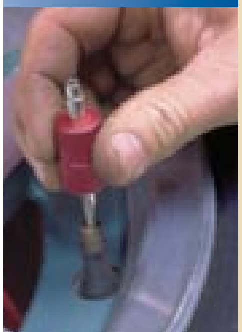

SECTION 4

Engine Performance

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To have an efficient running engine, there must be the correct amount of fuel mixed with the correct amount of air. These must be present in a sealed container and shocked by the right amount of heat, at the correct time. With total efficiency, the engine would burn all the fuel it receives and would release extremely low amounts of pollutants in its exhaust. Although total efficiency is not possible at this time, late-model engines emit very low amounts of pollutants, thanks to emission control devices.

To have highly efficient engines, the basic engine needs highly efficient ignition, fuel, and emission control systems. Although there are many different designs of these systems, the designs are similar in operation. Engine performance systems are some of the most technologically advanced systems found on modern vehicles. They all rely on a network of input sensors and output devices and tie directly into the electronic engine control system. Mastery of these systems is necessary for an automotive technician.

The material in Section 4 matches the content areas of the ASE certification test on engine performance and sections of the certification test on engine repair.

IGNITION SYSTEMS

21

OBJECTIVES

◆ ***Describe the three major functions of an ignition system.*** ◆ ***Name the operating conditions of an engine that affect ignition timing.*** ◆ ***Name the two major electrical circuits used in ignition systems and their common components.*** ◆ ***Describe the operation of ignition coils, spark plugs, and ignition cables.*** ◆ ***Explain how high voltage is induced in the coil secondary winding.*** ◆ ***Describe the various types of spark timing systems, including electronic switching systems and their related engine position sensors.*** ◆ ***Explain the basic operation of a computer-controlled ignition system.*** ◆ ***Explain how the fuel injection system may rely on components of the ignition system.*** ◆ ***Describe the various types of spark timing systems, including electronic switching systems and their related engine position sensors.*** ◆ ***Describe the operation of distributor-based ignition systems.*** ◆ ***Describe the operation of distributorless ignition systems.***

One of the requirements for an efficient engine is the correct amount of heat shock, delivered at the right time. This requirement is the responsibility of the ignition system. The ignition system supplies properly timed, high-voltage surges to the spark plugs. These voltage surges cause combustion inside the cylinder.

The ignition system must create a spark, or current flow, across each pair of spark plug electrodes at the proper instant, under all engine operating conditions. This may sound relatively simple, but when one considers the number of spark plug firings required and the extreme variation in engine operating conditions, it is easy to understand why ignition systems are so complex.

If a six-cylinder engine is running at 4,000 revolutions per minute (rpm), the ignition system must supply 12,000 sparks per minute because the ignition system must fire 3 spark plugs per revolution. These plug firings must also occur at the correct time and generate the correct amount of heat. If the ignition system fails to do these things, fuel economy, engine performance, and emission levels will be adversely affected.

PURPOSE OF THE IGNITION SYSTEM

For each cylinder in an engine, the ignition system has three main jobs. First, it must generate an electrical spark that has enough heat to ignite the air/fuel mixture in the combustion chamber. Secondly, it must maintain that spark long enough to allow for the combustion of all the air and fuel in the cylinders. Lastly, it must deliver the spark to each cylinder so combustion can begin at the right time during the compression stroke of each cylinder.

When the combustion process is completed, a very high pressure is exerted against the top of the piston. This pressure pushes the piston down on its power stroke. This pressure is the force that gives the engine power. For an engine to produce the maximum amount of power it can, the maximum pressure from combustion should be present when the piston is at 10 to 23 degrees after top dead center (ATDC). Because combustion of the air/fuel mixture within a cylinder takes a short period of time, usually measured in thousandths of a second (milliseconds), the combustion process must begin before the piston is on its power stroke. Therefore, the delivery of the spark must be timed to arrive at some point before the piston reaches top dead center.

Determining how much before TDC the spark should begin gets complicated because of the fact that as the speed of the piston as it moves from its compression stroke to its power stroke increases, the time needed for combustion stays about the same. This means the spark should be delivered earlier as the engine's speed increases **(Figure 21–1)**. However, as the engine has to provide more power to do more work, the load on the crankshaft

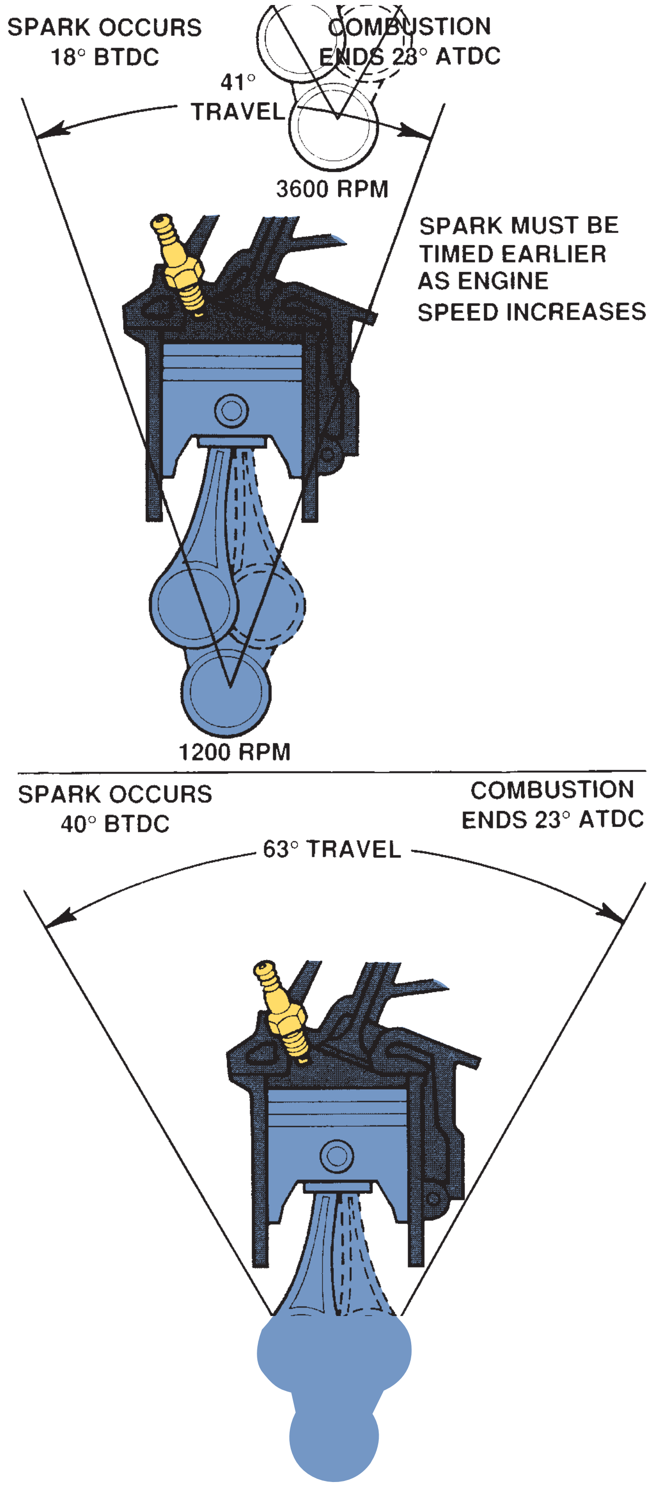

Figure 21-1 Ignition must begin earlier as engine speed increases. *Courtesy of Ford Motor Company*

tends to slow down the acceleration of the piston and the spark should be somewhat delayed.

Figuring out when the spark should begin gets more complicated due to the fact that the rate of combustion varies according to certain factors. Higher compression pressures tend to speed up combustion. Higher octane gasolines ignite less easily and require more burning time. Increased vaporization and turbulence tend to decrease combustion times. Other factors, including intake air temperature, humidity, and barometric pressure, also affect combustion. Because of all of these complications, delivering the spark at the right time is a difficult task.

There are basically two types of ignition found on today's vehicles: **distributor ignition** (**BDI**) and **electronic ignition** (**EI**) or **distributorless ignition systems** (**DIS**). The various designs and operation of these two types are discussed in this chapter.

IGNITION TIMING

Ignition timing refers to the precise time spark occurs. Ignition timing is specified by referring to the position of the #1 piston relation to crankshaft rotation. Ignition timing reference timing marks can be located on engine parts and on a pulley or flywheel to indicate the position of the #1 piston. Vehicle manufacturers specify initial or **base ignition timing**.

When the marks are aligned at TDC, or 0, the piston in cylinder #1 is at TDC of its compression stroke. Additional numbers on a scale indicate the number of degrees of crankshaft rotation before TDC (**BTDC**) or after TDC (**ATDC**). In a majority of engines, the initial timing is specified at a point between TDC and 20 degrees BTDC.

If optimum engine performance is to be maintained, the ignition timing of the engine must change as the operating conditions of the engine change. Ignition systems allow for these necessary changes in many ways; these are covered in greater detail later in this chapter. All the different operating conditions affect the speed of the engine and the load on the engine. All ignition timing changes are made in response to these primary factors.

Engine RPM

At higher rpms, the crankshaft turns through more degrees in a given period of time. If combustion is to be completed by 10 degrees ATDC, ignition timing must occur sooner or be advanced.

However, air/fuel mixture turbulence (**swirling**) increases with rpm. This causes the mixture inside the cylinder to turn faster. Increased turbulence requires that ignition must occur slightly later or be slightly retarded.

These two factors must be balanced for best engine performance. Therefore, while the ignition timing must be advanced as engine speed increases, the amount of advance must be decreased some to compensate for the increased turbulence.

Engine Load

The load on an engine is related to the work it must do. Driving up hills or pulling extra weight increases engine load. Under load there is resistance on the crankshaft, therefore the pistons have a harder time moving through their strokes. This is evident by the low measured vacuum during heavy loads.

Under light loads and with the throttle plate(s) partially opened, a high vacuum exists in the intake manifold. The amount of air/fuel mixture drawn into the manifold and cylinders is small. On compression, this thin mixture produces less combustion pressure and combustion time is slow. To complete combustion by 10 degrees ATDC, ignition timing must be advanced.

Under heavy loads, when the throttle is opened fully, a larger mass of air/fuel mixture can be drawn in, and the vacuum in the manifold is low. High combustion pressure and rapid burning results. In such a case, the ignition timing must be retarded to prevent complete burning from occurring before 10 degrees ATDC.

Firing Order

Up to this point, the primary focus of discussion has been ignition timing as it relates to any one cylinder. However, the function of the ignition system extends beyond timing the arrival of a spark to a single cylinder. It must perform this task for each cylinder of the engine in a specific sequence.

Each cylinder of an engine must produce power once in every 720 degrees of crankshaft rotation. Each cylinder must have a power stroke at its own appropriate time during the rotation. To make this possible, the pistons and rods are arranged in a precise fashion. This is called the engine's **firing order**. The firing order is arranged to reduce rocking and imbalance problems. Because the potential for this rocking is determined by the design and construction of the engine, the firing order varies from engine to engine. Vehicle manufacturers simplify cylinder identification by numbering each cylinder **(Figure 21–2)**.

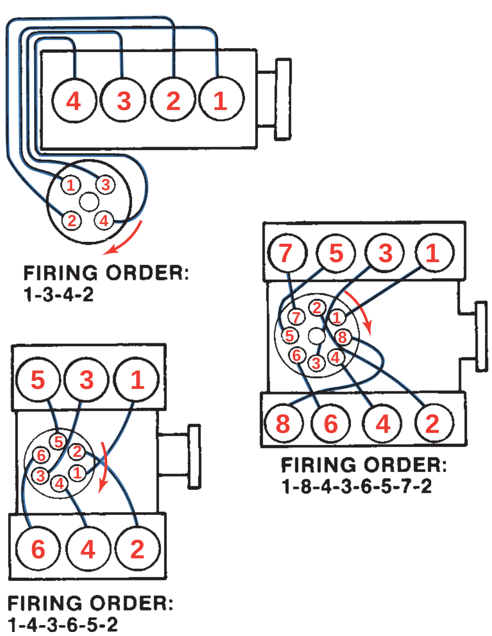

Figure 21-2 Examples of typical firing orders.

Regardless of the particular firing order used, the number 1 cylinder always starts the firing order, with the rest of the cylinders following in a fixed sequence.

The ignition system must be able to monitor the rotation of the crankshaft and the relative position of each piston to determine which piston is on its compression stroke. It must also be able to deliver a high-voltage surge to each cylinder at the proper time during its compression stroke. How the ignition system does these things depends on the design of the system.

BASIC CIRCUITRY

All ignition systems consist of two interconnected electrical circuits: a **primary** (low voltage) **circuit** and a **secondary** (high voltage) **circuit (Figure 21–3)**.

Depending on the exact type of ignition system, components in the primary circuit include the following.

- Battery
- Ignition switch
- Ballast resistor or resistance wire (some systems)
- Starting by-pass (some systems)
- Ignition coil primary winding
- Triggering device
- Switching device or control module

The secondary circuit includes these components.

- Ignition coil secondary winding
- Distributor cap and rotor (some systems)
- Ignition (spark plugs) cables
- Spark plugs

Primary Circuit Operation

When the ignition switch is on, current from the battery flows through the ignition switch and primary circuit resistor to the primary winding of the ignition coil. From here it passes through some type of switching device and back to ground. The switching device can be electronically or mechanically controlled by the triggering device. The current flow in the ignition coil's primary winding creates a magnetic field. The switching device or control module interrupts this current flow at predetermined times. When it does, the magnetic field in the primary winding collapses. This collapse generates a high-voltage surge in the secondary winding of the ignition coil. The secondary circuit of the system begins at this point.

Some ignition systems have a **ballast resistor** connected in series between the ignition switch and the coil positive terminal. This resistor supplies the correct amount of voltage and current to the coil. In some ignition systems, a calibrated resistance wire is used in place of the ballast resistor. Today, many ignition systems are

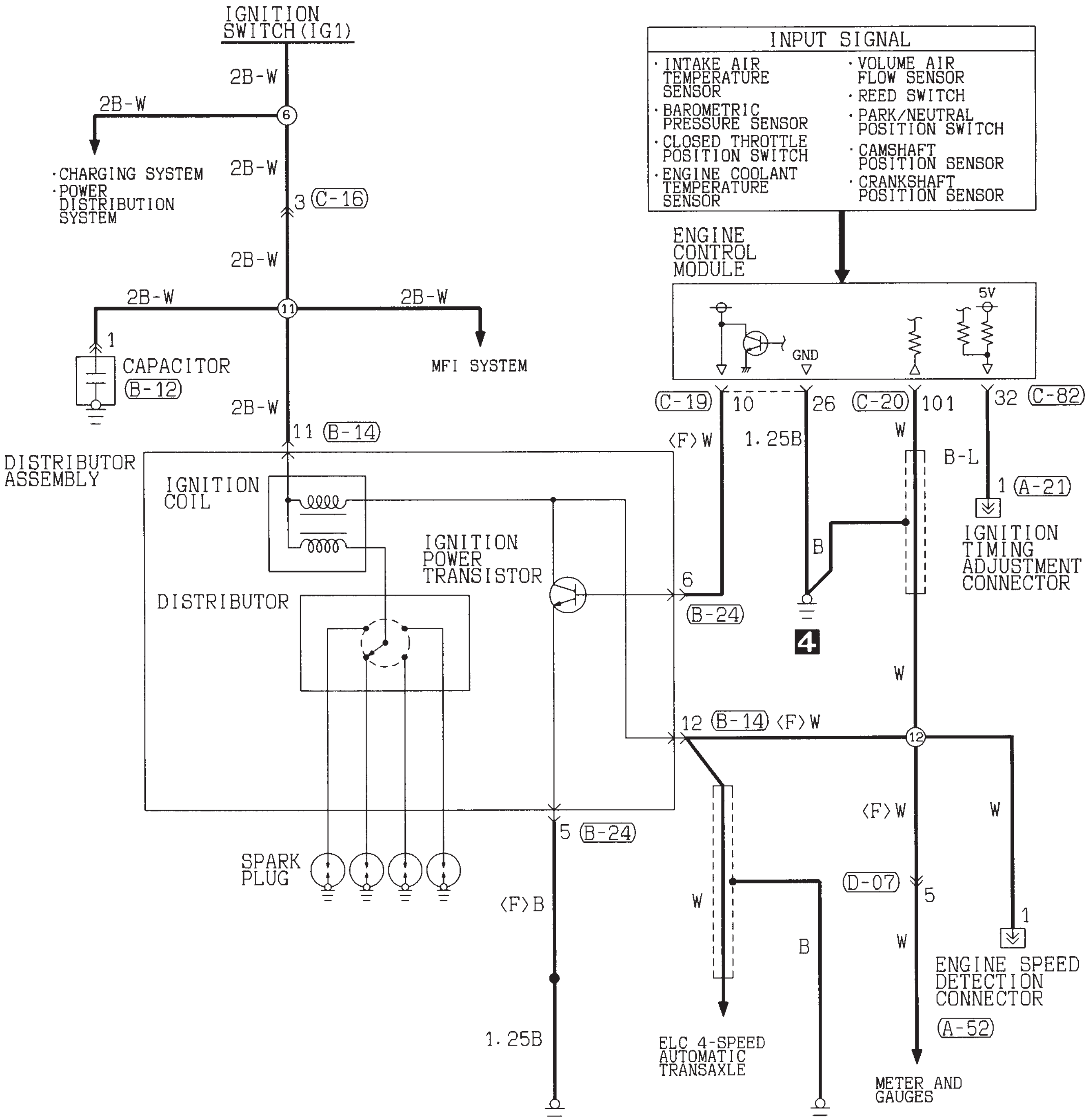

Figure 21-3 Ignition systems have a primary and secondary (high voltage) circuit. *Courtesy of Mitsubishi Motor Sales of America, Inc.*

not equipped with the resistor. These systems supply 12 volts directly to the coil.

There are also some ignition systems that do not require a ballast resistor. For instance, some control units directly regulate the current flow through the primary of the coil. Hall-effect and optical systems do not require ballast resistors either. The signal voltage is not changed by the speed of the distributor because it is in an inductive magnetic signal generating system.

Secondary Circuit Operation

The secondary circuit carries high voltage to the spark plugs. The exact manner in which the secondary circuit delivers these high voltage surges depends on the system design. Until 1984 all ignition systems used some type of distributor to accomplish this job. However, in an effort to reduce emissions, improve fuel economy, and boost component reliability, most auto manufacturers are now using distributorless or Electronic Ignition (EI) systems.

