The Ignition:

The Ignition: Primary and Secondary Circuits and Components

LEARNING OBJECTIVES

Upon completion and review of this chapter, you will be able to:

- Explain the process of mutual induction in the ignition coil.
- List the components in the primary ignition circuit.
- Describe the differences between electronic and distributorless ignition systems.
- Have knowledge of the different solid-state triggering devices.
- Describe the operation of the secondary ignition system.
- List the secondary ignition components.
- List conditions that cause high resistance in the secondary circuit.
- Explain the various design features of spark plugs.

KEY TERMS

Available Voltage Bakelite **Breaker Points** Burn Time Capacitive-Discharge Ignition System Current Limiting Hump **Distributor** Ignition (DI) System Dwell Dwell Time Electronic Ignition (EI) Systems Extended-Core Spark Plug Firing Line Firing Voltage Fixed Dwell Hall Effect Switch Heat Range Inductive-Discharge Ignition System

Ionize Magnetic Pulse Generator Magnetic Saturation Mechanical Ignition Systems No-Load Oscillation **Optical Signal** Generator Reach Required Voltage Resistor-Type Spark Plugs Self-Induction Spark Voltage Television-Radio-Suppression (TVRS) Cables Variable Dwell Voltage Decay Voltage Reserve

INTRODUCTION

The primary ignition circuit is considered to be the heart of the ignition system. The secondary ignition circuit cannot function efficiently if the primary ignition circuit is damaged. This chapter explains components of the low-voltage primary ignition circuit and how the circuit operates. Breaker points opened and closed the low-voltage primary circuit until the 1970s when solid-state electronic switching devices took their place. Whether breaker points or electronic switches are used, the principles of producing high voltage by electromagnetic induction remain the same.

NEED FOR HIGH VOLTAGE

Energy is supplied to the automotive electrical system by the battery. The battery supplies about twelve volts, but the voltage required to ignite the air-fuel mixture ranges from about 5,000 to more than 40,000 volts, depending upon engine operating conditions.

High voltage is required to create an arc across the spark plug air gap. The required voltage level increases when the:

- · Spark plug air gap increases
- Engine operating temperature increases
- Air-fuel mixture is lean
- Air-fuel mixture is at a greater pressure

Battery voltage must be greatly increased to meet the needs of the ignition system. Engine operating temperature increases the required voltage because resistance increases with greater temperature. A lean air-fuel mixture contains fewer volatile fuel particles, so resistance increases. More voltage is needed when the air-fuel mixture is at a greater pressure because resistance increases with an increase in pressure. The ignition system boosts voltage using electromagnetic induction.

HIGH VOLTAGE THROUGH INDUCTION

Any current-carrying conductor or coil is surrounded by a magnetic field. As current in the coil increases or decreases, the magnetic field expands or contracts. If a second coiled conductor is placed within this magnetic field, the expanding or contracting magnetic flux lines will cut the second coil, causing a voltage to be induced into the second coil. This transfer of energy between two unconnected conductors is called mutual induction.

Induction in the Ignition Coil

The ignition coil uses the principle of mutual induction to step up or transform low battery voltage to high ignition voltage. The ignition coil, Figure 11-1, contains two windings of copper wire wrapped around a soft iron core. The primary winding is made of a hundred or so turns of heavy wire. It connects to the battery and carries current. The secondary winding is made of many thousand turns of fine wire. When current in the primary winding increases or decreases, a voltage is induced into the secondary winding, Figure 11-1.

The ratio of the number of turns in the secondary winding to the number of turns in the primary winding is generally between 100:1 and 200:1. This ratio is the voltage multiplier. That is, any voltage induced in the secondary winding is 100 to 200 times the voltage present in the primary winding.

Several factors govern the induction of voltage. Only two of these factors are easily controllable in an ignition system. Induced voltage increases with:

- More magnetic flux lines
- · More rapid movement of flux lines

More magnetic flux lines produce a stronger magnetic field because there is a greater current. The rapid movement of flux lines results in a faster collapse of the field because of the abrupt end to the current.

