaker points or by some device which requires less maintenance.

Advantages

Large currents mean high energy, similarly fast switching speeds mean high voltage generation — this gives reliable firing when cranking and at high engine speeds. Dwell angle is less critical. Points sets, if used, carry only small currents and therefore last longer without adjustment.

Switching is clean, no arcing, so timing is more accurate. Also the effects of points bounce can be eliminated which ensures more accurate timing.

Overall the result is a car which starts more reliably, produces more power and is more drivable when cold and needs less choke. This is bound to improve emissions and fuel economy.

How To Recognize

This type of system has now been superseded but was normally housed in a module attached to the side of the distributor or attached to the coil. The coils have a low primary resistance of about three-quarters of an ohm.

Any system which is electronic but still uses the points is likely to be of this type. The modules are commonly called "amplifiers" or "igniters".

Ignition Triggering Systems

Contact points are mechanical switches; because they are mechanical they wear and need regular adjustment. They also bounce when they open and close at high speed, this can affect the accuracy of their timing.

Alternatives

With transistor ignition systems it is no longer necessary to rely on the points to perform the triggering function. With only a little more circuitry it is possible to trigger them with sensors which have no moving parts.

Early systems sometimes used photoelectric light sensors which produced a pulse when masked from a light source by a revolving disc. These were perfectly satisfactory but modern practice is to use a magnetic sensor and two systems now predominate.

Hall Effect

Modern semiconductor technology has produced a device which when placed in a magnetic field deflects an electric current and is called a *Hall Effect* device. See Fig. 3.

The actual arrangement is to fix a Hall Effect chip in a distributor so that a flanged disc rotating on the distributor shaft masks it from a magnet. Slots in the flange allow the magnetism to reach the Hall Effect device when the trigger pulse is required.

The Hall Effect chip is supplied with current and at the correct moment a trigger pulse appears on the output connection which is fed to the control module. No adjustment should ever be required. See Fig. 4.

Reluctor Systems

When a magnetic circuit is broken any coil in that circuit will experience an induced voltage. This voltage can be used to rigger a transistor ignition system. If a toothed wheel is part of the magnetic circuit then the circuit will be interrupted when a tooth is not in alignment with a pole piece.

An early method was to put the toothed wheel into a distributor and this has that advantage of being able to utilize the centrifugal advance and the vacuum advance systems. The advantages are that distributor bearing wear, gear backlash and the mechanical advance systems still produce some inaccuracy. See Fig. 5.

A more recent method is to put the toothed wheel on the flywheel there is no backlash or possibility of drive gear wear. Additionally extra teeth can be provided so that engine speed can be sensed by the same sensor. However, alternative systems are then required to replace the vacuum and centrifugal advance. See Fig. 2.

Advantages

Accurate ignition timing from a no-main-

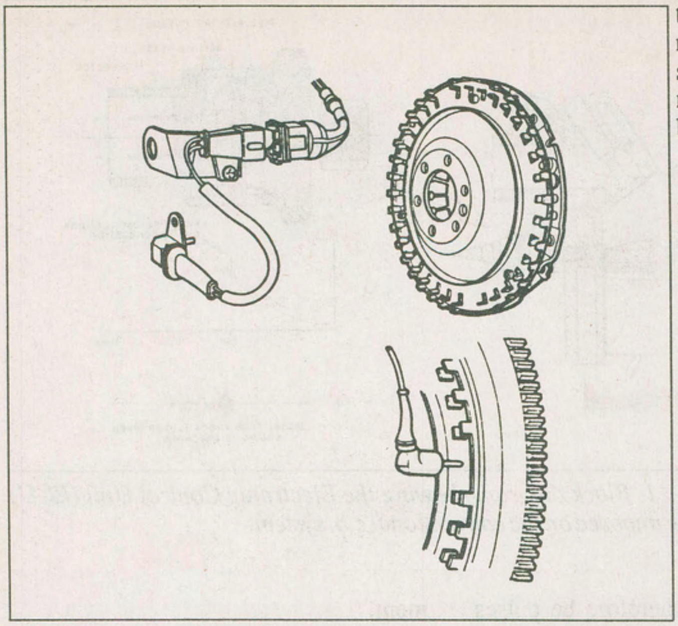


Fig. 6. Flywheel reluctor sensor. This comprises a magnet with a projecting pole piece and a reluctor disk on the flywheel.

tenance system once set should not need adjustment.