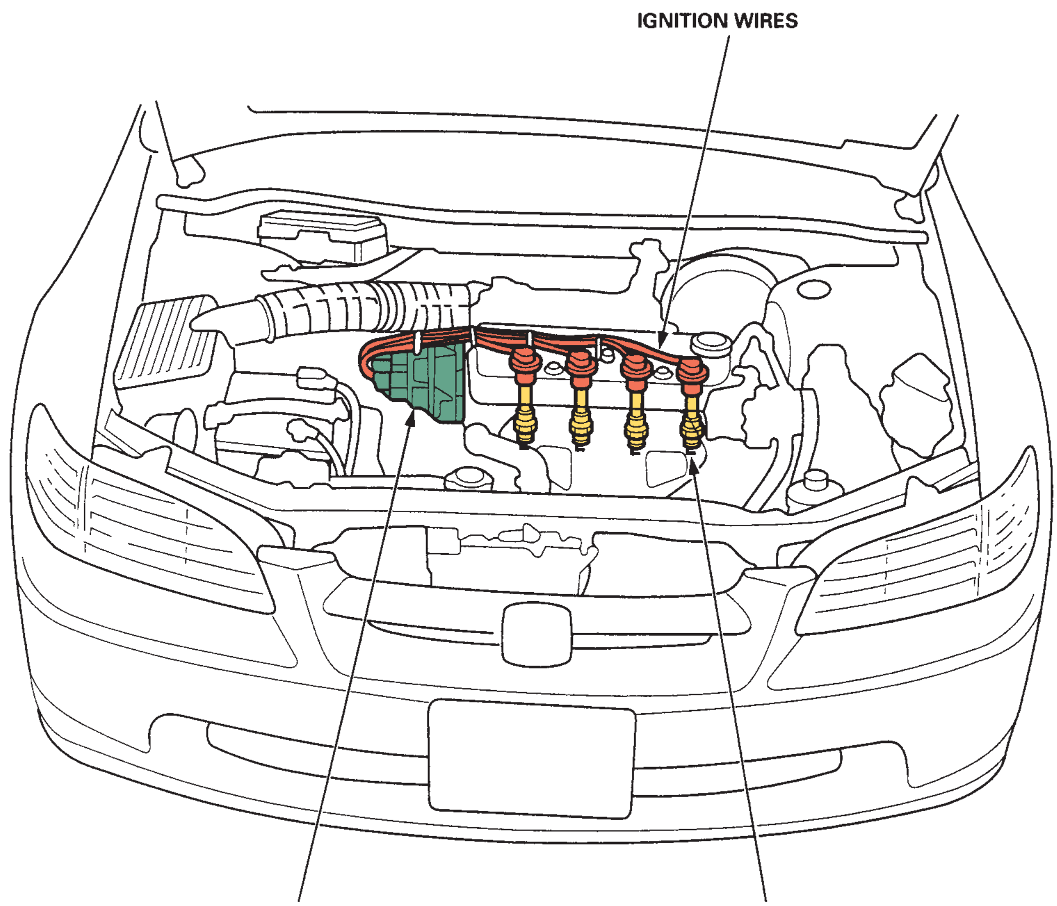

Figure 21–4 Typical spark distribution system. *Courtesy of American Honda Motor Co., Inc.*

In a Distributor Ignition (DI) system, high-voltage from the secondary winding passes through an ignition cable running from the coil to the distributor. The **distributor** then distributes the high voltage to the individual spark plugs through a set of ignition cables **(Figure 21–4)**. The cables are arranged in the distributor cap according to the firing order of the engine. A **rotor** which is driven by the distributor shaft rotates and completes the electrical path from the secondary winding of the coil to the individual spark plugs. The distributor delivers the spark to match the compression stroke of the piston. The distributor assembly may also have the capability of advancing or retarding ignition timing.

The distributor cap is mounted on top of the distributor assembly and an alignment notch in the cap fits over a matching lug on the housing. Therefore the cap can only be installed in one position, which assures the correct firing sequence.

The rotor is positioned on top of the distributor shaft, and a projection inside the rotor fits into a slot in the shaft. This allows the rotor to only be installed in one position. A metal strip on the top of the rotor makes contact with the center distributor cap terminal, and the outer end of the strip rotates past the cap terminals as it rotates **(Figure 21–5)**. This action completes the circuit between the ignition coil and the individual spark plugs according to the firing order.

EI systems have no distributor; spark distribution is controlled by an electronic control unit and/or the vehi-

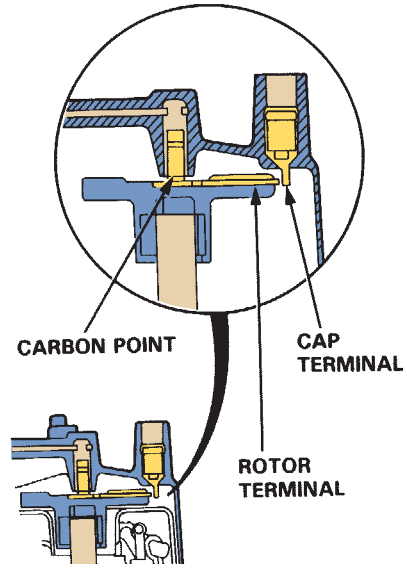

Figure 21–5 Relationship of a rotor and distributor cap. *Courtesy of American Honda Motor Co., Inc.*

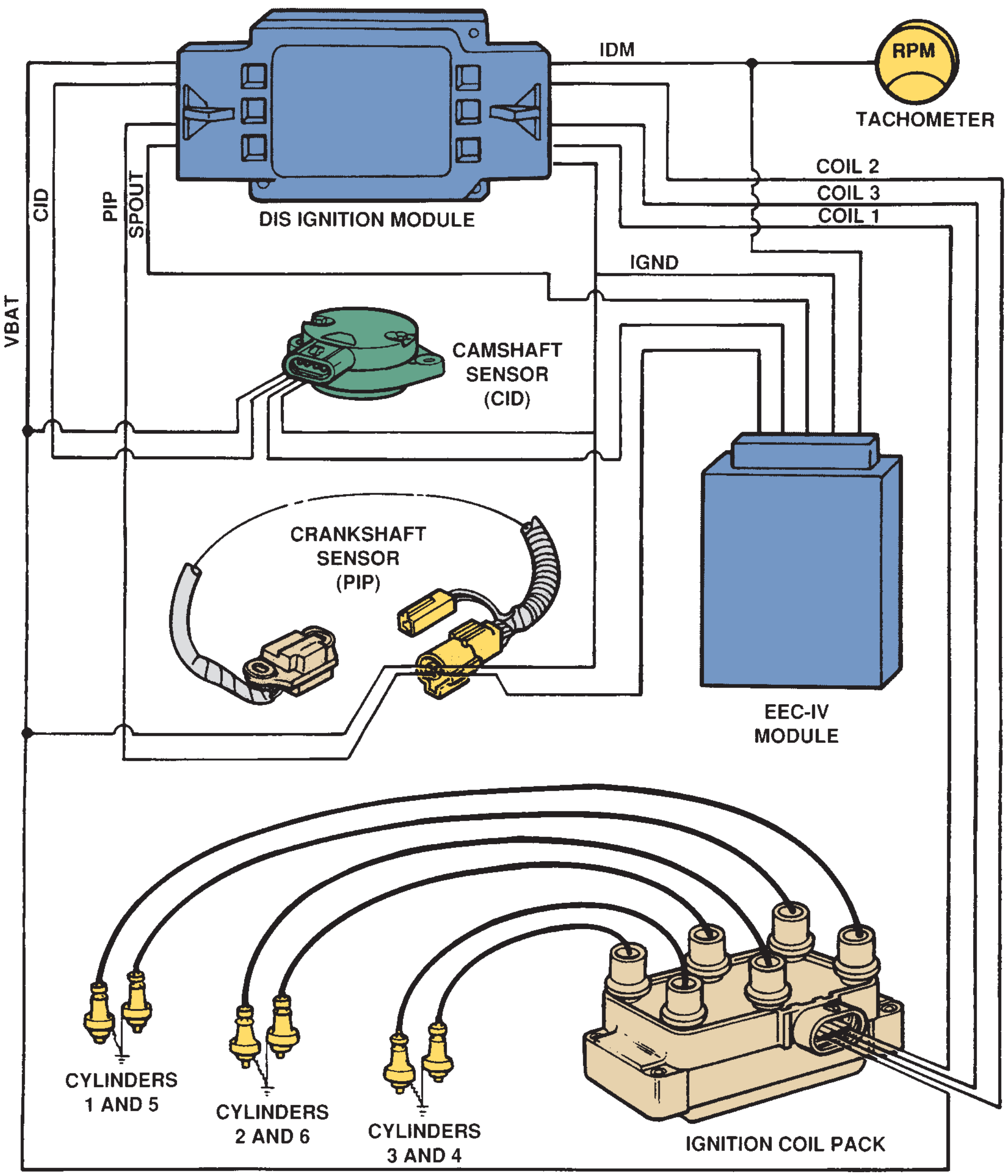

Figure 21-6 An electronic ignition system for a 6-cylinder engine. *Courtesy of Ford Motor Company*

cle's computer **(Figure 21–6)**. Instead of a single ignition coil for all cylinders, each cylinder may have its own ignition coil, or two cylinders may share one coil. The coils are wired directly to the spark plug they control. An ignition control module, tied into the vehicle's computer control system, controls the firing order and the spark timing and advance. This module is typically located under the coil assembly.

A specific amount of energy is available in a secondary ignition circuit. In a secondary ignition circuit, the energy is normally produced in the form of voltage required to start firing the spark plug and then a certain amount of current flow across the spark plug electrodes to maintain the spark. Distributorless ignition systems are capable of producing much higher energy than conventional ignition systems.

Since distributor ignition and electronic ignition systems are both firing spark plugs with approximately the same air gap across the electrodes, the voltage required to start firing the spark plugs in both systems is similar. If the additional energy in the EI systems is not released in the form of voltage, it will be released in the form of current flow. This results in longer spark plug firing times. The average firing time across the spark plug electrodes in an EI system is 1.5 milliseconds compared to approximately 1 millisecond in a DI system. This extra time may seem insignificant, but it is very important. Current emission standards demand leaner air-fuel ratios, and this additional spark duration on EI systems helps to prevent cylinder misfiring with leaner air-fuel ratios. This is why most car manufacturers have equipped their engines with EI systems.

IGNITION COMPONENTS

All ignition systems share a number of common components. Some, such as the battery and ignition switch, perform simple functions. The battery supplies low-voltage current to the ignition primary circuit. The current flows when the ignition switch is in the start or run position. Full-battery voltage is always present at the ignition switch, as if it were directly connected to the battery.

Ignition Coils

To generate a spark to begin combustion, the ignition system must deliver high voltage to the spark plugs. Because the amount of voltage required to bridge the gap of the spark plug varies with the operating conditions, most late-model vehicles can easily supply 30,000 to 60,000 volts to force a spark across the air gap. Since the battery delivers 12 volts, a method of stepping up the voltage must be used. Multiplying battery voltage is the job of a coil.

The ignition coil is a **pulse transformer**. It transforms battery voltage into short bursts of high voltage. As explained previously, when a wire is moved through a magnetic field, voltage is induced in the wire. The inverse of this principle is also true—when a magnetic field moves across a wire, voltage is induced in the wire.

If a wire is bent into loops forming a coil and a magnetic field is passed through the coil, an equal amount of voltage is generated in each loop of wire. The more loops of wire in the coil, the greater the total voltage induced.

Also, the faster the magnetic field moves through the coil, the higher the voltage induced in the coil. If the speed of the magnetic field is doubled, the voltage output doubles.

An ignition coil uses these principles and has two coils of wire wrapped around an iron core. An iron or steel core is used because it has low **inductive reluctance**. In other words, iron freely expands or strengthens the magnetic field around the windings. The first, or primary, coil is normally composed of 100 to 200 turns of 20-gauge wire. This coil of wire conducts battery current. When a current is passing through the primary coil, it magnetizes the iron core. The strength of the magnet depends directly on the number of wire loops and the amount of current flowing through those loops. The secondary coil of wires may consist of 15,000 to 25,000, or more, turns of very fine copper wire.

Because of the effects of counter EMF on the current flowing through the primary winding, it takes some time for the coil to become fully magnetized or saturated. Therefore current flows in the primary winding for some time between firings of the spark plugs. The period of time during which there is primary current flow is called **dwell**. The length of the dwell period is important.

When current flows through a conductor, it will immediately reach its maximum value as allowed by the resistance in the circuit. If a conductor is wound into a coil, maximum current will not be immediately present. As the magnetic field begins to form as the current begins to flow, the magnetic lines of force of one part of the winding pass over another part of the winding. This tends to cause an opposition to current flow. This occurrence is called **reactance**. Reactance causes a temporary resistance to current flow and delays the flow of current from reaching its maximum value. When maximum current flow is present in a winding, the winding is said to be saturated and the strength of its magnetic field will also be at a maximum.

Saturation can only occur if the dwell period is long enough to allow for maximum current flow through the primary windings. A less than saturated coil will not be able to produce the voltage it was designed to produce. If the energy from the coil is too low, the spark plugs may not fire long enough or not fire at all.

When the primary coil circuit is suddenly opened, the magnetic field instantly collapses. The sudden collapsing of the magnetic field produces a very high voltage in the secondary windings. This high voltage is used to push current across the gap of the spark plug. **Figure 21–7** shows the coil's primary and secondary circuits in basic terms.

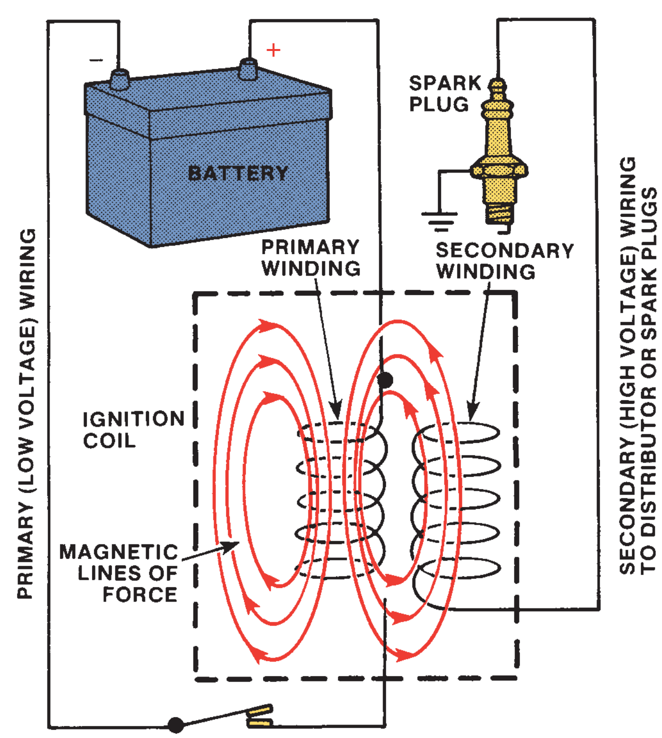

Figure 21-7 Current passing through the coil's primary winding creates magnetic lines of force that cut across and induce voltage in the secondary windings.

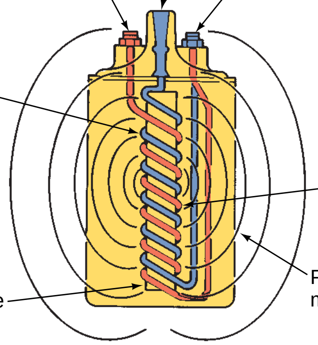

Figure 21–8 Ignition coil design. *Courtesy of DaimlerChrysler Corporation*

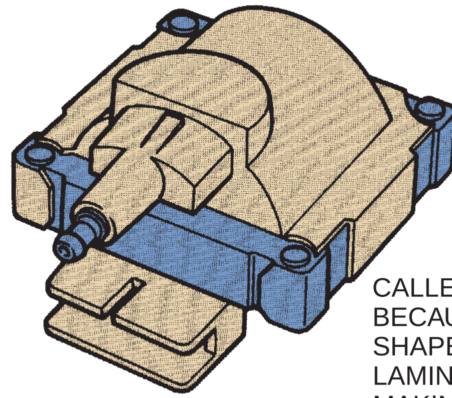

Figure 21–9 Typical E-core ignition coil. *Courtesy of Ford Motor Company*

IGNITION COIL CONSTRUCTION A laminated soft iron core is positioned at the center of the ignition coil and an insulated primary winding is wound around the core. The two ends of the primary winding are connected to the primary terminals on top of the coil **(Figure 21–8)**. These terminals are usually identified with positive and negative symbols. Enamel-type insulation prevents the primary windings from touching each other. Paper insulation is also placed between the layers of windings.

Secondary coil windings are on the inside of the primary winding. A similar insulation method is used on the secondary and primary windings. The ends of the secondary winding are usually connected to one of the primary terminals and to the high-tension terminal in the coil tower. When the windings and core assembly is mounted in the coil container, the core rests on a ceramic insulating cup in the bottom of the container. Metal sheathing is placed around the outside of the coil windings in the container. This sheathing concentrates the magnetic field on the outside of the windings. A sealing washer is positioned between the tower and the container to seal the unit. The coil assembly is filled with oil through the screw hole in the high-tension terminal. The unit is sealed to protect the windings and to keep the oil inside. The oil helps to cool the coil.

Most newer coils are not oil-cooled; they are air-cooled instead. These coils are constructed in much the same way, except the core is constructed from laminated sheets of iron. These sheets are shaped like the letter "E" and the primary and secondary windings are wound around the center of the E-core **(Figure 21–9)**.

SECONDARY VOLTAGE The typical amount of secondary coil voltage required to jump the spark plug gap is 10,000 volts. Most coils have at least 25,000 volts available from the secondary. The difference between the required voltage and the maximum available voltage is referred to as secondary reverse voltage. This reserve voltage is necessary to compensate for high cylinder pressures and increased secondary resistances as the spark plug gap increases through use. The maximum available voltage must always exceed the required firing voltage or ignition misfire will occur. If there is an insufficient amount of voltage available to push current across the gap, the spark plug will not fire.

Since DI and EI systems are both firing spark plugs with approximately the same air gaps, the amount of voltage required to fire the spark is nearly the same in both systems. However, EI systems have higher voltage reserves. If the additional voltage in an EI system is not used to start the spark across the plug's gap, it is used to maintain the spark for a longer period of time.

The number of ignition coils used in an ignition system varies with the type of ignition system found on a vehicle. In most ignition systems with a distributor, only one ignition coil is used. The high voltage of the secondary winding is directed, by the distributor, to the various spark plugs in the system. Therefore, there is one secondary circuit with a continually changing path.

While distributor systems have a single secondary circuit with a continually changing path, distributorless systems have several secondary circuits, each with an unchanging path.

Spark Plugs

Every type of ignition system uses spark plugs. The spark plugs provide the crucial air gap across which the high voltage from the coil flows in the form of an arc. The three main parts of a spark plug are the steel core, the ceramic core, or insulator, which acts as a heat conductor; and a pair of electrodes, one insulated in the core and the

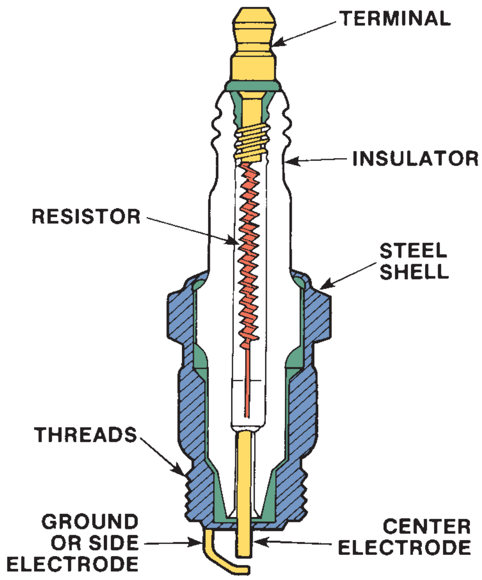

Figure 21–10 Components of a typical spark plug.

other grounded on the shell. The shell holds the ceramic core and electrodes in a gas-tight assembly and has the threads needed for plug installation in the engine **(Figure 21–10)**. An ignition cable connects the secondary to the top of the plug. Current flows through the center of the plug and arcs from the tip of the center (or side) electrode to the ground electrode. The resulting spark ignites the air/fuel mixture in the combustion chamber. Most automotive spark plugs also have a resistor between the top terminal and the center electrode. This resistor reduces radio frequency interference (RFI), which prevents noise on stereo equipment. Voltage peaks from RFI could also interfere with, or damage, on-board computers. Therefore, when resistor-type spark plugs are used as original equipment, replacement spark plugs must also be resistor-type. The resistor, like all other resistances in the secondary, increases the voltage needed to jump the gap of the spark plug.

Spark plugs come in many different sizes and designs to accommodate different engines. To fit properly, spark plugs must be of the proper size and reach. Another design factor that determines the usefulness of a spark plug for a specific application is its **heat range**. The desired heat range depends on the design of the engine and on the type of driving conditions the vehicle is subject to.

A terminal post on top of the center electrode is the point of contact for the spark plug cable. The center electrode, commonly made of a copper alloy, is surrounded by a ceramic insulator and a copper and glass seal is located between the electrode and the insulator. These seals prevent combustion gases from leaking out of the cylinder. Ribs on the insulator increase the distance between the terminal and the shell to help prevent electric arcing on the outside of the insulator. The steel spark plug shell

Figure 21–11 A platinum-tipped spark plug.

is crimped over the insulation and a ground electrode, on the lower end of the shell, is positioned directly below the center electrode. There is an **air gap** between these two electrodes, and the width of this air gap is specified by the auto manufacturer. Some spark plugs have platinum-tipped electrodes **(Figure 21–11)**, that greatly extend the life of the plug.

A spark plug socket may be placed over a hex-shaped area near the top of the shell for plug removal and installation. Threads on the lower end of the shell allow the plug to be threaded into the engine's cylinder head.

Size. Automotive spark plugs are available in either 14- or 18-millimeter diameters. All 18-millimeter plugs feature tapered seats that match similar seats in the cylinder head and need no gaskets. The 14-millimeter variety can have either a flat seat that requires a gasket or a tapered seat that does not. The latter is the most commonly used. All spark plugs have a hex-shaped shell that accommodates a socket wrench for installation and removal. The 14-millimeter, tapered seat plugs have shells with a $\frac{5}{8}$-inch hex; 14-millimeter gasketed and 18-millimeter tapered seat plugs have shells with a $\frac{13}{16}$-inch hex.

Reach. One of the most important design characteristics of spark plugs is the **reach (Figure 21–12)**. This refers to

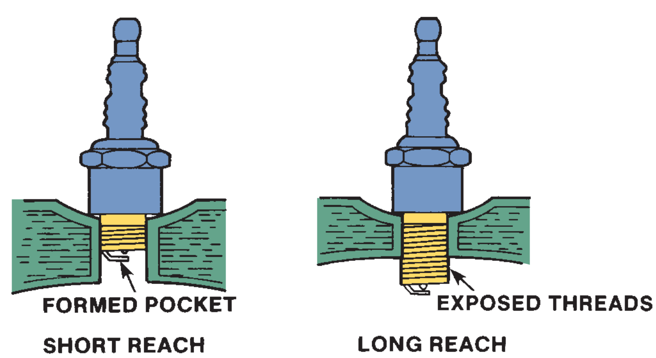

Figure 21–12 Spark plug reach: long versus short.

the length of the shell from the contact surface at the seat to the bottom of the shell, including both threaded and nonthreaded sections. Reach is crucial. The plug's air gap must be properly placed in the combustion chamber so it can produce the correct amount of heat. Installing plugs with too short a reach means the electrodes are in a pocket and the arc is not able to adequately ignite the air/fuel mixture. If the reach is too long, the exposed plug threads can get so hot they will ignite the air/fuel mixture at the wrong time, causing **preignition**. Preignition is a term used to describe abnormal combustion, which is caused by something other than the heat of the spark.

Heat Range. When the engine is running, most of the plug's heat is concentrated on the center electrode. Heat is quickly dissipated from the ground electrode because it is threaded into the cylinder head. The spark plug heat path is from the center electrode through the insulator into the shell and to the cylinder head, where the heat is absorbed by engine coolant circulating through the cylinder head. Spark plug heat range is determined by the depth of the insulator before it contacts the shell. For example, in a cold-range spark plug, the depth of the insulator is short before it contacts the shell. This cold-type spark plug has a short heat path, which provides cooler electrode operation **(Figure 21–13)**.

In a hot spark plug, the insulator depth is increased before it makes contact with the shell. This provides a longer heat path and increases electrode temperature. A spark plug needs to retain enough heat to clean itself between firings, but not be so hot that it damages itself or causes premature ignition of the air/fuel mixture in the cylinder.

If an engine is driven continually at low speeds, the spark plugs may become carbon fouled. Under this condition, a hotter range spark plug may be required. Severe high-speed driving over an extended time period may require a colder range spark plug to prevent electrode burning from excessive combustion chamber heat.

The heat range is indicated by a code imprinted on the side of the plug, usually on the porcelain insulator.

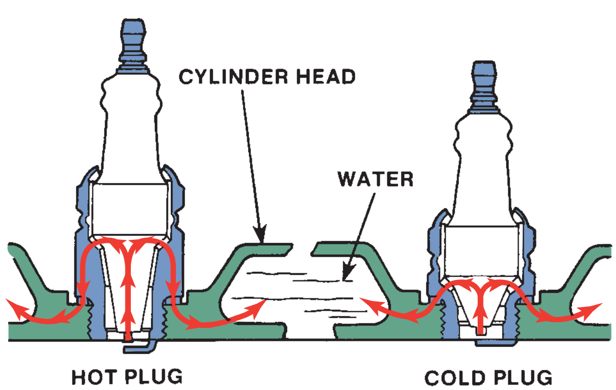

Figure 21–13 Spark plug heat range: hot versus cold.

SHOP TALK

When spark plugs must be replaced, follow the recommendations for plug type as specified by the engine and plug manufacturers. These are recommendations only. However, until you know more about the engine and its operating conditions than the manufacturers do, follow their recommendations. ■

Spark Plug Air Gap. The correct spark plug air gap is essential to achieve optimum engine performance and long plug life. A gap that is too wide requires higher voltage to jump the gap. If the required voltage is greater than what is available, the result is **misfiring**. Misfiring results from the inability of the ignition to jump the gap or the inability to maintain the spark. On the other hand, a gap that is too narrow requires lower voltages, which leads to rough idle and prematurely burned electrodes, due to higher current flow. Always set the gap according to the manufacturer's specifications.

Ignition Cables

Spark plug cables, or ignition cables, make up the secondary wiring. These cables carry the high voltage from the distributor or the multiple coils to the spark plugs. The cables are not solid wire; instead they contain fiber cores that act as resistors in the secondary circuit **(Figure 21–14)**. They cut down on radio and television interference, increase firing voltages, and reduce spark plug wear by decreasing current. Insulated boots on the ends of the cables strengthen the connections as well as prevent dust and water infiltration and voltage loss.

Some engines have spark plug cable heat shields **(Figure 21–15)** pressed into the cylinder head. These shields surround each spark plug boot and spark plug. They protect the spark plug boot from damage due to the extreme heat generated by the nearby exhaust manifold.

SPARK TIMING SYSTEMS

To better understand the operation of current ignition systems, it is helpful to first review how older, fully mechanical distributor systems worked.

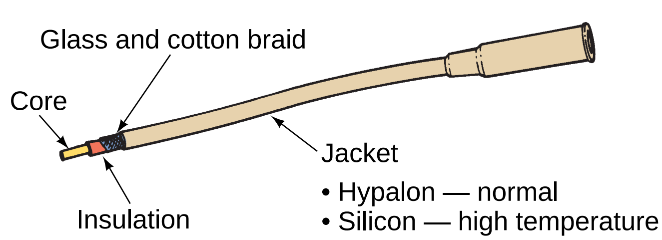

Figure 21–14 Spark plug cable construction. *Courtesy of DaimlerChrysler Corporation*

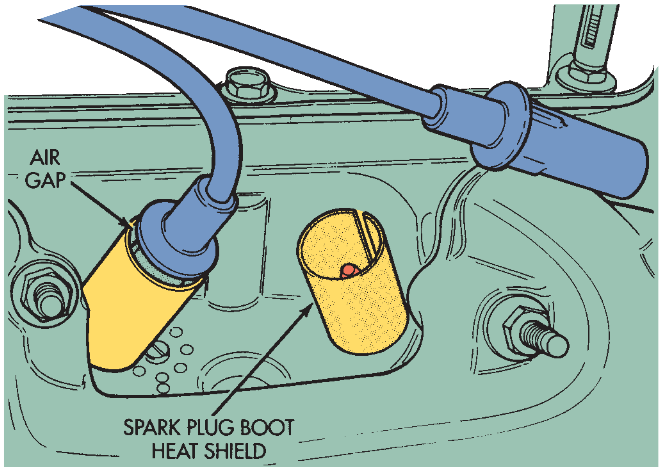

Figure 21-15 Spark plug boot heat shields. *Courtesy of DaimlerChrysler Corporation*

Breaker Point Ignition

Breaker point ignition systems were used on vehicles for more than 60 years, but were abandoned many years ago as engineers looked for ways to decrease emissions and increase fuel efficiency.

The distributor assembly acted as a mechanical switch to turn the primary circuit on and off. The distributor's shaft, cam, breaker points, and condenser performed this function. **Contact points** are used as the primary circuit triggering and switching device. The breaker point assembly, which was mounted on the **breaker plate** inside the distributor, consisted of a fixed contact, movable contact, movable arm, rubbing block, pivot, and spring. The fixed contact was grounded through the distributor housing, and the movable contact was connected to the negative terminal of the coil's primary winding. As the cam turned by the camshaft, the movable arm opened and closed, which opened and closed the primary circuit in the coil. When the points were closed, primary current flow attempted to saturate the coil. When the points opened, primary current stopped and the magnetic field collapsed, causing high voltage to be induced in the secondary. The firing of the plug was the result of opening the points.

Because voltage was still present at the movable arm when the breaker arms opened, current could continue to arc across the open point gap, which could damage the points. To prevent this, a condenser was attached to the movable arm. In this way, the voltage at the movable arm was retained by the condenser instead of arcing across the gap.

The distributor also mechanically adjusted the time the spark arrived at the cylinder through the use of two mechanisms: the centrifugal advance and the vacuum advance units. This improved engine performance, fuel efficiency, and emission levels.

As its name implies, the distributor mechanically distributed the spark so that it arrived at the right time during the compression stroke of each cylinder. The distributor's shaft, rotor, and cap performed this function.

Solid-State Ignition

From the fully mechanical breaker point system, ignition technology progressed to basic electronic or solid-state ignitions **(Figure 21–16)**. Breaker points were replaced

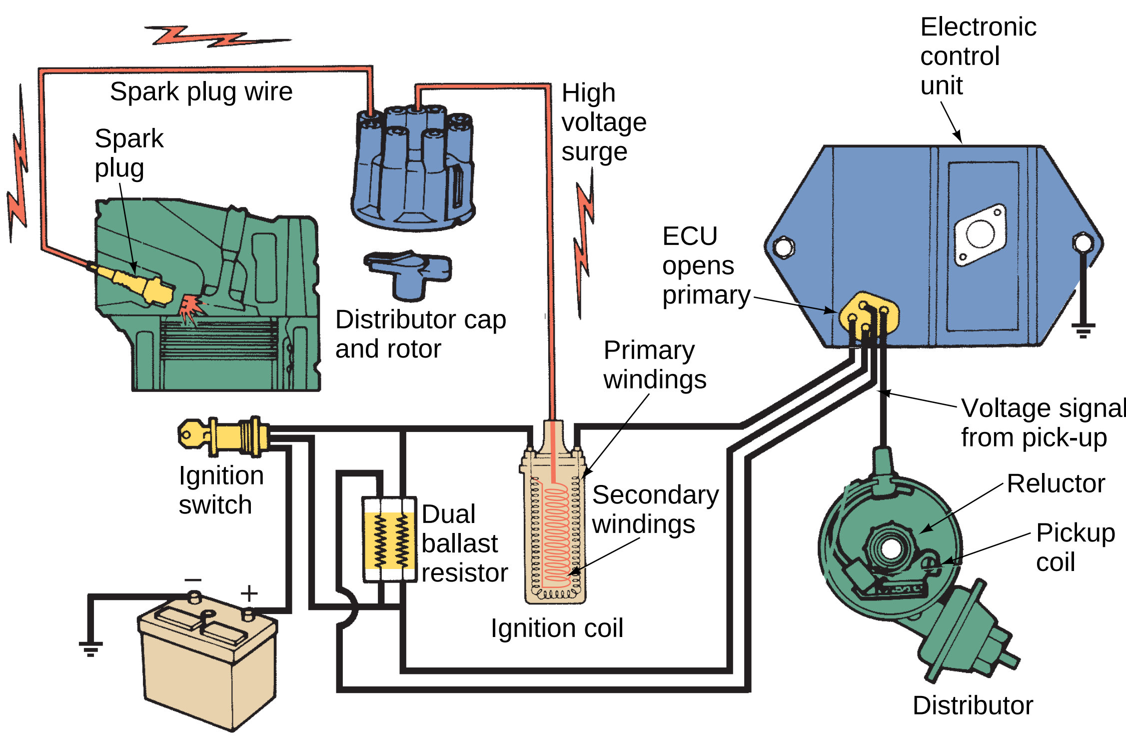

Figure 21-16 Typical early solid-state ignition system. *Courtesy of DaimlerChrysler Corporation*

with electronic triggering and switching devices. The electronic switching components are normally inside a separate housing known as an electronic control unit (ECU) or control module. The original (solid state) electronic ignitions still relied on mechanical and vacuum advance mechanisms in the distributor.

As technology advanced, many manufacturers expanded the ability of the ignition control modules. For example, by tying a manifold vacuum sensor into the ignition module circuitry, the module could now detect when the engine was under heavy load and retard the timing automatically. Similar add-on sensors and circuits were designed to control spark knock, start-up emissions, and altitude compensation.

Computer-Controlled Ignition

Computer-controlled ignition systems offer continuous spark timing control through a network of engine sensors and a central microprocessor. Based on the inputs it receives, the central microprocessor or computer makes decisions regarding spark timing and sends signals to the ignition module to fire the spark plugs according to those inputs and the programs in its memory.

SWITCHING SYSTEMS

Electronic ignition systems control the primary circuit with an NPN transistor. The transistor's emitter is connected to ground. The collector is connected to the negative (–) terminal of the coil. When the triggering device supplies a small amount of current to the base of the switching transistor, the collector and emitter allow current to build up in the coil primary circuit. When the current to the base is interrupted by the switching device, the collector and emitter interrupt the coil primary current. An example of how this works is shown in **Figure 21–17**, which is a simplified diagram of an electronic ignition system.

Engine Position Sensors

The time when the primary circuit must be opened and closed is related to the position of the pistons and the crankshaft. Therefore, the position of the crankshaft is used to control the flow of current to the base of the switching transistor.

A number of different types of sensors are used to monitor the position of the crankshaft and control the flow of current to the base of the transistor. These engine position sensors and generators serve as triggering devices and include magnetic pulse generators, metal detection sensors, Hall-effect sensors, and photoelectric (optical) sensors.

The mounting location of these sensors depends on the design of the ignition system. All four types of sensors can be mounted in the distributor, which is turned by the camshaft.

Magnetic pulse generators and Hall-effect sensors can also be located on the crankshaft. These sensors are also commonly used on EI systems.

Magnetic Pulse Generator

Basically, a magnetic pulse generator consists of two parts: a timing disc and a pick-up coil. The timing disc may also be called a reluctor, trigger wheel, pulse ring, armature, or timing core. The pick-up coil, which consists of a length of wire wound around a weak permanent magnet, may also be called a stator, sensor, or pole piece. Depending on the type of ignition system used, the timing disc may be mounted on the distributor shaft, at the rear of the crankshaft **(Figure 21–18)**, or on the crankshaft vibration damper **(Figure 21–19)**.

The magnetic pulse or PM generator operates on basic electromagnetic principles. Remember that a voltage can only be induced when a conductor moves through a magnetic field. The magnetic field is provided by the pick-up unit and the rotating timing disc provides the movement through the magnetic field needed to induce voltage.

As the disc teeth approach the pick-up coil, they repel the magnetic field, forcing it to concentrate around the pick-up coil **(Figure 21–20A)**. Once the tooth passes by the pick-up coil, the magnetic field is free to expand or unconcentrate **(Figure 21–20B)**, until the next tooth on the disc approaches. Approaching teeth concentrate the

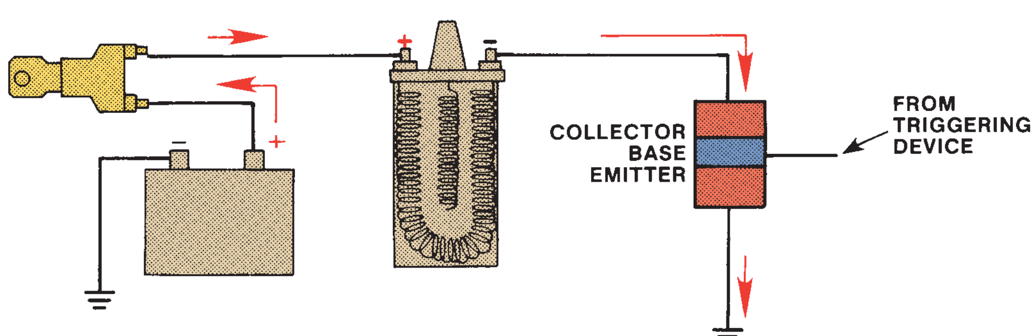

Figure 21–17 When the triggering device supplies a small amount of current to the transistor's base, the primary coil circuit is closed and current flows.

Figure 21-18 Magnetic pulse generator positioned to sense flywheel rotation. *Courtesy of DaimlerChrysler Corporation*

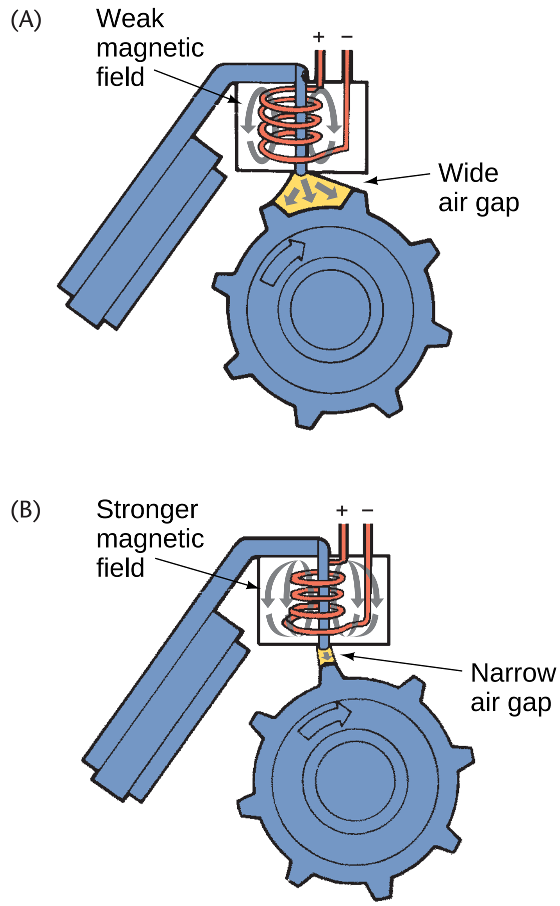

Figure 21-20 (A) Wide gap produces a weak magnetic signal (B) Narrow gap produces a strong magnetic field. *Courtesy of DaimlerChrysler Corporation*

magnetic lines of force, while passing teeth allow them to expand. This pulsation of the magnetic field causes the lines of magnetic force to cut across the winding in the pick-up coil, inducing a small amount of AC voltage that is sent to the switching device in the primary circuit.

When a disc tooth is directly in line with the pick-up coil, the magnetic field is not expanding or contracting.

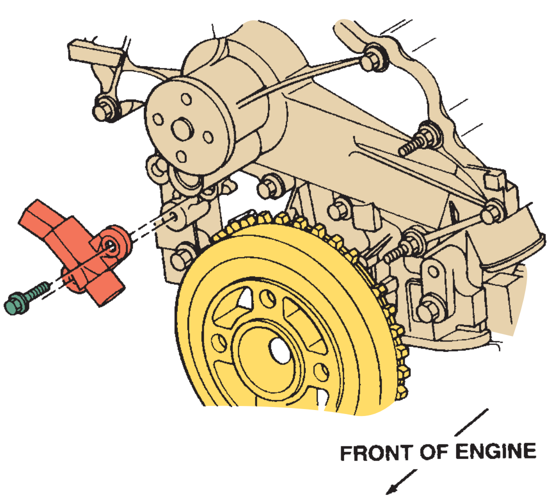

Figure 21-19 Crankshaft position sensor. *Courtesy of Ford Motor Company*

Since there is no movement or change in the field, voltage at this precise moment drops to zero. At this point, the switching device inside the ignition module reacts to the zero voltage signal by turning the ignition's primary circuit current off. As explained earlier, this forces the magnetic field in the primary coil to collapse, discharging a secondary voltage to the distributor or directly to the spark plug.

As soon as the tooth rotates past the pick-up coil, the magnetic field expands again and another voltage signal is induced. The only difference is that the polarity of the charge is reversed. Negative becomes positive or positive becomes negative. Upon sensing this change in voltage, the switching device turns the primary circuit back on and the process begins all over.

The slotted disc is mounted on the crankshaft, vibration damper, or distributor shaft in a very precise manner. When the disc teeth align with the pick-up coil, this corresponds to the exact time certain pistons are nearing TDC. This means the zero voltage signal needed to trigger the secondary circuit occurs at precisely the correct time.