Constant Energy Ignition

It takes time between each spark for the current and hence the magnetic field in the coil to grow to its maximum. If the coil does not reach full capacity it will not generate its full output and will be unable to ignite weak mixtures and misfiring can occur.

Certainly incomplete combustion leading to poor power and high emissions do occur. This is particularly the case with high reving engines and 6, 8 and 12 cylinder units.

There are numerous solutions to this problem but because electronics are relatively cheap it is common to find combined systems. The commonest are described below:

Electronic Dwell Control

Dwell period is related to the angle that the cam in the distributor rotates through while the points are closed. This is called the dwell angle and is usually about 50 degrees on a contact breaker system (see Fig. 2).

If dwell angle is increased at high revs, there will be an increase in dwell *period* compared with a fixed dwell angle system. This is easy to arrange if electronic triggering is in use. The increased period allows the coil time to reach its maximum current flow and hence maximum energy storage.

The reduced dwell at low revs, reduces current consumption and heating of the coil.

Constant Current Operation

With constant current operation the coil resistance is made so low (0.80 ohm) that the coil current rises to its maximum even in the short time available at high revs. The constant current circuitry prevents it from rising too high in the longer periods available at low revs.

Stationary Engine Cut-Off

Both the above systems employ a circuit which cuts off current to the coil when the engine is stationary. Tis is essential as otherwise the coil would overheat with the high current (as high as about 18A) which would flow if the ignition were left on.

These systems optimize the ignition system so that regardless of engine speed, battery voltage, starting or high revs, the engine is provided with a powerful and consistently timed spark. And yet at low revs, or when stationary, components are protected from excessive heat and power is not wasted.

How To Recognize

Most modular electronic ignition systems now incorporate all or some of the previously mentioned techniques. These systems are usually housed in packs which are attached to the side of distributors or on the bulkhead with the coil.

However, note they still use the mechanical vacuum and centrifugal advance mechanisms so there is still a distributor- like casing driven by the cambelt or camshaft. Only in the programmed ignition systems is the distributor eliminated (except for cap and rotor arm).

Programmed Ignition

Transistor ignition systems with a conventional distributor using centrifugal advance and vacuum advance do not completely meet the requirements of modern engines in modern environments.

Distributor systems sense engine load by the use of manifold depression. This is arranged to mechanically vary the rotation of the distributor. Apart from the usual difficulties associated with mechanical control systems such as fric-

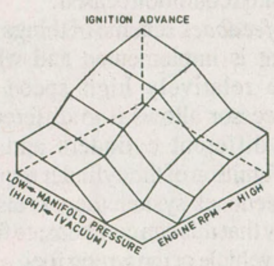


Fig. 7. Ignition or engine map using the distributor system.

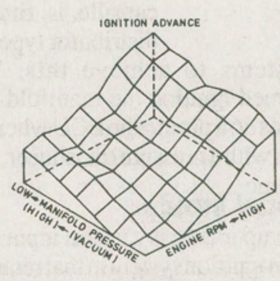


Fig. 8. Engine map using the programmed ignition system.

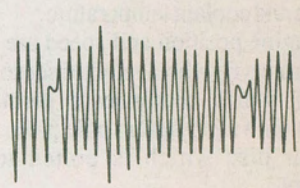


Fig. 9. Typical waveform to be expected from a reluctor sensor output.

tion, wear and backlash, there is a limitation in the range of different amounts of advance which can be accommodated. See Fig. 7.

Similarly centrifugal (bob weight) advance systems mentioned previously have all the mechanical disadvantages mentioned and can provide only tow stages of advance. Finally mechanical systems have no facility for the input of additional information such as engine temperature.

Microprocessor Ignition Control

Programmed ignition comes in the ubiquitous "black box" called an ECU (electronic control unit). It makes use of a ROM IC to store information about a particular engine's advance requirement under all load and speed conditions. In operation this is then read by a *microprocessor* and further modified by additional inputs such as coolant temperature and engine knocking ("pinking") to provide the optimum ignition advance.

The stored information called an engine *map*, is worked out by the engine manufacturer on an engine test bed (see Fig. 8). Even the most rudimentary programmed ignition system will require the following inputs: engine position, engine speed, manifold depression, battery voltage and coolant temperature.