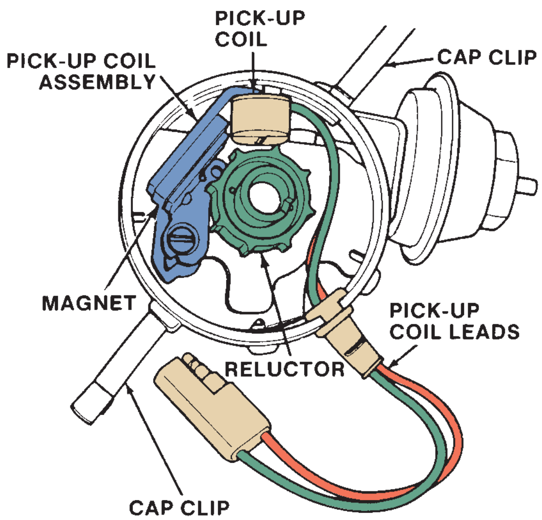

Figure 21–21 Magnetic pulse generator (pick-up coil) used on early Chrysler electronic ignition systems.

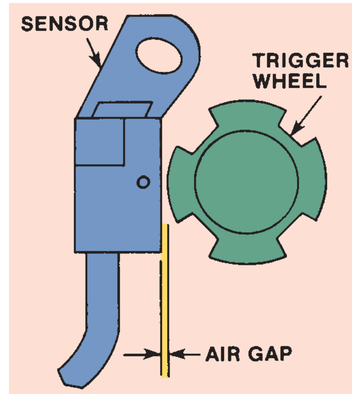

Figure 21–22 In a metal detecting sensor, the revolving trigger wheel teeth alter the magnetic field produced by the electromagnet in the pick-up coil.

The pick-up coil might have only one pole as shown as **Figure 21–21**. Other magnetic pulse generators have pick-up coils with two or more poles.

Metal Detection Sensors

Metal detection sensors are found on early electronic ignition systems. They work much like a magnetic pulse generator with one major difference.

A trigger wheel is pressed over the distributor shaft and a pick-up coil detects the passing of the trigger teeth as the distributor shaft rotates. However, unlike a magnetic pulse generator, the pick-up coil of a metal detection sensor does not have a permanent magnet. Instead, the pick-up coil is an electromagnet. A low level of current is supplied to the coil by an electronic control unit, inducing a weak magnetic field around the coil. As the reluctor on the distributor shaft rotates, the trigger teeth pass very close to the coil **(Figure 21–22)**. As the teeth pass in and out of the coil's magnetic field, the magnetic field builds and collapses, producing a corresponding change in the coil's voltage. The voltage changes are monitored by the control unit to determine crankshaft position.

Hall-Effect Sensor

The Hall-effect sensor or switch is the most commonly used engine position sensor. There are several good reasons for this. Unlike a magnetic pulse generator, the Hall-effect sensor produces an accurate voltage signal throughout the entire rpm range of the engine. Furthermore, a Hall-effect switch produces a square wave signal that is more compatible with the digital signals required by on-board computers.

Functionally, a Hall switch performs the same tasks as a magnetic pulse generator. But the Hall switch's method of generating voltage is quite unique. It is based on the Hall-effect principle, which states: If a current is allowed to flow through a thin conducting material, and that material is exposed to a magnetic field, voltage is produced.

The heart of the Hall generator is a thin semiconductor layer (Hall layer) derived from a gallium arsenate crystal. Attached to it are two terminals-one positive and the other negative-that are used to provide the source current for the Hall transformation.

Directly across from this semiconductor element is a permanent magnet. It is positioned so that its lines of flux bisect the Hall layer at right angles to the direction of current flow. Two additional terminals, located on either side of the Hall layer, form the signal output circuit.

When a moving metallic shutter blocks the magnetic field from reaching the Hall layer or element, the Hall-effect switch produces a voltage signal. When the shutter blade moves and allows the magnetic field to expand and reach the Hall element, the Hall-effect switch does not generate a voltage signal **(Figure 21–23)**.

The Hall switch is described as being "on" any time the Hall layer is exposed to a magnetic field and a Hall voltage is being produced **(Figure 21–24)**. However, before this signal voltage can be of any use, it has to be modified. After leaving the Hall layer, the signal is routed to an amplifier where it is strengthened and inverted so the signal reads high when it is actually coming in low and vice versa. Once it has been inverted, the signal goes through a pulse-shaping device called the Schmitt trigger where it is turned into a clean square wave signal. After conditioning, the signal is sent to the base of a switching transistor that is designed to turn on and off in response to the signals generated by the Hall switch assembly.

The shutter wheel is the last major component of the Hall switch. The shutter wheel consists of a series of alternating windows and vanes that pass between the Hall layer and magnet. The shutter wheel may be part of

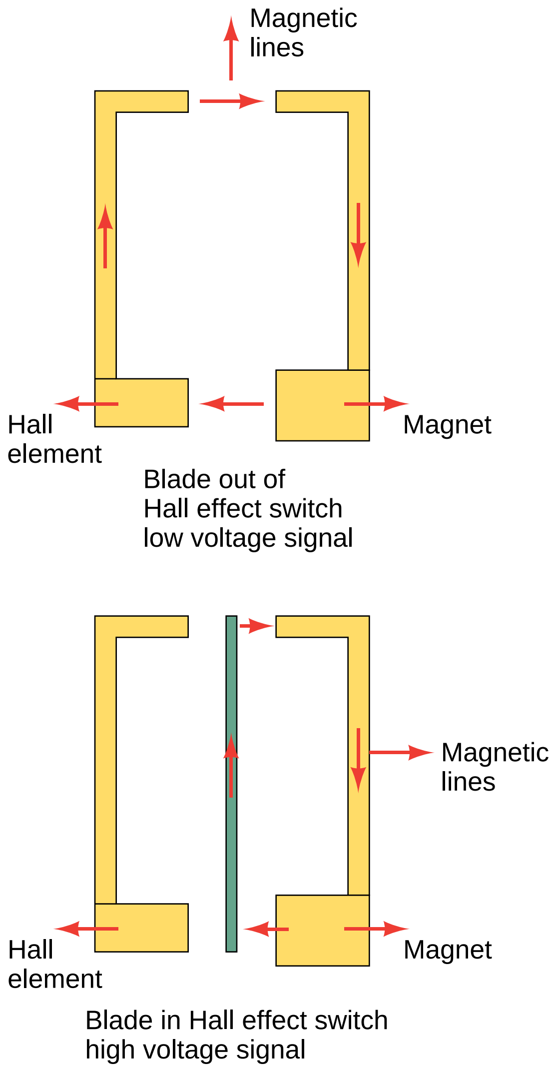

Figure 21–23 Blade and magnetic field action in a Hall-effect switch.

the distributor rotor **(Figure 21–25)** or be separate from the rotor.

The points where the shutter vane begins to enter and begins to leave the air gap are directly related to primary circuit control. As the leading edge of a vane enters the air gap, the magnetic field is deflected away from the Hall layer; Hall voltage decreases. When that happens, the modified Hall output signal increases abruptly and turns on the switching transistor. Once the transistor is turned on, the primary circuit closes and the coil's energy storage cycle begins.

Primary current continues to flow as long as the vane is in the air gap. As the vane starts to leave the gap, however, the reforming Hall voltage signal prompts a parallel decline in the modified output signal. When the output signal goes low, the bias of the transistor changes. Primary current flow stops.

In summary, the ignition module supplies current to the coil's primary winding as long as the shutter wheel's vane is in the air gap. As soon as the shutter wheel moves away and the Hall voltage is produced, the control unit stops primary circuit current, high secondary voltage is induced, and ignition occurs.

In addition to ignition control, a Hall switch can also be used to generate precise rpm signals (by determining

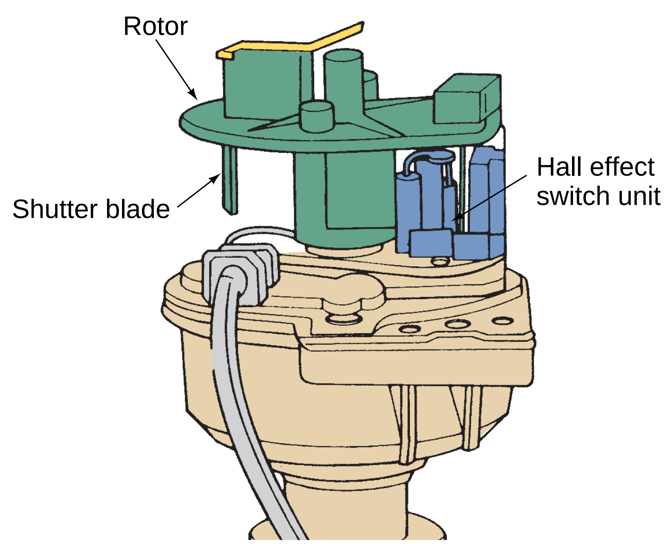

Figure 21–25 Hall effect switch mounted inside a distributor. *Courtesy of DaimlerChrysler Corporation*

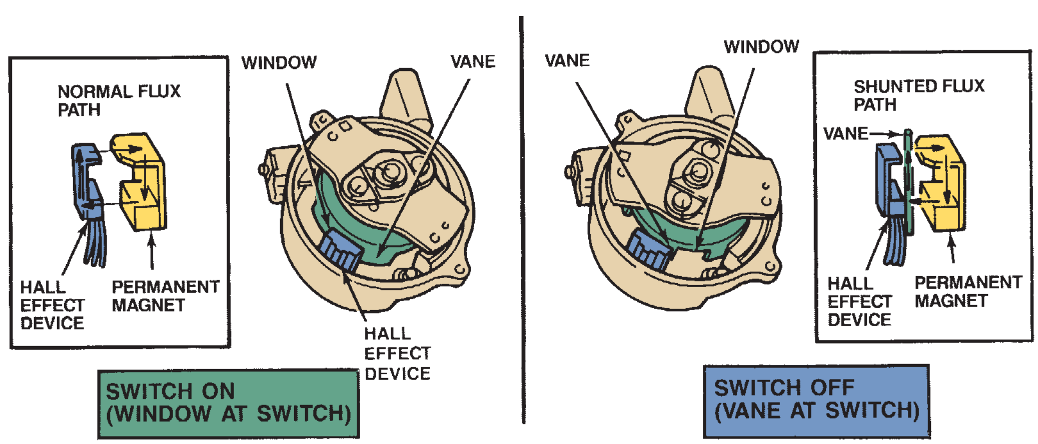

Figure 21–24 Operation of a Hall-effect switch. *Courtesy of Ford Motor Company*

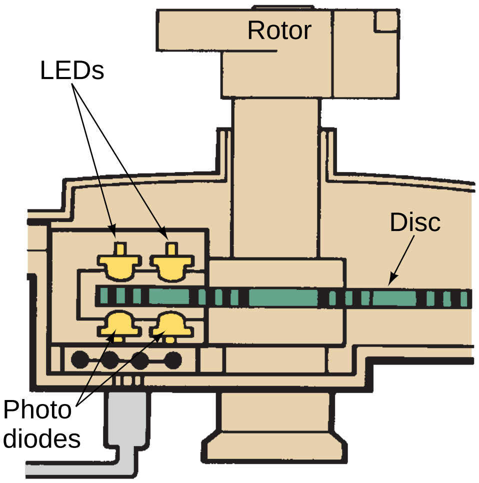

Figure 21–26 Distributor with optical-type pick-ups.
Courtesy of DaimlerChrysler Corporation

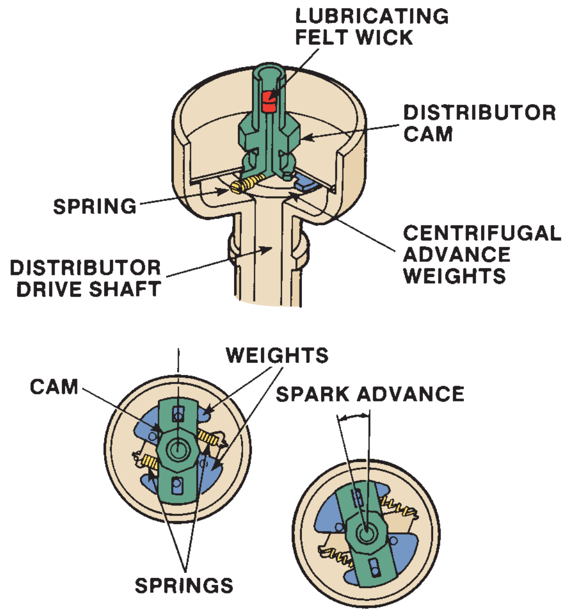

Figure 21–27 Typical centrifugal advance mechanism.

the frequency at which the voltage rises and falls) and provide the sync pulse for sequential fuel ignition operation.

Photoelectric Sensor

A fourth type of crankshaft position sensor is the **photoelectric sensor**. The parts of this sensor include a light-emitting diode (LED), a light-sensitive phototransistor (photo cell), and a slotted disc called a light beam interrupter **(Figure 21–26)**.

The slotted disc is attached to the distributor shaft. The LED and the photo cell are situated over and under the disc opposite each other. As the slotted disc rotates between the LED and photo cell, light from the LED shines through the slots. The intermittent flashes of light are translated into voltage pulses by the photo cell. When the voltage signal occurs, the control unit turns on the primary system. When the disc interrupts the light and the voltage signal ceases, the control unit turns the primary system off, causing the magnetic field in the coil to collapse and sending a surge of voltage to a spark plug.

The photoelectric sensor sends a very reliable signal to the control unit, especially at low engine speeds. These units have been primarily used on Chrysler and Mitsubishi engines. Some Nissan and General Motors products have used them as well.

Timing Advance

As stated, early solid-state ignition systems changed the timing mechanically. At idle, the firing of the spark plug usually occurs just before the piston reaches top dead center. At higher engine speeds, however, the spark must be delivered to the cylinder much earlier in the cycle to achieve maximum power from the air/fuel mixture because the engine is moving through the cycle more quickly. To change the timing of the spark in relation to rpm, the **centrifugal advance** mechanism was used **(Figure 21–27)**.

CENTRIFUGAL ADVANCE This mechanism consists of a set of pivoted weights and springs connected to the distributor shaft and a distributor armature assembly. During idle speeds, the springs keep the weights in place and the armature and distributor shaft rotate as one assembly. When speed increases, centrifugal force causes the weights to slowly move out against the tension of the springs. This allows the armature assembly to move ahead in relation to the distributor shaft rotation. The ignition's triggering device is mounted to the armature assembly. Therefore, as the assembly moves ahead, ignition timing becomes more advanced.

VACUUM ADVANCE During part-throttle engine operation, high vacuum is present in the intake manifold. To get the most power and the best fuel economy from the engine, the plugs must fire even earlier during the compression stroke than is provided by a centrifugal advance mechanism.

The heart of the **vacuum advance** mechanism **(Figure 21–28)** is the spring-loaded diaphragm, which fits inside a metal housing and connects to a movable plate on which the pick-up coil is mounted. Vacuum is applied to one side of the diaphragm in the housing chamber, while the other side of the diaphragm is open to the atmosphere. Any increase in vacuum allows atmospheric pressure to push the diaphragm. In turn, this causes the movable plate to rotate. The more vacuum present on one side of the diaphragm, the more atmospheric pressure is able to cause a change in timing. The rotation of the movable plate moves the pick-up coil so the armature develops a signal earlier. These units are also equipped with a spring that returns the timing back to basic as the vacuum decreases.

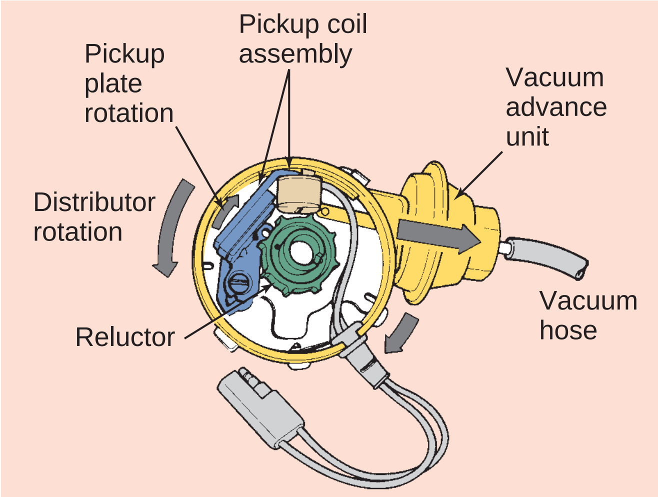

Figure 21-28 Typical vacuum advance unit operation.
Courtesy of DaimlerChrysler Corporation

The vacuum advance unit is bolted to the side of the distributor housing. On some models, the vacuum hose for the vacuum advance is connected directly to the intake manifold, whereas on other models this hose is connected to a fitting right above the throttle plates. The diaphragm is pushed inward toward the distributor housing by a spring positioned between the diaphragm and the end of the sealed chamber. An arm is attached to the side of the diaphragm next to the distributor housing, and the inner end of the arm is mounted over a pin on the pickup plate.

If the engine is operating at a moderate cruising speed, high intake manifold vacuum is applied to the vacuum advance diaphragm, thereby advancing the timing. When the engine is operating at a moderate cruising speed with a partially opened throttle, the amounts of cylinder air intake, compression pressure, and compression temperature are low. Under these conditions, the air/fuel mixture does not burn as fast and the additional spark advance provides more burn time, which increases fuel economy and engine performance.

If the engine is operating at or near wide-open throttle, the amounts of cylinder air intake, compression pressure, and compression temperature are increased, which causes faster burning of the air/fuel mixture. During these operating conditions, the spark advance must be retarded to prevent engine detonation. Intake manifold vacuum is very low at wide throttle opening. Therefore, little vacuum is present to work against the spring in the vacuum advance unit. When this action occurs, the pick-up coil is moved back toward the base timing position and the amount of spark advance is reduced.

If the vacuum advance hose is connected above the throttle plates, the vacuum advance does not provide any spark advance when the engine is idling. When the vacuum advance hose is connected directly into the intake manifold, the vacuum advance is fully advanced at idle speed, which provides lower engine temperatures.

Distributor

The reluctor and distributor shaft assembly rotates on bushings in the aluminum distributor housing. A roll pin extends through a retainer and the distributor shaft to retain the shaft in the distributor. Another roll pin retains the drive gear to the lower end of the shaft. On many engines, this drive gear is meshed with the camshaft gear to drive the distributor. Some distributors have an offset slot on the end of the distributor shaft that meshes with a matching slot in a gear driven from the camshaft. The gear size is designed to drive the distributor at the same speed as the camshaft, which rotates at one-half the speed of the crankshaft in a four-stroke cycle engine.

If the distributor has advance mechanisms, the centrifugal advance is sometimes mounted under the pickup plate, and the vacuum advance is positioned on the side of the distributor. Most engines manufactured in recent years have computer-controlled spark advance, and the distributor advance mechanisms are eliminated.

DISTRIBUTOR IGNITION SYSTEM OPERATION

The primary circuit of a distributor ignition (DI) system is controlled electronically by one of the sensors just described and an electronic control unit (module) that contains some type of switching device.

Primary Circuit

When the ignition switch is in the ON position, current from the battery flows through the ignition switch and primary circuit resistor to the primary winding of the ignition coil. From there it passes through some type of switching device and back to ground. The switching device is controlled by the triggering device. The current flow in the ignition coil's primary winding creates a magnetic field. The switching device or control module interrupts this current flow at predetermined times. When it does, the magnetic field in the primary winding collapses. This collapse generates a high-voltage surge in the secondary winding of the ignition coil. The secondary circuit of the system begins at this point and as a result the spark plug fires.

Once the plug stops firing, the transistor closes the primary coil circuit. The length of time the transistor allows current flow in the primary ignition circuit is determined by the electronic circuitry in the control module.

Some systems used a dual ballast resistor. The ceramic ballast resistor assembly is mounted on the fire wall and has a ballast resistor for primary current flow and an auxiliary resistor for the control module. The ballast resistor has a 0.5-ohm resistance that maintains a constant primary current. The auxiliary ballast resistor uses a 5-ohm resistance to limit voltage to the electronic control unit.

DI System Design

Through the years there have been many different designs of DI systems. All operate in the basically the same way but are configured differently. The systems described in this section represent the different designs used by manufacturers. These designs are based on the location of the electronic control module (unit) (ECU) and or the type of triggering device used.

DI Systems with External Ignition Module. Ford Motor Company used two generations of Dura-Spark ignition systems **(Figure 21–29)**. The second design (Dura-Spark II) was based on the first (Dura-Spark I). The Dura-Spark II had the ECU mounted away from the distributor, typically on a fender wall. The distributor was fitted with centrifugal and vacuum advance assemblies. The negative primary coil terminal is referred to as a distributor electronic control (dec) or tachometer (tach) terminal. This terminal is connected to the ignition module.

The distributor pick-up coil is connected through two wires to the module. A wire is also connected from the distributor housing to the module. This wire supplies a ground connection from the module to the pick-up plate; therefore, the module does not need to be grounded at its mounting.

An armature is mounted on the distributor shaft with a roll pin. The armature has a high point for each cylinder of the engine. Rivets are used to attach the pick-up coil to the plate, which indicates that the pick-up gap is not adjustable.

A unique feature of this ignition system is the design of the distributor. The cap is a two-piece unit. An adapter, the lower portion of the cap, is positioned on top of the distributor housing. Its upper diameter is larger than the lower. This increased diameter allows for a larger distributor cap. The larger diameter cap places the spark plug terminals farther apart. This helps to prevent cross firing.

DI Systems with Module Mounted on the Distributor. **A thick film integrated** (**TFI**) ignition system has the ECU mounted on the distributor. This ignition system from Ford uses an epoxy (E) core ignition coil. The windings of the coil are set in epoxy and are surrounded by an iron core. Neither a ballast resistor nor resistor wire are used to connect the ignition switch to the coil. The negative primary coil terminal is referred to as a tach terminal. This terminal is connected to the module. A wire is connected from the ignition switch start terminal to the module. The module-to-pick-up terminals extend through the distributor housing, and three pick-up lead wires are connected to these terminals **(Figure 21–30)**. Heat-dissipating grease must be placed on the back of the module to prevent overheating of the module. Con-

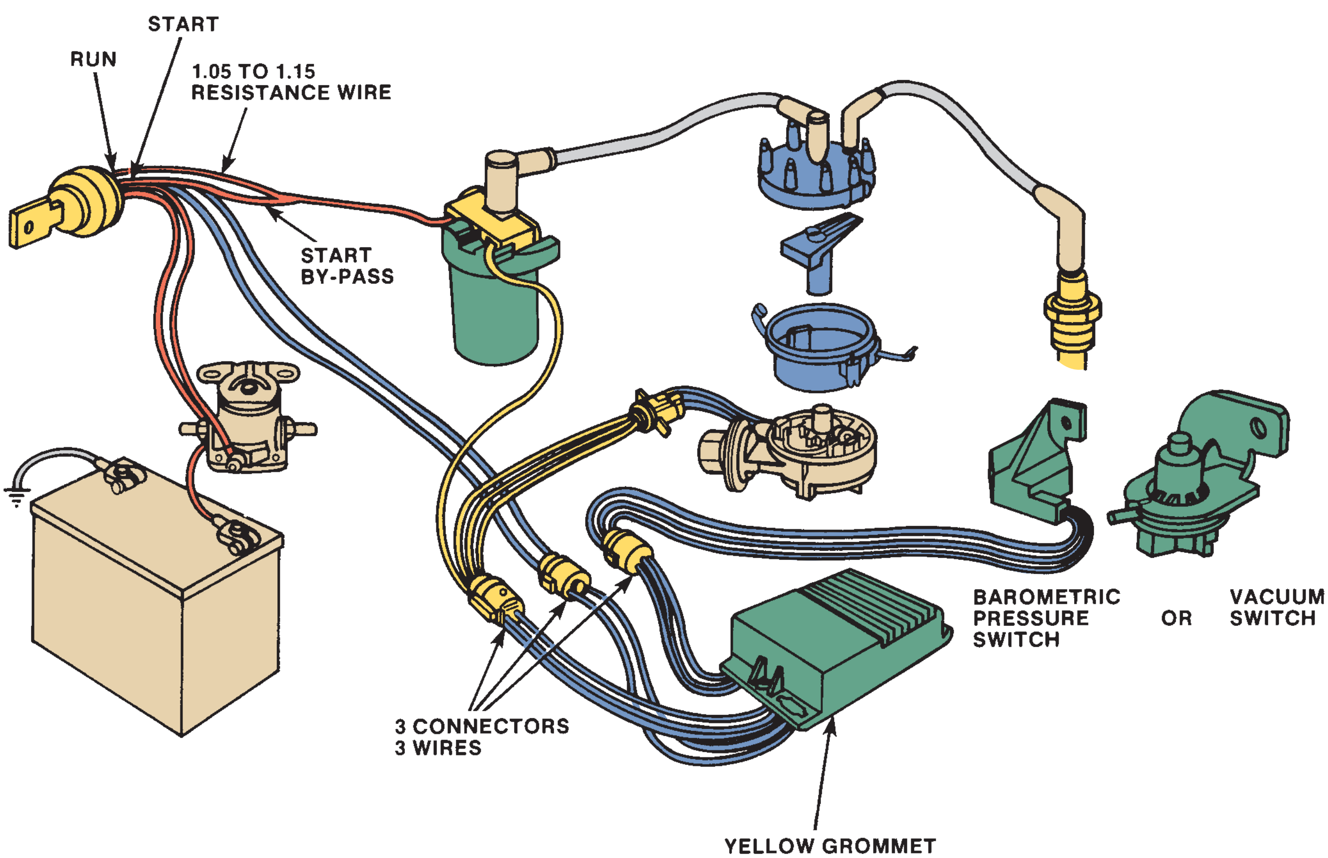

Figure 21–29 A typical DI system. *Courtesy of Ford Motor Company*

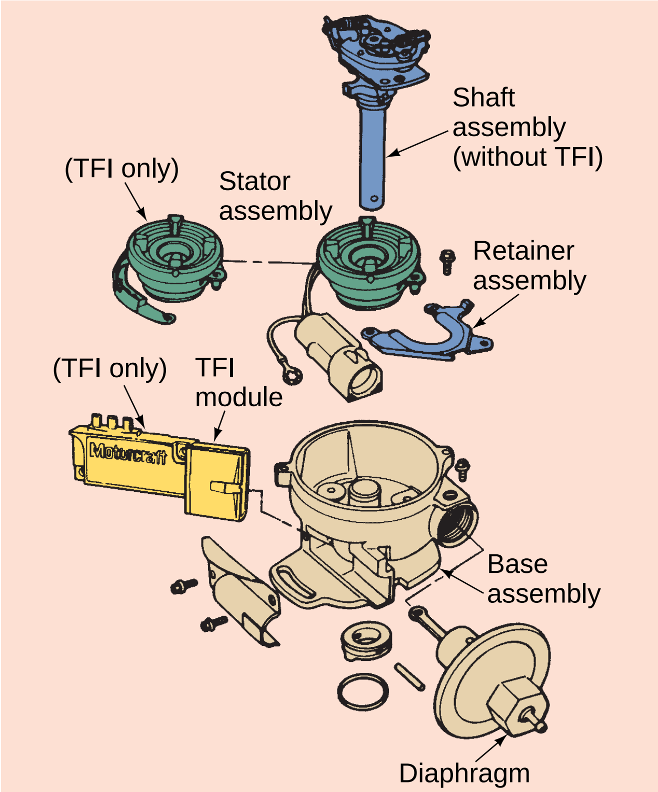

Figure 21–30 TFI distributor assembly. *Courtesy of Ford Motor Company*

ventional centrifugal and vacuum advances are used in the TFI distributor.

DI Systems with Internal Ignition Module. Perhaps the best example of a DI system with the ignition module inside the distributor is the GM **High Energy Ignition** (**HEI**) system **(Figure 21–31)**. Some HEI units also contain the ignition coil, others have the coil remotely mounted away from the distributor. Some early HEI designs have centrifugal and vacuum advance units, while others utilize electronic spark timing.

The pick-up coil surrounds the distributor shaft, and a flat magnetic plate is bolted between the pick-up coil and the pole piece. A **timer core** that has one high point for each engine cylinder is attached to the distributor shaft. The number of timer core high points matches the number of teeth on the pole piece. This design allows the timer core high points to be aligned with the pole piece teeth at the same time. The module is mounted to the breaker plate and is set in heat-dissipating grease. A capacitor is connected from the module voltage supply terminal to ground on the distributor housing.

In some HEI designs, the coil is mounted in the top of the distributor cap; other designs have externally mounted coils. The coil battery terminal is connected directly to the ignition switch, and the coil tachometer (tach) terminal is connected to the module **(Figure 21–32)**. HEI coils are basically E core coils and rely on the surrounding air to dissipate the coil's heat.

A wire also extends from the coil's battery terminal to the module. In systems with an internal ignition coil, a ground wire is connected between the frame of the coil and the distributor housing. This lead is used to dissipate any voltage induced in the coil's frame.

When the ignition switch is on and the distributor shaft is not turning, the module opens the primary ignition circuit. As the engine is cranked and the timer core high points approach alignment with the pole piece teeth, a positive voltage is induced in the pick-up coil. This voltage signal causes the module to close the primary circuit, and current begins to flow through the primary windings, causing a magnetic field to form around them.

At the instant of alignment between the timer core high points and pole piece teeth, the pick-up coil voltage drops to zero. As these high points move out of alignment,

Figure 21–31 The control module mounted inside a GM HEI distributor.

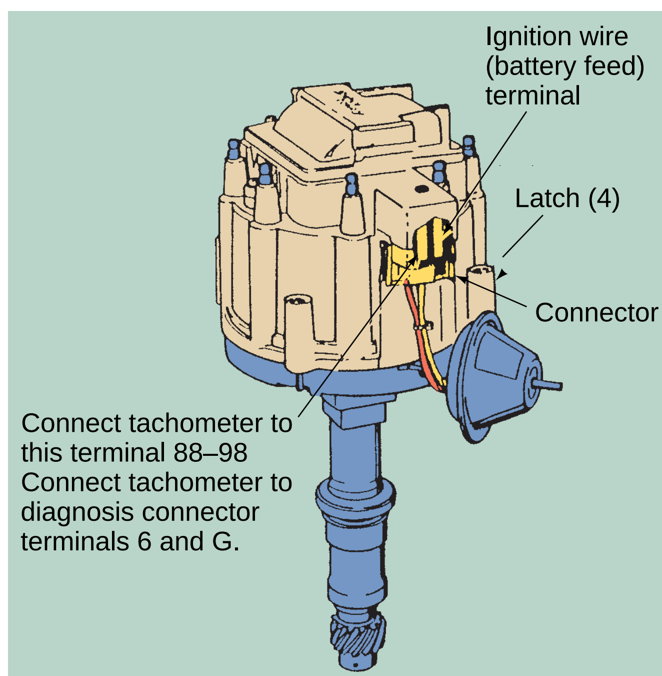

Figure 21–32 HEI distributor terminal identification. *Courtesy of General Motors Corporation—Oldsmobile Motor Division*

a negative voltage is induced in the pick-up coil. This voltage signal to the module causes the module to open the primary circuit. When this action occurs, the magnetic field collapses across the ignition coil windings, and the induced secondary voltage forces current through the secondary circuit and across the spark plug gap.

HEI modules have a variable dwell feature, which closes the primary circuit sooner as engine speed increases. In an eight-cylinder distributor, there are 45 degrees of distributor shaft rotation between the timer core high points. At idle speed, the module closes the primary circuit for 15 degrees and opens the circuit for 30 degrees. If the engine is operating at high speed, the module may close the primary circuit for 32 degrees and open the circuit for 13 degrees. This dwell increase which occurs with speed increase allows for better coil saturation at higher speeds. Since dwell is a function of the module, there is no dwell adjustment.

Computer-Controlled DI Systems

Spark timing on these systems is controlled by a computer that continuously adjusts ignition timing to obtain optimum combustion. The computer monitors the engine operating parameters with various sensors. Based on this input, the computer signals an ignition module to collapse the primary circuit, allowing the secondary circuit to fire the spark plugs.

Timing control is selected by the computer's program. During engine starting, computer control is by-passed and the mechanical setting of the distributor controls spark timing. Once the engine is started and running, spark timing is controlled by the computer. This scheme or **strategy** allows the engine to start regardless of whether the electronic control system is functioning properly or not.

The goal of computerized spark timing is to produce maximum engine power, top fuel efficiency, and minimum emissions levels during all types of operating conditions. The computer does this by continuously adjusting ignition timing. The computer determines the best spark timing based on certain engine operating conditions such as crankshaft position, engine speed, throttle position, engine coolant temperature, and initial and operating manifold or barometric pressure. Once the computer receives input from these and other sensors, it compares the existing operating conditions to information permanently stored or programmed into its memory. The computer matches the existing conditions to a set of conditions stored in its memory, determines proper timing setting, and sends a signal to the ignition module to fire the plugs.

The computer continuously monitors existing conditions, adjusting timing to match what its memory tells it is the ideal setting for those conditions. It can do this very quickly, making thousands of decisions in a single second. The control computer typically has the following types of information permanently programmed into it.

- Speed-related spark advance. As engine speed increases to a particular point, there is a need for more advanced timing. As the engine slows, the timing should be retarded or have less advance. The computer bases speed-related spark advance decisions on engine speed and signals from the TP sensor.
- Load-related spark advance. This is used to improve power and fuel economy during acceleration and heavy load conditions. The computer defines the load and the ideal spark advance by processing information from the TP sensor, MAP, and engine speed sensors. Typically, the more load on an engine, the less spark advance is needed.
- Warm-up spark advance. This is used when the engine is cold, because a greater amount of advance is required while the engine warms up.
- Special spark advance. This is used to improve fuel economy during steady driving conditions. During constant speed and load conditions, the engine will be more efficient with much advance timing.
- Spark advance due to barometric pressure. This is used when barometric pressure exceeds a preset calibrated value.

All of this information is looked at by the computer to determine the ideal spark timing for all conditions. The calibrated or programmed information in the computer is contained in what is called software **look-up tables**.

Ignition timing can also work in conjunction with the electronic fuel control system to provide emission control, optimum fuel economy, and improved driveability. They are all dependent on spark advance. Some examples of computer-controlled DI systems follow.

Chrysler's Dual Pick-up System. This system has two Hall-effect switches in the distributor when the engine is equipped with port fuel injection. In some units, the pick-up unit used for ignition triggering is located above the pick-up plate in the distributor and is referred to as the reference pick-up. The second pick-up unit is positioned below the plate. A ring with two notches is attached to the distributor shaft and rotates through the lower pick-up unit. This lower pick-up is called the synchronizer (SYNC) pickup.

In other designs, the two pick-up units are mounted below the pick-up plate and one set of blades rotates through both Hall-effect units **(Figure 21–33)**. The shutter blade representing number one cylinder has a large opening in the center of the blade. When this blade rotates through the SYNC pick-up, a different signal is produced compared to the other blades. This number one blade signal informs the PCM when to activate the injectors.

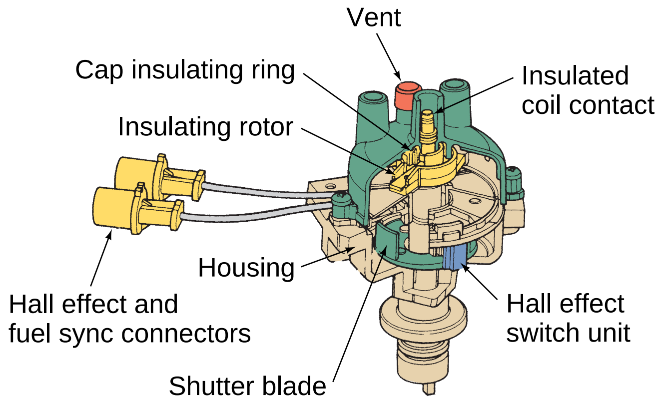

Figure 21–33 A distributor assembly with two Hall-effect switches below the pick-up plate. *Courtesy of DaimlerChrysler Corporation*

There are two Hall-effect pick-ups in distributors used with Chrysler port fuel injection, whereas the distributors used with throttle body injection have a single pick-up. When the SYNC pickup signal is received by the PCM every one-half distributor shaft revolution, or once every crankshaft revolution, the PCM grounds two injectors to inject fuel into two cylinders.

Distributors with Optical-Type Pick-ups. The 3.0 L V-6 engine available in some Chrysler products has a distributor fitted with an optical pick-up assembly with two light-emitting diodes and two photo diodes. A thin plate attached to the distributor shaft rotates between the LEDs above the plate and the photo diodes below the plate. This plate contains six equally spaced slots, which rotate directly below the inner LED and photo diode.

The inner LED and photo diode act as the reference pick-up. As in Hall-effect-pickup systems, the reference pick-up in the optical distributor provides a crankshaft position and speed signal to the PCM. When the ignition switch is on, the PCM supplies voltage to the optical pick-up, which causes the LEDs to emit light. If a solid part of the plate is under the reference LED, this light does not shine on the photo diode. Under this condition, the photo diode does not conduct current, and the reference voltage signal to the PCM is 5 V. As a reference slot moves under the LED, the light shines on the photo diode. The diode then conducts current and the reference voltage signal to the PCM is 0 V.

The outer LED, photo diode, and row of slots perform a function similar to that of the SYNC pick-up in a distributor with Hall-effect pick-ups. The outer row of slots is closely spaced, and the width between each slot represents 2 degrees of crankshaft rotation. On the outer row there is one area where the slots are missing. When this blank area rotates under the LED, a different SYNC voltage signal is produced, which informs the PCM regarding the number one piston position. The PCM uses this signal for injector control. As the outer row of slots rotates under the outer LED, the SYNC voltage signal to the PCM cycles from 0 V to 5 V. The reference pick-up signal informs the PCM when each piston is a specific number of degrees before TDC on the compression stroke.

When this signal is received, the PCM scans the inputs and calculates the spark advance required by the engine. The SYNC sensor signals always keep the PCM informed of the exact position of the crankshaft. The PCM opens the primary ignition circuit and fires the next spark plug in the firing order to provide the calculated spark advance.

GM's HEI with EST. A seven- **(Figure 21–34)** or eight-terminal module is used in some General Motors distributors with computer-controlled spark advance and fuel injection. Two of the module terminals are connected to the coil primary terminals, and two other module terminals are connected to the pick-up coil. The other four module terminals are connected through a four-wire harness to the PCM. These four wires are identified as by-pass, **electronic spark timing** (**EST**), ground, and reference wires.

When the engine is starting, the pick-up coil signal goes directly to the module. Immediately after the engine starts, the PCM sends a 5-V signal through the by-pass wire to the module. This signal is converted to a digital signal and causes the module circuit to switch, which forces the pick-up signal to travel through the reference wire to the PCM. Crankshaft position and speed information are obtained from the pick-up signal to the PCM.

The PCM scans the input sensors and then sends a signal on the EST wire to the module. This signal commands the module to open the primary circuit and fire the next spark plug at the right instant to provide the precise spark advance indicated by the input signals.

Honda's DI System with EST. Honda, as well as other manufacturers, also fit the ignition module inside the dis-

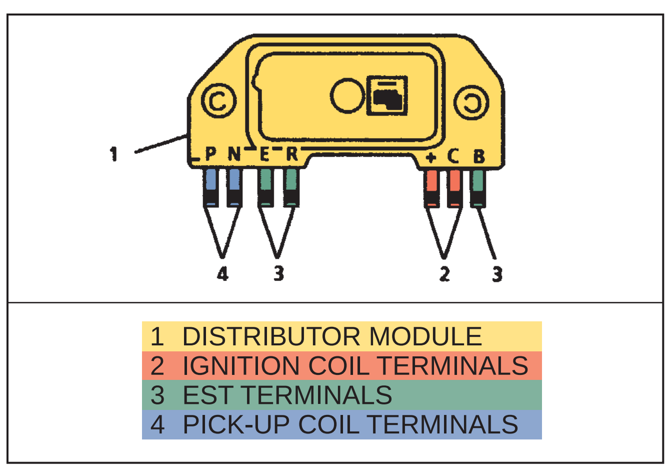

Figure 21–34 A seven-terminal GM HEI/EST ignition module. *Courtesy of General Motors Corporation—Chevrolet Motor Division*

tributor **(Figure 21–35)**. The distributor is also fitted with a Hall-effect switch that is directly connected to the control module. The only external electrical connections for the module are from the PCM and to the ignition coil. The PCM controls the activity of the module which, in turn, controls the dwell of the primary and therefore the ignition timing.