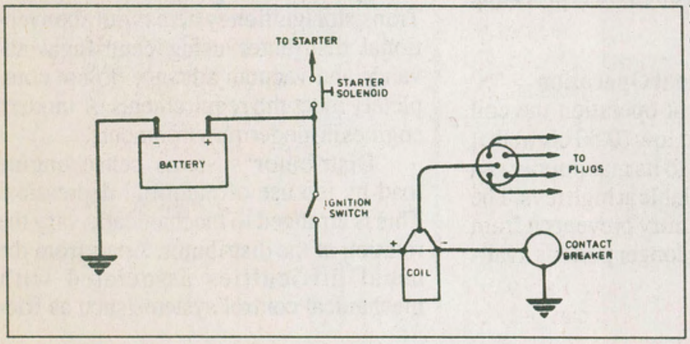


Fig. 10. Mechanical arrangement for the piezoelectric transducer knock sensor and examples of output waveforms. The sensor is mounted on the engine block.

Engine position and speed are often taken from a flywheel reluctor sensor (see Fig. 6), which comprises a permanent magnet with a projecting pole piece and a reluctor disc which is bolted to the flywheel.

The disc has pairs of lugs projecting at 10 degree intervals around the circumference. The sensor is mounted in such a way on the engine that as the flywheel rotates the pairs of lugs pass each side of the projecting pole piece. Thus for an instant at 10 degree intervals the sensor and the lugs form a magnetic circuit and also pulses are generated, their frequency indicating the speed of rotation of the engine.

However, at Top-Dead-Center (TDC) for cylinders 1 and 4 and at 180 degrees further round thus TDC for cylinders 2 and 3 there are pairs of lugs missing. There will therefore be pulses missing at these points and the ECU can thus detect TDC for the appropriate cylinders (see Fig. 9). In this way engine speed and position is passed to the ECU.

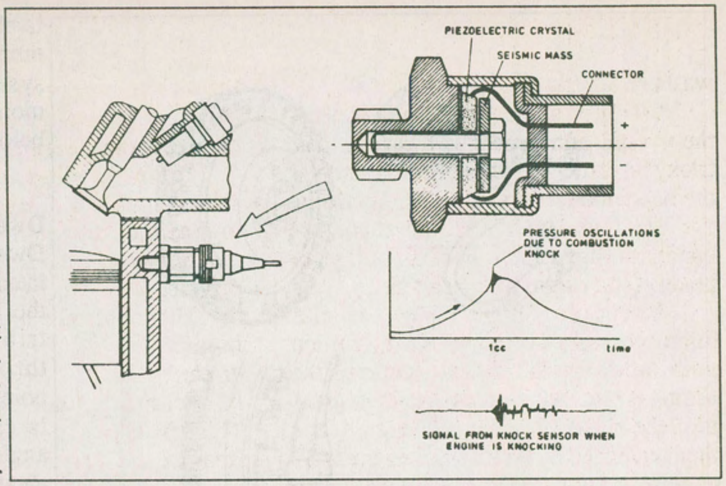


Fig. 11. Block diagram showing the Electronic Control Unit (ECU) superimposed on the conventional c.b. system.

Engine Load

Engine load is the other important parameter and this is related to manifold depression will hardly exist as the manifold will be at virtually atmospheric pressure. If on the other hand the car is descending a hill on a trailing throttle (no load) there will be a large vacuum or high manifold depression.

On light loads the engine runs much more economically if the ignition is advanced. You may recall that a vacuum capsule is fitted to distributor type ignition systems to achieve this. With programmed ignition the manifold pressure passes up a pipe to the ECU where it is measured with a pressure transducer.

Additional Inputs

Engine temperature is a useful input to include in an ignition system in that retarding of the timing can lead to better drivability from cold and speedier warm-up. A coolant sensor is already available on most cars anyway (for the temperature gauge) and so this is relatively cheap to implement.

Temperature sensors are made from a negative temperature coefficient semiconductor, encapsulated in a brass housing and screwed into the engine block or thermostat housing. Their resistance varies from about 10 kilohms at -10°C to about 300 ohms at engine running temperature.

Knock Sensor

A significant addition with programmed ignition is the *knock sensor*. Engines are more economical, more powerful and produce less harmful emissions if run at maximum advance.

In the past the standard setting always had to allow a margin for error because the consequences of an *over-advanced* engine are dire: broken pistons and burnt valves to name a couple. But with a microprocessor looking after the ignition it could run the engine at maximum safe advance and it could sense the onset of "knocking", "pinking" (or whatever you call it) it could then retard the ignition until the unwanted condition ceased.