Ford's TFI-IV System. In some DI systems with computer-controlled spark advance, the module is mounted away from the distributor or mounted to it. Ford Motor Company's TFI-IV system is such a system. This system is similar to the TFI-IV system that relied on a distributor fitted with mechanical and vacuum advance units.

The distributor contains the Profile Ignition Pickup (PIP), an octane rod, and a Hall-effect vane switch stator. During the period of time the Hall-effect device is turned "on" and "off", a digital voltage pulse is produced. The pulse is used by EEC-IV electronics for crankshaft position and the calculation of the required ignition timing. Ignition timing required for a particular operating condition is determined by inputs from various sensors that are correlated with values in the computer's memory.

The PIP signal is an indication of crankshaft position and engine speed. This signal is fed into the TFI-IV module and to the PCM. This signal, along with many others, allows the PCM to accurately calculate ignition timing needs for the conditions. The PCM produces a signal "Spout" and sends it to the TFI-IV module. The module compares the spout signal to the PIP signal then controls the activity of the ignition coil and the firing of the spark plugs.

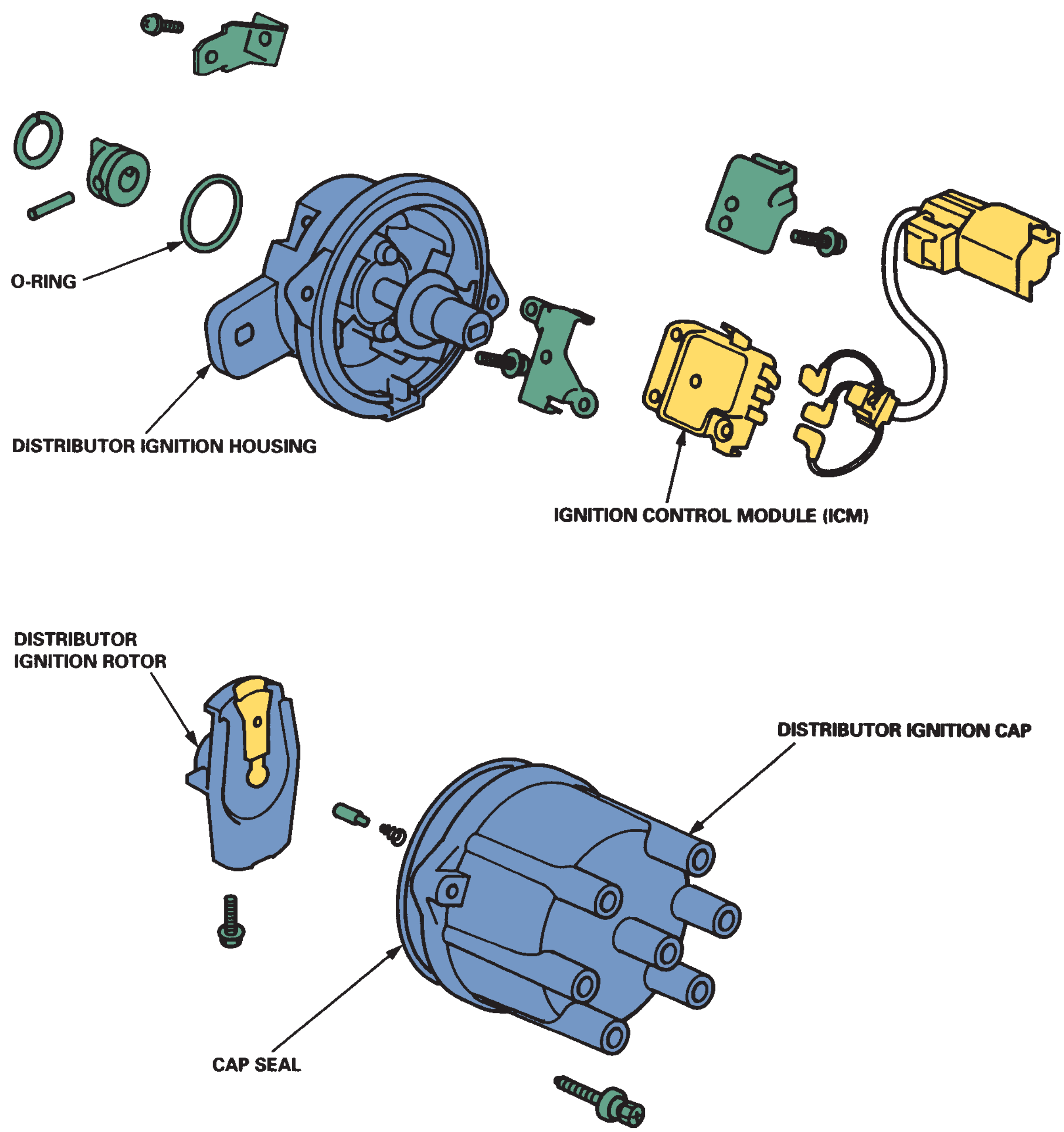

Figure 21-35 Honda's distributor with a built-in control module. *Courtesy of American Honda Motor Co., Inc.*

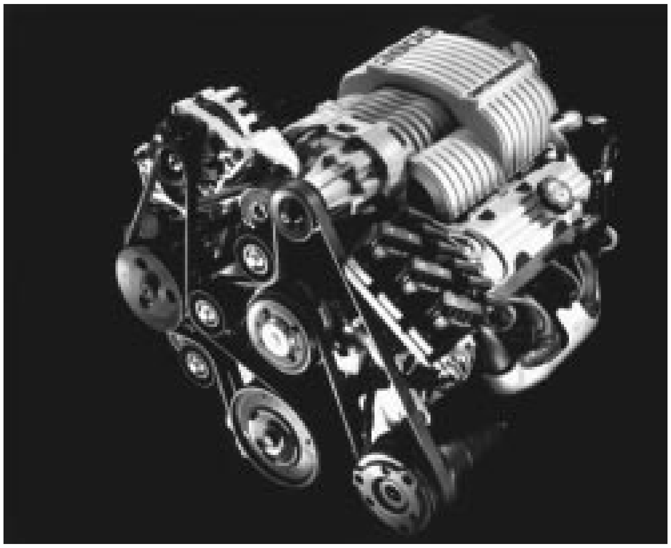

Figure 21-36 A supercharged Buick 3800 V-6 with an electronic ignition system. *Courtesy of General Motors Corporation—Buick Motor Division*

ELECTRONIC IGNITION SYSTEM OPERATION

In Electronic Ignition (EI) systems **(Figure 21–36)**, each cylinder may have its own ignition coil, or two cylinders may share one coil. The coils are wired directly to the spark plug they control. An ignition control module, tied into the vehicle's computer control system, controls the firing order and the spark timing and advance.

In many EI systems, a crank sensor located at the front of the crankshaft is used to trigger the ignition system. When a distributor is used in the ignition system, the distributor drive gear, shaft, and bushings are subject to wear. Worn distributor components cause erratic ignition timing and spark advance, which results in reduced economy and performance plus increased exhaust emissions. Since the distributor is eliminated in EI systems, ignition timing remains more stable over the life of the engine, which means improved economy and performance with reduced emissions.

There are many advantages of a distributorless ignition system over one that uses a distributor. Here are some of the more important ones:

- Fewer moving parts, therefore less friction and wear.
- Flexibility in mounting location. This is important because of today's smaller engine compartments.
- Less required maintenance; there is no rotor or distributor cap to service.
- Reduced radio frequency interference because there is no rotor to cap gap.
- Elimination of a common cause of ignition misfire, the buildup of water and ozone/nitric acid in the distributor cap.
- Elimination of mechanical timing adjustments.
- Places no mechanical load on the engine in order to operate.
- Increased available time for coil saturation.
- Increased time between firings, which allows the coil to cool more.

Basic Components

The computer, ignition module, and position sensors combine to control spark timing and advance. The computer collects and processes information to determine the ideal amount of spark advance for the operating conditions. The ignition module uses crank/cam sensor data to control the timing of the primary circuit in the coils **(Figure 21–37)**. Remember that there is more than one coil in a distributorless ignition system. The ignition module synchronizes the coils' firing sequence in relation to crankshaft position and firing order of the engine. Therefore, the ignition module takes the place of the distributor.

Primary current is controlled by transistors in the control module. There is one switching transistor for each ignition coil in the system. The transistors complete the ground circuit for the primary, thereby allowing for a dwell period. When primary current flow is interrupted, secondary voltage is induced in the coil and the coil's spark plug(s) fire. The timing and sequencing of ignition coil action is determined by the control module and input from a triggering device.

The control module is also responsible for limiting the dwell time. In EI systems there is time between plug firings to saturate the coil. Achieving maximum current flow through the coil is great if the system needs the high voltage that may be available. However if the high voltage is not needed, the high current is not needed and the heat it produces is not desired. Therefore, the control module is programmed to only allow total coil saturation when the very high voltage is needed or the need for it is anticipated.

The ignition module also adjusts spark timing below 400 rpm (for starting) and when the vehicle's control computer by-pass circuit becomes open or grounded. Depending on the exact DIS system, the ignition coils can be serviced as a complete unit or separately. The coil assembly is typically called a **coil pack (Figure 21–38)** and is comprised of two or more individual coils.

On those DIS systems that use one coil per spark plug, the electronic ignition module determines when each spark plug should fire and controls the on/off time of each plug's coil.

The systems with a coil for every two spark plugs also use an electronic ignition module, but they use the **waste spark** method of spark distribution. Each end of the coil's

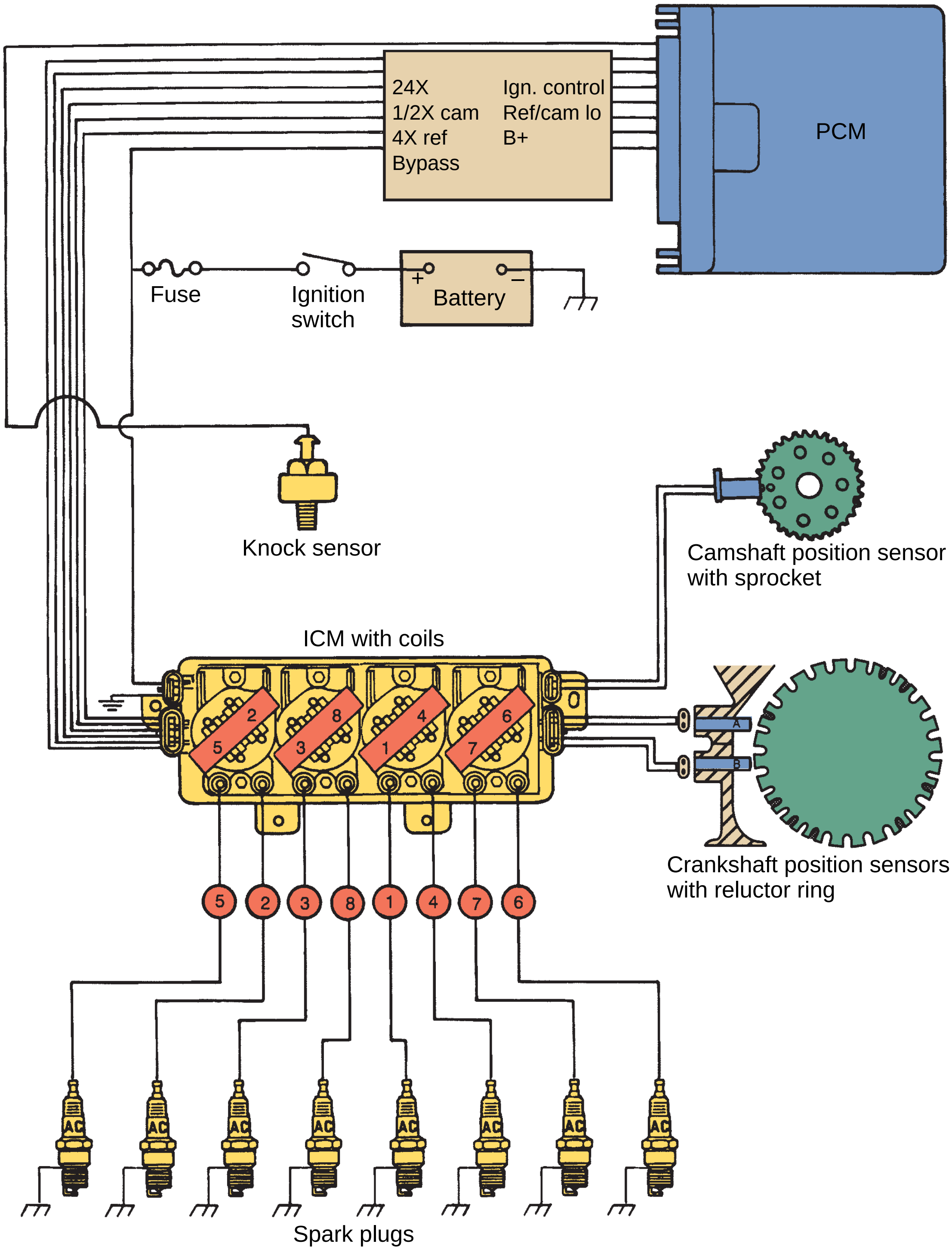

Figure 21-37 An EI system with two crankshaft position sensors and one camshaft position sensor. *Courtesy of General Motors Corporation—Cadillac Motor Car Division*

secondary winding is attached to a spark plug. Each coil is connected to a pair of spark plugs in cylinders whose pistons rise and fall together. When the field collapses in the coil, voltage is sent to both spark plugs that are attached to the coil. In all V-6s, the paired cylinders are 1 and 4, 2 and 5, and 3 and 6 (or 4 and 1 and 3 and 2 on 4-cylinder engines). With this arrangement, one cylinder of each pair is on its compression stroke while the other is on the exhaust stroke. Both cylinders get spark simultaneously, but only one spark generates power, while the other is wasted out the exhaust. During the next revolution, the roles are reversed.

Due to the way the secondary coils are wired, when the induced voltage cuts across the primary and secondary windings of the coil, one plug fires in the normal direction—positive center electrode to negative side elec-

Figure 21–38 A coil pack for a distributorless ignition system.

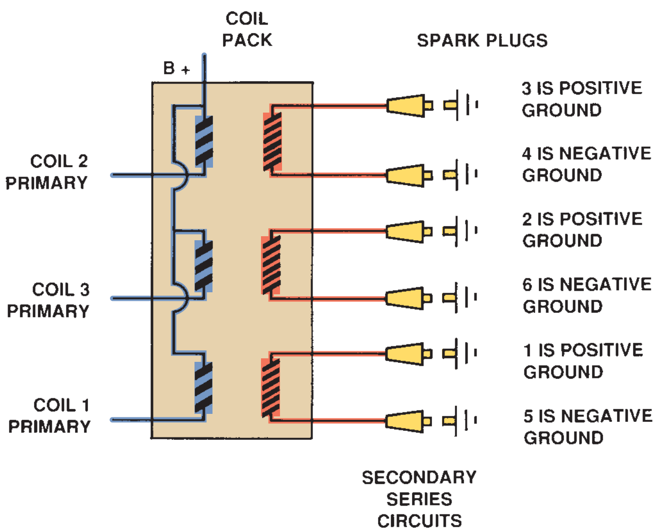

Figure 21–39 Polarity of spark plugs in an EI system. *Courtesy of Ford Motor Company*

trode—and the other plug fires just the reverse side to center electrode **(Figure 21–39)**. As shown in **Figure 21–40**, both plugs fire simultaneously, completing the series circuit. Each plug always fires the same way on both the exhaust and compression strokes.

The coil is able to overcome the increased voltage requirements caused by reversed polarity and still fire two plugs simultaneously because each coil is capable of producing up to 100,000 volts. There is very little resistance across the plug gap on exhaust, so the plug requires very little voltage to fire, thereby providing its mate (the plug that is on compression) with plenty of available voltage.

Figure 21–41 shows a waste spark system in which the coils are mounted directly over the spark plugs so no wiring between the coils and plugs is necessary. On other systems, the coil packs are mounted remote from the spark plugs. High-tension secondary wires carry high-voltage current from the coils to the plugs.

Some EI systems use the waste spark method of firing but only have one secondary wire coming off each ignition coil. In these systems **(Figure 21–42)**, one spark

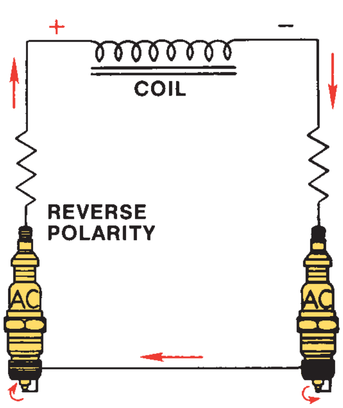

Figure 21–40 The manner in which two spark plugs are fired by a single ignition coil in EI system circuits.

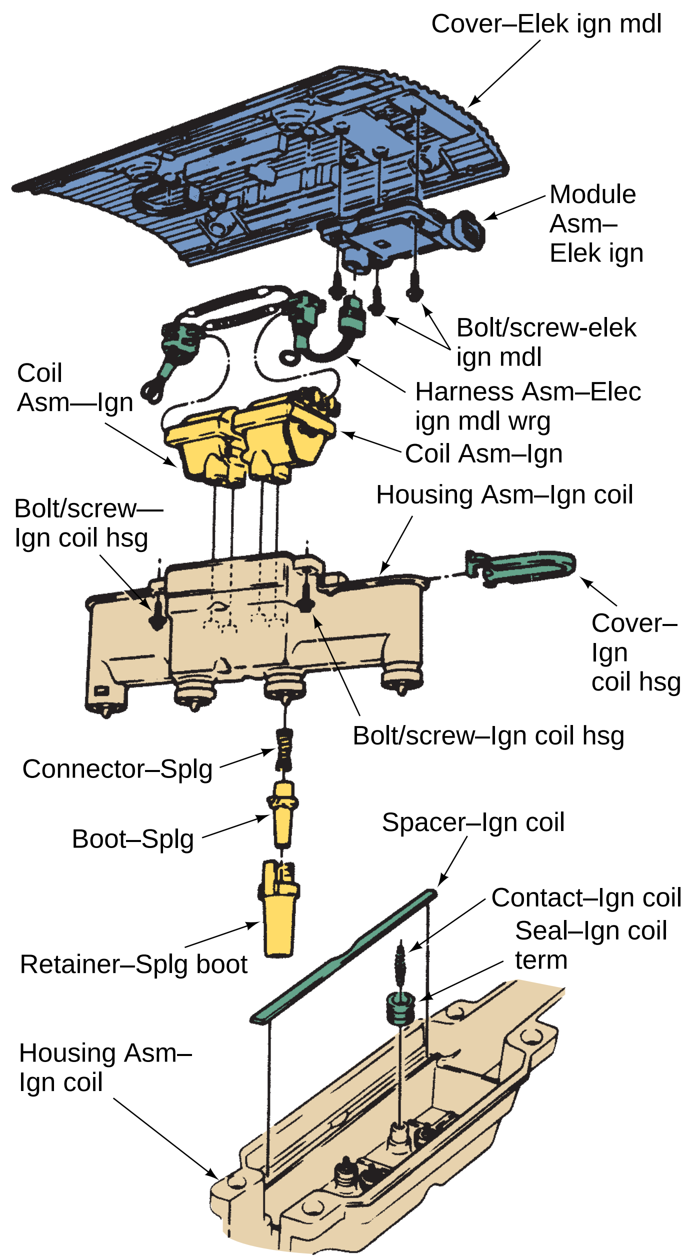

Figure 21–41 A cableless EI system. *Courtesy of General Motors Corporation—Oldsmobile Division*

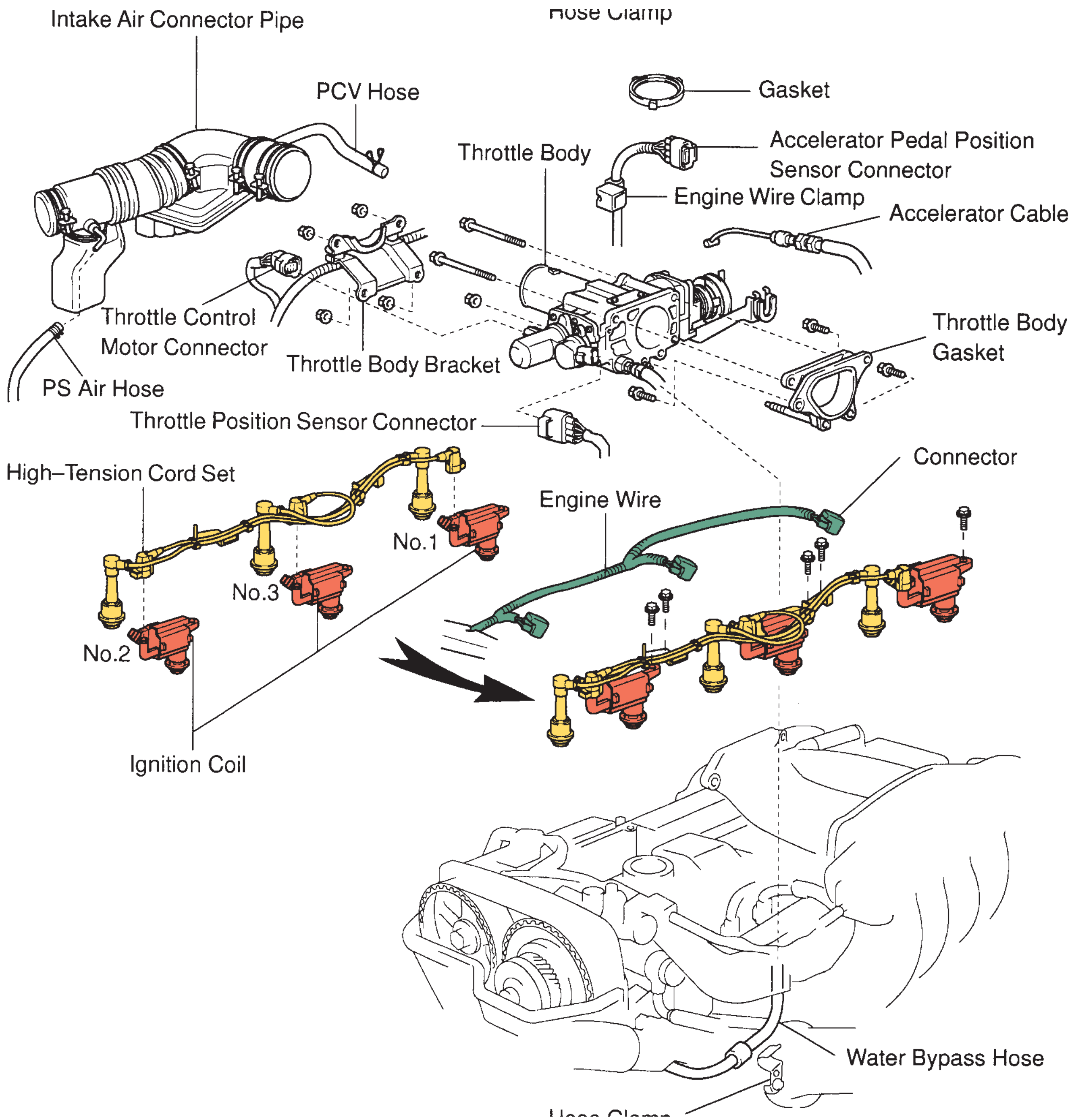

Figure 21–42 A six-cylinder engine with three coils and three spark plug wires. *Reprinted with permission*

plug is connected directly to the ignition coil and the companion spark plug is connected to the coil by a high-tension cable.

Other EI systems have one coil for every spark plug. The coil mounts directly to the spark plug and the assembly **(Figure 21–43)** is called a "coil-on-plug" assembly.

A few DIS systems have one coil per cylinder with two spark plugs per cylinder. During starting only one plug is fired. Once the engine is running the other plug also fires. One spark plug is located on the intake side of the combustion chamber while the other is located on the exhaust side. Two coil packs are used, one for the plugs on the intake side and the other for the plugs on the exhaust side. These systems are called **dual plug** systems **(Figure 21–44)**. During dual plug operation, the two coil packs are synchronized so each cylinder's two plugs fire at the same time. The coils fire two spark plugs at the same time. Therefore, on a four-cylinder engine, four spark plugs are fired at a time: two during the compression stroke of the cylinder and two during the exhaust stroke of another cylinder.

EI System Operation

From a general operating standpoint, most distributorless ignition systems are similar. However, there are variations in the way different distributorless systems obtain

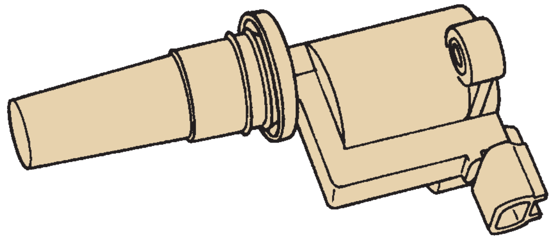

Figure 21-43 A coil-on-plug assembly. *Courtesy of Ford Motor Company*

a timing reference in regard to crankshaft and camshaft position.

Some engines use separate Hall-effect sensors to monitor crankshaft and camshaft position for the control of ignition and fuel injection firing orders. The crankshaft pulley has interrupter rings that are equal in number to half of the cylinders of the engine **(Figure 21–45)**. The resultant signal informs the PCM as to when to fire the plugs. The camshaft sensor helps the computer determine when the number one piston is at TDC on the compression stroke.

Defining the different types of EI systems used by manufacturers focuses on the location and type of sensors used. There are other differences, such as the construction of the coil pack, wherein some are a sealed assembly and others have individually mounted ignition coils. Some EI systems have a camshaft sensor mounted in the opening where the distributor was mounted. The camshaft sensor ring has one notch and produces a leading edge and trailing edge signal once per camshaft revolution. These systems also use a crankshaft sensor. Both the camshaft and crankshaft sensors are Hall-effect sensors.

Locating the cam sensor in the opening previously occupied by the distributor merely takes advantage of the bore and gear that was already present. Seeing that the distributor was driven at camshaft speed, driving a camshaft position sensor by the same mechanism just made sense **(Figure 21–46)**. This modification really made sense when older engine designs were modified for distributorless ignition.

As the crankshaft rotates and the interrupter passes in and out of the Hall-effect switch, the switch turns the module reference voltage on and off. The three signals are identical and the control module can not distinguish which of these signals to assign to a particular coil. The signal from the cam sensor gives the module the information it needs to assign the signals from the crankshaft sensors to the appropriate coils **(Figure 21–47)**. The camshaft sensor synchronizes the crankshaft sensor signals with the position of the number one cylinder. From there the module can energize the coils according to the firing order of the engine. Once the engine has started, the camshaft signal serves no purpose.

Figure 21-45 A crankshaft pulley for a six-cylinder engine has three interrupter rings.

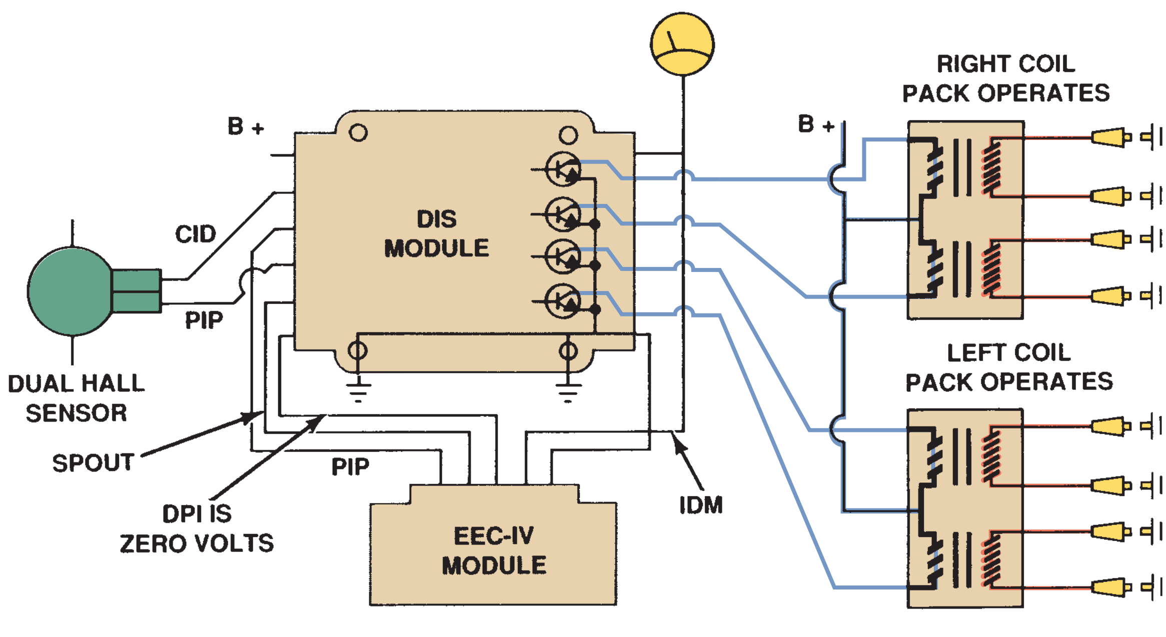

Figure 21-44 A dual plug system for a four-cylinder engine. *Courtesy of Ford Motor Company*

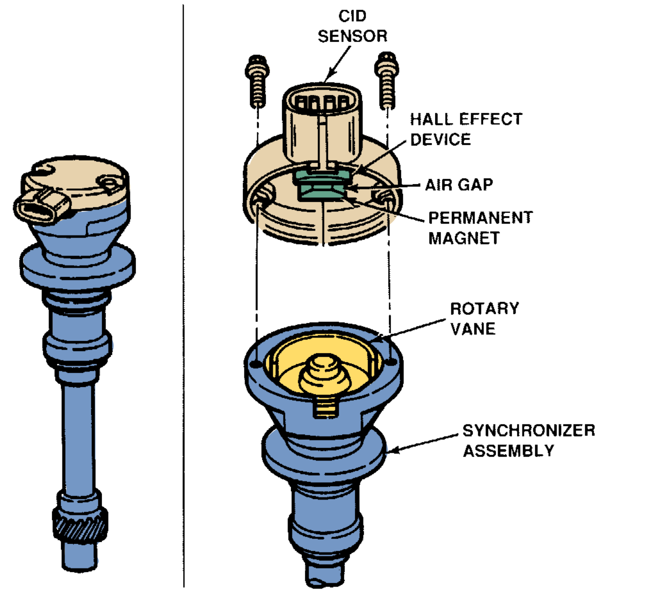

Figure 21-46 A camshaft sensor assembly designed to fit into the distributor bore. *Courtesy of Ford Motor Company*

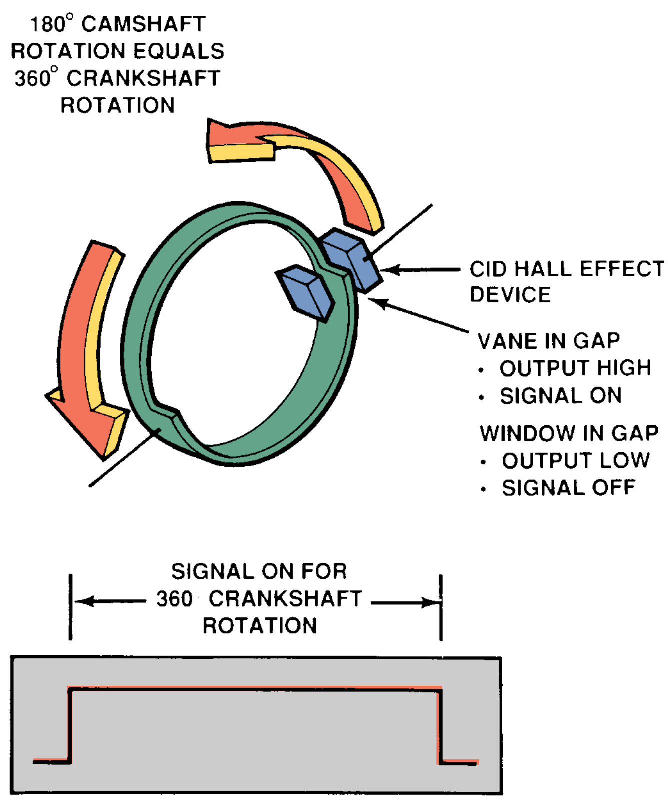

Figure 21-47 Camshaft sensor operation and the resulting signal. *Courtesy of Ford Motor Company*

Some systems have the camshaft sensor mounted in the front of the timing chain cover **(Figure 21–48)**. A magnet on the camshaft gear rotates past the inner end of the camshaft sensor and produces a signal for each camshaft revolution. GM's 3.8 L non-turbocharged SFI V-6 engine has a firing order of 1-6-5-4-3-2. Spark plugs

Figure 21-48 A camshaft position sensor mounted on the timing chain cover.

1-4, 6-3, and 5-2 are paired together on the coil assembly. When a trailing edge camshaft sensor signal is received during initial starting, the coil module prepares to fire the coil connected to spark plugs 5-2. After the camshaft sensor signal is received, the next trailing edge crankshaft sensor signal turns on the primary circuit of the 5-2 coil, and the next leading edge crankshaft sensor signal informs the coil module to open the primary circuit of the 5-2 coil **(Figure 21–49)**. When this coil fires, one of these cylinders is always on the compression stroke and the other cylinder is on the exhaust stroke. After the 5-2 coil firing, the coil module fires the 1-4 coil and the 6-3 coil in sequence. This firing sequence provides the correct firing order.

On an SFI engine, the PCM grounds each injector individually. The cam sensor signal is also used for injector sequencing. This cam sensor signal is sent from the cam sensor through the coil module to the PCM. The PCM grounds each injector in the intake port when the piston for that cylinder is at 70 degrees before TDC on the intake stroke.

When a crankshaft sensor failure occurs, the engine does not start. If the camshaft sensor signal becomes defective with the engine running, the engine continues to run, but the PCM reverts to multiport fuel injection without the camshaft signal information. Under this condition, engine performance and economy decrease and emission levels may increase. When an engine with a defective cam sensor is shut off, it will not restart.

Other systems use a dual crankshaft sensor located behind the crankshaft pulley. When this type of sensor is used, there are two interrupter rings on the back of the

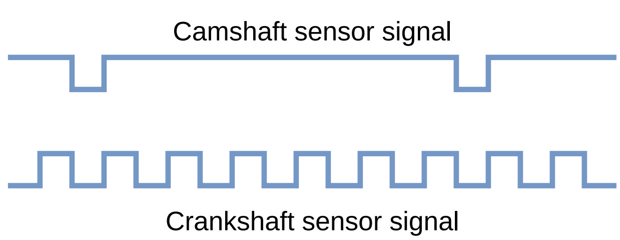

Figure 21-49 Relationship between crankshaft and camshaft signals on a GM 3.8L SFI engine. *Courtesy of General Motors Corporation—Buick Motor Division*

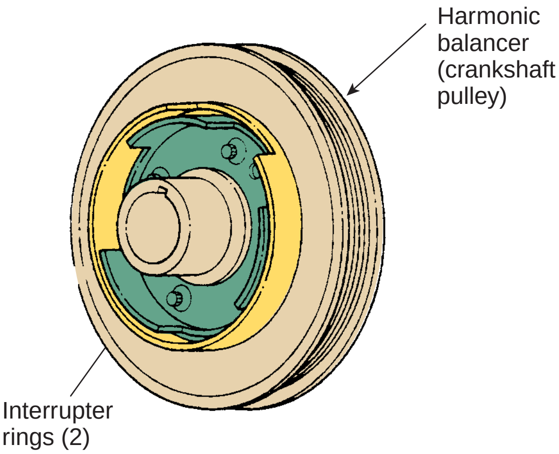

Figure 21–50 The two sets of interrupter rings on a crankshaft pulley designed for a dual crankshaft sensor. *Courtesy of General Motors Corporation—Oldsmobile Division*

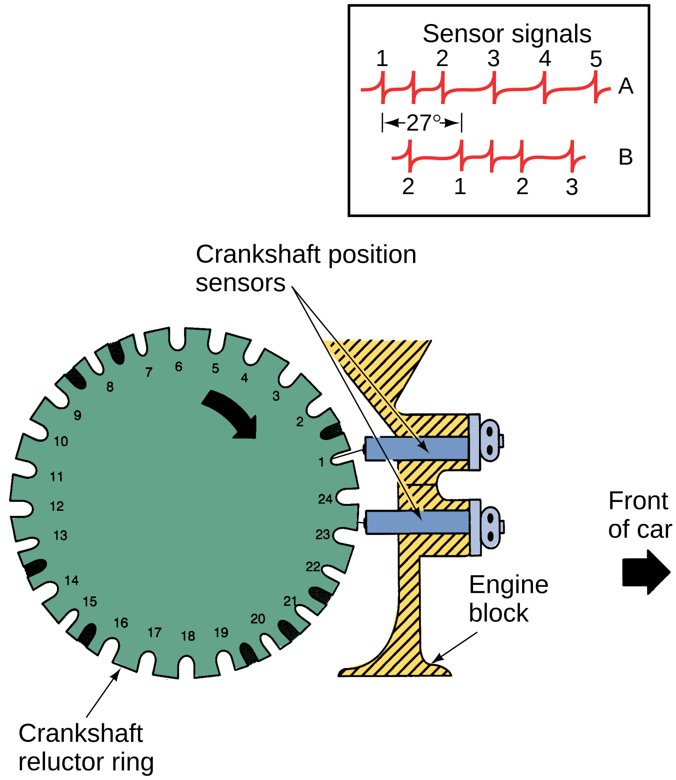

Figure 21–51 A and B crankshaft sensors in a Northstar engine. *Courtesy of General Motors Corporation—Cadillac Motor Car Division*

pulley **(Figure 21–50)** that rotate through the Hall-effect switches at the dual crankshaft sensor. The inner ring with three equally spaced blades rotate through the inner Hall-effect switch, whereas the outer ring with one opening rotates through the outer Hall-effect.

In this dual sensor, the inner sensor provides three leading edge signals and the outer sensor produces one leading edge during one complete revolution of the crankshaft. The outer sensor is the SYNC sensor. This outer sensor is referred to as a synchronizer (SYNC) sensor. The signal from this sensor informs the coil module regarding crankshaft position. The SYNC sensor signal occurs once per crankshaft revolution and this signal is synchronized with the inner crankshaft sensor signal to fire the 6-3 coil.

The examples given so far depend on two revolutions of the crankshaft to inform the PCM as to which number cylinder is ready. These systems are referred to as slow-start systems because the engine must crank through two crankshaft revolutions before ignition begins.

The **Fast-Start** electronic ignition system used in GM's Northstar system uses two crankshaft position sensors **(Figure 21–51)**. A reluctor ring with 24 evenly spaced notches and 8 unevenly spaced notches is cast onto the center of the crankshaft. When the reluctor ring rotates past the magnetic-type sensors, each sensor produces 32 high- and low-voltage signals per crankshaft revolution. The "A" sensor is positioned in the upper crankcase, and the "B" sensor is positioned in the lower crankcase. Since the A sensor is above the B sensor, the signal from the A sensor occurs 27 degrees before the B sensor signal.

The signals from the two sensors are sent to the ignition control module. This module counts the number of signals from one of the sensors that are between the other sensor signals to sequence the ignition coils properly. This allows the ignition system to begin firing the spark plugs within 180 degrees of crankshaft rotation while starting the engine. This system allows for much quicker starting than other EI systems which require the crankshaft to rotate one or two times before the coils are sequenced.

The camshaft position sensor is located in the rear cylinder bank in front of the exhaust camshaft sprocket. A reluctor pin in the sprocket rotates past the sensor, and this sensor produces one high- and one low-voltage signal every camshaft revolution, or every two crankshaft revolutions. The PCM uses the camshaft position sensor signal to sequence the injectors properly.