This *feedback* scheme of things is exactly what is implemented and what is more the relatively high speed of a microprocessor allows it to differentiate between different cylinders and only retard the ignition of the cylinder required. Being a feedback system there is also the possibility that this can compensate for the age of the vehicle or the wrong fuel.

The knock sensor is a piezo electric accelerometer and is screwed into the block. The name belies a simple construction of a piezo crystal which is clamped between the block and a weight (ie. a thick washer). See Fig. 10.

Vibration of the engine thus squeezes the crystal and produces a signal. The tricky bit is then to sort out which signal is the one which indicates knocking. Inside the ECU you can imagine there are bandpass filters and other bits of jiggery pokery (sorry signal processing).

A typical algorithm for the microprocessor is: at the fourth ignition pulse after the knock has occurred the timing is retarded in steps of 1.25 degrees until the knock disappears. the ignition is then advanced by 0.625 degrees every 32 engine revs until the advance agrees with the figure in the ROM (read only memory) or the knock occurs again.

Programmed Ignition Advances

The advantages of programmed ignition are: better drivability, easier starting, smother running, improved economy and power, and automatic adjustment for the age of the vehicle. Additional inputs can be added to give traction control, smooth idle, smoothed auto gear change, turbo boost control and exhaust gas recirculation. Inter-connection with a fuel management system is also possible which enhances the effect of both systems.

How To Recognize

Apart from the rotor arm and distributor cap all the other functions of a distributor have been replaced by an electric control unit (ECU). The ECU is a box, often black, it has a finned section and apart from a multiplug has a vacuum pipe from the inlet manifold leading into it. It is often mounted on the bulkhead or suspension turret.

Fault-Finding

Both programmed ignition and the simpler module type ignition system are easy to fault find as long as you remember that thier function is to replace the contact breaker. Have a look at the diagram of the basic system (Fig. 1 and Fig. 11) and visualize the ECU in place of the contact breaker and ignore all the sensors.

Clearly a bulb connected across the two coil terminals should flash when the engine is cranked, if not then check for battery voltage from the coil all the way back to the battery. You should also find battery voltage on the coil negative with the engine stationary — due to "stationary engine cut-off" referred to earlier. If the test bulb still does not flash then it has to be the feed to the module or ECU which is often taken from the coil positive terminal or direct from the ignition switch.

If the car still does not star, *and assuming it is the ignition*, then it must be the high tension circuit. *A word of caution is due here: electronic ignition circuits produce quite a kick, so be careful.*

High tension circuits must be tested in such a way that you always provide an ground path. If you don't it'll find one of its own and do some damage on the way. The best check is to dive in the middle. Remove the lead to the center of the distributor cap and rest it on the engine in such a way that a spark can jump to the block. When cranking if you don't get a healthy spark which will jump across 1/4in. then you've got problems with the coil. If you have a spark then the fault must be in the distributor cap or rotor arm.

With a programmed ignition system the sensors can cause a problem. Obviously if the TDC sensor has failed the system will not function. Check out with a multimeter, reluctor coils have a resistance in the couple of hundred to three or four kilohms bracket. Failed ones are open circuit or short circuit.

Similarly with coolant temperature sensors, open or short. Good ones range from 10 kilohms when cold down to 300 ohms at 100°C. Hall Effect sensors are difficult but try your multimeter switched to AC volts on the output lead. With the engine cranking any reading probably means OK.

Poor Performance

Apart from tired components like plugs and leads poor performance can only be caused by bad timing, so with the module type of ignition check it and also check the operation of the vacuum and centrifugal advance systems.

Programmed ignition cannot get its ignition timing wrong except if it thinks the engine is cold so check out the coolant temperature sensor. The only other problem could be "pinking" and this points the finger at the knock sensor.

Incidentally, correct function of this component can be verified by tapping the engine block close to the sensor quite hard and repeatedly with a spanner. If the engine is ticking over at hot idle speed you will detect a drop in speed which indicates the timing has been retarded. However, some cars have a stepper motor controlling the idle speed so this will have to be disconnected first.

In Conclusion

We have purposely not attempted to explain the workings of the inside of "black boxes" found in the ignition system on cars. Nobody in their right mind is going to attempt to fix one of them at the side of the road.

The guts of the ECUs however are very interesting and will perhaps be considered at a later date. What we have attempted to do is show that although sophisticated, these systems are quite easy to understand at the block diagram level and give enough, we hope, information to quickly resolve any problem associated with them.

Do please look before you leap — like any electrical device in the hostile environment of a car engine component — most faults are caused by poor connections.