Another example of a fast-start system also uses a dual crankshaft sensor at the front of the crankshaft. The cam sensor is mounted in the timing gear cover. Two Hall-effect switches are located in the dual crankshaft sensor, and two matching interrupter rings are attached to the back of the crankshaft pulley. The inner ring on the crankshaft pulley has three blades of unequal lengths with unequal spaces between the blades. On the outer ring, there are 18 blades of equal length with equal spaces between the blades. The signal from the inner Hall-effect switch is referred to as the 3X signal, while the outer Hall-effect switch is called the 18X signal. These signals are sent from the dual crankshaft sensor to the coil module.

The coil module knows which coil to fire from the number of 18X signals received during each 3X window rotation **(Figure 21–52)**. For example, when two 18X signals are received, the coil module is programmed to sequence coil 3-6 next in the firing sequence. Within 120

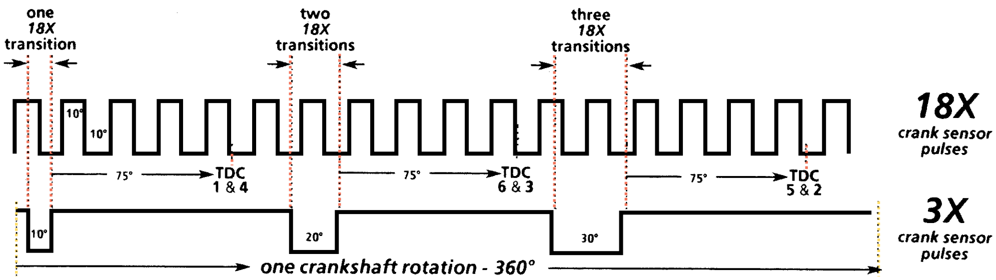

Figure 21-52 3X and 18X crankshaft signals. *Courtesy of General Motors Corporation—Cadillac Motor Car Division*

degrees of crankshaft rotation, the coil module can identify which coil to sequence, and thus start firing the spark plugs. Therefore, the system fires the spark plugs with less crankshaft rotation during initial starting than the previous slow-start systems.

Once the engine is running, the system switches to the EST mode. The PCM uses the 18X signal for crankshaft position and speed information. The 18X signal may be referred to as a high-resolution signal. If the 18X signal is not present, the engine will not start. When the 3X signal fails with the engine running, the engine continues to run, but the engine refuses to restart.

In this system, the cam sensor signal is used for injector sequencing, but it is not required for coil sequencing. If the cam sensor signal fails, the PCM logic begins sequencing the injectors after two cranking revolutions. There is a one-in-six chance that the PCM logic will ground the injectors in the normal sequence. When the PCM logic does not ground the injectors in the normal sequence, the engine hesitates on acceleration.

Finally, some engines use a magnetic pulse generator. The timing wheel is cast on the crankshaft and has machined slots on it. If the engine is a six-cylinder, there will be seven slots, six of which are spaced exactly 60 degrees apart. The seventh notch is located 10 degrees from the number six notch and is used to synchronize the coil firing sequence in relation to crankshaft position **(Figure 21–53)**. The same triggering wheel can be and is used on four-cylinder engines. The computer only needs to be programmed to interpret the signals differently than on a six-cylinder.

The magnetic sensor, which protrudes into the side of the block, generates a small AC voltage each time one of the machined slots passes by. By counting the time between pulses, the ignition module picks out the unevenly spaced seventh slot, which starts the calculation of the ignition coil sequencing. Once its counting is synchronized with the crankshaft, the module is programmed to accept the AC voltage signals of the select notches for firing purposes.

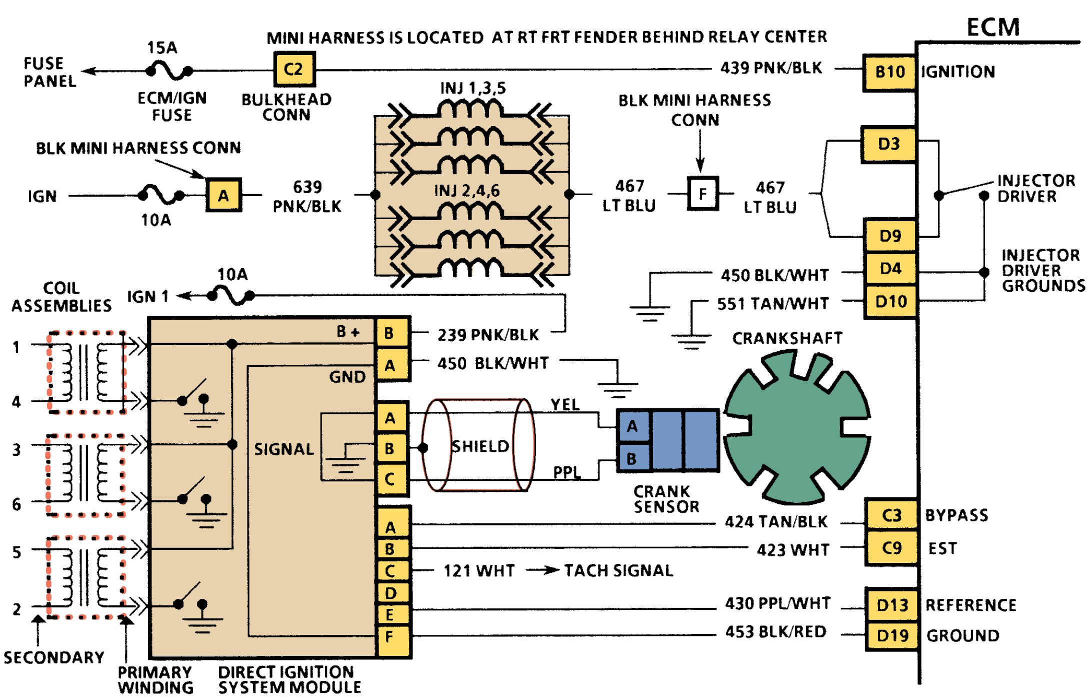

Figure 21-53 Schematic of an EI system with a magnetic pulse generator-type crankshaft sensor. Note the notches on the crankshaft-timing wheel. *Courtesy of General Motors Corporation—Oldsmobile Division*

Ford uses a similar system; however, the reluctor ring has many more slots. The crankshaft sensor for their 4.6 L V-8 engine is a variable reluctance sensor that is triggered by a 36 minus 1 (or 35) tooth trigger wheel located inside the front cover of the engine **(Figure 21–54)**. The sensor provides two types of information: crankshaft position and engine speed.

The trigger wheel has a tooth every 10 degrees, with one tooth missing. When the part of the wheel that is missing a tooth passes by the sensor, there is a longer than normal pause between signals from the sensor. The ignition control module recognizes this and is able to identify this long pause as the location of piston #1.

Chrysler also uses a similar system. However, it uses a different number of teeth on the reluctor, a camshaft sensor, and a camshaft reluctor; therefore, the signals received by the control module are also different. The crankshaft timing sensor is mounted in an opening in the transaxle bell housing. The inner end of this sensor is positioned near a series of notches and slots that are integral with the engine's flywheel.

A group of four slots is located on the flywheel for each pair of engine cylinders. Thus, a total of 12 slots are positioned around the flywheel. When the slots rotate past the crankshaft timing sensor, the voltage signal from the sensor changes from 0 V to 5 V. This varying voltage signal informs the PCM regarding crankshaft position and speed. The PCM calculates spark advance from this signal. The PCM also uses the crankshaft timing sensor signal along with other inputs to determine air-fuel ratio. Base timing is determined by the signal from the last slot in each group of slots.

The camshaft reference sensor is mounted in the top of the timing gear cover **(Figure 21–55)**. A notched ring on the camshaft gear has two single slots, two double slots, and a triple slot. When a notch rotates past the camshaft reference sensor, the signal from the sensor changes from 0 V to 5 V. The single, double, and triple notches provide different voltage signals. These signals are sent to the PCM. The PCM determines the exact camshaft and crankshaft position from the camshaft reference sensor signals, and the PCM uses these signals to

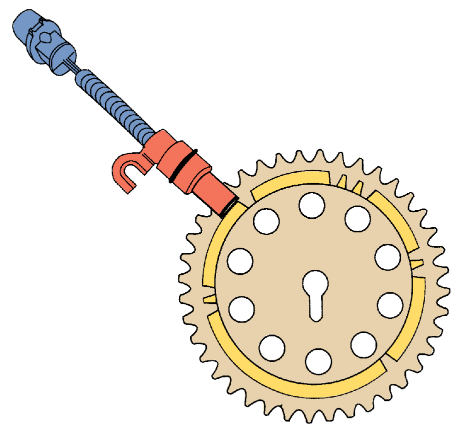

Figure 21–55 Camshaft sensor and notched cam gear. *Courtesy of DaimlerChrysler Corporation*

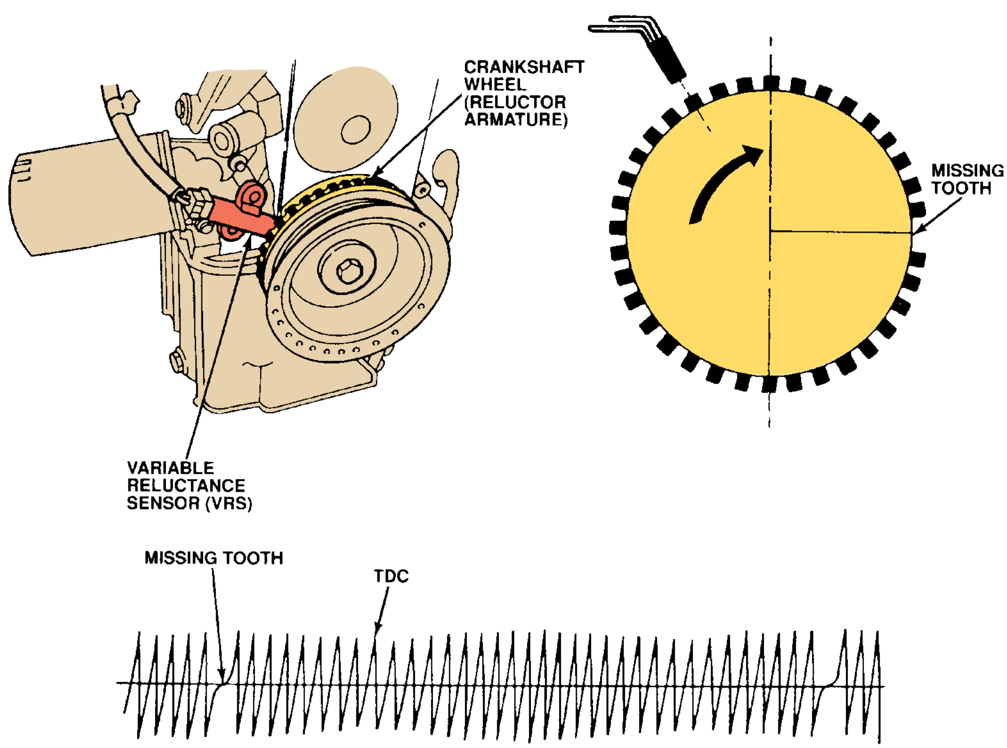

Figure 21–54 Sensor activity to monitor engine speed and crankshaft position, as well as the location of the number one piston. *Courtesy of Ford Motor Company*

sequence the coil primary windings and each pair of injectors at the correct instant.

The development and spreading popularity of EI is the result of reduced emissions, improved fuel economy, and increased component reliability brought about by these systems.

EI also offers advantages in production costs and maintenance considerations. By removing the distributor, the manufacturers realize substantial savings in ignition parts and related machining costs. Also, by eliminating the distributor, they do away with cracked caps, eroded carbon buttons, burned-through rotors, moisture misfiring, base timing adjustments, and the like.

CAUTION!

Since EI systems have considerably higher maximum secondary voltage compared to point-type or electronic ignition systems, greater electrical shocks are obtained from EI systems. Although such shocks may not be directly harmful to the human body, they may cause you to jump or react suddenly, which could result in personal injury. For example, when you jump suddenly as a result of an EI electrical shock, you may hit your head on the vehicle hood or push your hand into a rotating cool-

CASE STUDY

***A** vehicle equipped with an early electronic distributor ignition system is experiencing spark detonation (knocking) and erratic spark advance problems. The vehicle has 82,000 miles on it.*

The technician checks the engine's base timing and finds it to be 5 degrees out of adjustment. The technician makes the adjustment, but it does not seem to hold steady. In fact, the problem still occurs on the test drive made immediately after the timing adjustment is made.

The technician then removes the distributor for closer inspection. The centrifugal advance mechanism appears to be in good order, but the technician notices shiny worn areas on the tangs of the distributor shaft's drive coupling. Wear on the tangs could mean the distributor shaft is not in proper mesh with the camshaft. The technician replaces the worn drive coupling and reinstalls the distributor. After resetting initial timing, the problem of erratic advance disappears.

KEY TERMS

Air gap
ATDC
Ballast resistor
Base ignition timing
Breaker plate
Breaker point
BTDC
Centrifugal advance
Coil pack
Contact points
DI
DIS
Distributor
Dual plug
Dwell
EI
EST
Fast-Start
Firing order
Heat range
HEI
Ignition timing
Inductive reluctance
Look-up tables
Misfire
Photoelectric sensor
Preignition
Primary circuit
Pulse transformer
Reach
Reactance
Rotor
Secondary circuit
Strategy
Swirling
TFI
Timer core
Vacuum advance
Waste spark

SUMMARY

- The ignition system supplies high voltage to the spark plugs to ignite the air/fuel mixture in the combustion chambers.
- The arrival of the spark is timed to coincide with the compression stroke of the piston. This basic timing can be advanced or retarded under certain conditions, such as high engine rpm or extremely light or heavy engine loads.
- The ignition system has two interconnected electrical circuits: a primary circuit and a secondary circuit.
- The primary circuit supplies low voltage to the primary winding of the ignition coil. This creates a magnetic field in the coil.
- A switching device interrupts primary current flow, collapsing the magnetic field and creating a high-voltage surge in the ignition coil secondary winding.
- The switching device used in electronic systems is an NPN transistor. Old ignitions use mechanical breaker point switching.
- The secondary circuit carries high voltage surges to the spark plugs. On some systems, the circuit runs from the ignition coil, through a distributor, to the spark plugs.
- The distributor may house the switching device plus centrifugal or vacuum timing advance mechanisms. Some systems locate the switching device outside the distributor housing.

- Ignition timing is directly related to the position of the crankshaft. Magnetic pulse generators and Hall-effect sensors are the most widely used engine position sensors. They generate an electrical signal at certain times during crankshaft rotation. This signal triggers the electronic switching device to control ignition timing.
- EI systems eliminate the distributor. Each spark plug, or in some cases, pair of spark plugs, has its (their) own ignition coil. Primary circuit switching and timing control is done using a special ignition module tied into the vehicle control computer.
- Computer-controlled ignition eliminates centrifugal and vacuum timing mechanisms. The computer receives input from numerous sensors. Based on this data, the computer determines the optimum firing time and signals an ignition module to activate the secondary circuit at the precise time needed.
- In some distributors, one pick-up is used for ignition triggering and a second pick-up is used for injector sequencing.
- In some EI systems, the camshaft sensor signal informs the computer when to sequence the coils and fuel injectors.
- In some EI systems, the crankshaft sensor signal provides engine speed and crankshaft position information to the computer.
- Some EI systems are called fast-start systems because the spark plugs begin firing within 120 degrees of crankshaft rotation.
- Some EI systems have a combined crankshaft and SYNC sensor at the front of the crankshaft.
- Some EI systems may be called slow-start systems because as many as two crankshaft revolutions are required before the ignition system begins firing.

TECH MANUAL

The following procedures are included in Chapter 21 of the *Tech Manual* that accompanies this book:

1. Set ignition timing dynamically.
2. Check the resistance of primary circuit components.
3. Test spark plug firing voltages.
4. Test secondary circuit insulation.

REVIEW QUESTIONS

1. Explain how the voltage is induced in the distributor pick-up coil as the reluctor high point approaches alignment with the pick-up coil.
2. Explain why dwell time is important to ignition system operation.
3. Name the engine operating conditions that affect ignition timing requirements.
4. Explain how the plugs fire in a two-plug-per-coil EI system.
5. Explain the components and operation of a magnetic pulse generator.
6. What happens when the low-voltage current flow in the coil primary winding is interrupted by the switching device?
   a. The magnetic field collapses.
   b. A high-voltage surge is induced in the coil secondary winding.
   c. Both a and b.
   d. Neither a nor b.
7. Which of the following is a function of all ignition systems?
   a. to generate sufficient voltage to force a spark across the spark plug gap
   b. to time the arrival of the spark to coincide with the movement of the engine's pistons
   c. to vary the spark arrival time based on varying operating conditions
   d. all of the above
8. Reach, heat range, and air gap are all characteristics that affect the performance of which ignition system component?
   a. ignition coils **c.** spark plugs
   b. ignition cables **d.** breaker points
9. Technician A says a magnetic pulse generator is equipped with a permanent magnet. Technician

B says a Hall-effect switch is equipped with a permanent magnet. Who is correct?

a. Technician A **c.** Both A and B

b. Technician B **d.** Neither A nor B

10. While discussing ignition systems, Technician A says an ignition system must supply high voltage surges to the spark plugs. Technician B says the system must maintain the spark long enough to burn all of the air/fuel mixture in the cylinder. Who is correct?

a. Technician A **c.** Both A and B

b. Technician B **d.** Neither A nor B

11. While discussing ignition timing requirements, Technician A says more advanced timing is desired when the engine is under a heavy load. Technician B says more advanced timing is desired when the engine is running at high engine speeds. Who is correct?

a. Technician A **c.** Both A and B

b. Technician B **d.** Neither A nor B

12. While discussing secondary voltage, Technician A says the normal required secondary voltage is higher at idle speed than at wide-open throttle conditions. Technician B says the maximum available secondary voltage must always exceed the normally required secondary voltage. Who is correct?

a. Technician A **c.** Both A and B

b. Technician B **d.** Neither A nor B

13. Technician A says an ignition system must generate sufficient voltage to force a spark across the spark plug gap. Technician B says the ignition system must time the arrival of the spark to coincide with the movement of the engine's pistons and vary it according to the operating conditions of the engine. Who is correct?

a. Technician A **c.** Both A and B

b. Technician B **d.** Neither A nor B

14. While discussing electronic ignition systems, Technician A says a transistor actually controls primary current flow through the coil. Technician B says a reluctor controls the primary coil current. Who is correct?

a. Technician A **c.** Both A and B

b. Technician B **d.** Neither A nor B

15. Modern ignition cables contain fiber cores that act as a _____ in the secondary circuit to cut down on radio and television interference and reduce spark plug wear.

a. conductor **c.** semiconductor

b. resistor **d.** heat shield

16. In EI systems using one ignition coil for every two cylinders, Technician A says two plugs fire at the same time, with one wasting the spark on the exhaust stroke. Technician B says one plug fires in the normal direction (center to side electrode) and the other in reversed polarity (side-to-center electrode). Who is correct?

a. Technician A **c.** Both A and B

b. Technician B **d.** Neither A nor B

17. The magnetic field surrounding the pick-up coil in a magnetic pulse generator moves when the ______.

a. reluctor tooth approaches the coil

b. reluctor tooth begins to move away from the pick-up coil pole

c. reluctor is aligned with the pick-up coil pole

d. both a and b

18. The pick-up coil in a magnetic pulse generator does not produce a voltage signal when

a. a reluctor tooth approaches the coil.

b. a reluctor tooth is aligned with the coil.

c. a reluctor tooth begins to move away from the coil.

d. the coil is midway between two reluctor teeth.

19. Which type of engine position sensor requires its voltage signal be amplified, inverted, and shaped into a clean square wave signal?

a. magnetic pulse generator

b. metal detection sensor

c. Hall-effect sensor

d. photoelectric sensor

20. Which of the following electronic switching devices has a reluctor with wide shutters rather than teeth?

a. magnetic pulse generator

b. metal detection sensor

c. Hall-effect sensor

d. all of the above