Voltage applied to the coil primary winding with breaker points is about nine to ten volts. However, at high speeds, voltage may rise to twelve volts or more. This voltage pushes from one to four amperes of current through the primary winding. Primary current causes a magnetic field buildup around the windings. Building up a complete magnetic field is called magnetic saturation, or coil saturation. When this current stops, the primary winding magnetic field collapses. A greater voltage is self-induced in the primary winding by the collapse of its own magnetic field. This self-induction creates from 250 to 400 volts in the primary winding. For example, in a typical electronic ignition system, when the switching device turns ON, the current in the primary ignition circuit increases to approximately 5.5 amps. As the magnetic field builds in the primary cir-



Figure 11-1. The ignition coil produces high-voltage current in the secondary winding when current is cut off in the primary winding.

cuit, the magnetic flux lines cross over into the secondary windings of the coil and induce an even greater voltage charge. The amount of voltage in the primary circuit builds up to 240 volts. The secondary windings meanwhile are building 200 times the primary voltage, or 48,000 volts. This is enough voltage to ignite the air-fuel mixture under most operating conditions.

This collapsing magnetic field can be observed on an oscilloscope as a primary waveform pattern and is often referred to as the **firing line**. The voltage fluctuations vary by manufacturer, but most ignition systems range in amplitude between 250 to 400 volts. The secondary windings within the ignition coil are much thinner and have between 100 to 200 times the amount of windings. The voltage induced by the collapsing magnetic field is in the kilovolt (1000 X) range.

This kind of ignition system, based on the induction of a high voltage in a coil, is called an **inductive-discharge ignition system.** An inductive-discharge system, using a battery as the source of low-voltage current, has been the standard automotive ignition system for about eighty years.

BASIC CIRCUITS AND CURRENT

The ignition system consists of two interconnected circuits:

- The low-voltage primary circuit
- The high-voltage secondary circuit

When the ignition switch is turned on, battery current travels:

- Through the ignition switch or the primary resistor if present
- To and through the coil primary winding
- Through a switching device
- To ground at the negative and the grounded terminal of the battery

Low-voltage current in the coil primary winding creates a magnetic field. When the switching device interrupts this current:

- A high-voltage surge is induced in the coil secondary winding.
- Secondary current is routed from the coil to the distributor.

- Secondary current passes through the distributor cap, rotor, across the rotor air gap, and through another ignition cable to the spark plug.
- Secondary current creates an arc across the spark plug gap, as it travels to ground.

PRIMARY CIRCUIT COMPONENTS

The primary circuit contains the:

- Battery
- Ignition switch
- Pickup coil in the distributor
- Coil primary winding
- Ignition control module

Battery

The battery supplies low-voltage current to the ignition primary circuit. Battery current is available to the system when the ignition switch is in the START or the RUN position.

Ignition Switch

The ignition switch controls low-voltage current through the primary circuit. The switch allows

current to the coil when it is in the START or the RUN position. Other switch positions route current to accessory circuits and lock the steering wheel in position.

Manufacturers use differing ignition switch circuitry. The differences lie in how battery current is routed to the switch. Regardless of variations, full system voltage is always present at the switch because it is connected directly to the battery.

General Motors automobiles draw ignition current from a terminal on the starter motor solenoid. Ford Motor Company systems draw ignition current from a terminal on the starter relay, Figure 11-2. In Chrysler Corporation vehicles, ignition current comes through a wiring splice installed between the battery and the alternator, Figure 11-3. Imported and domestic automobiles may use different connections. Ignition current is drawn through a wiring splice between the battery and the starter relay to simplify the circuitry on some systems, Figure 11-4.

SWITCHING AND TRIGGERING

All ignition systems regardless of design use a switching device usually called an **ignition control module (ICM)** or **igniter** that contains a power



Figure 11-2. Ford products draw ignition current from a terminal on the starter relay. (Courtesy of Ford Motor Company)



Figure 11-3. Chrysler products draw ignition current from a wiring splice between the battery and the alternator.



Figure 11-4. The ignition current is drawn from a wiring splice between the battery and the starter relay.

transistor that turns the primary current on and off through the ignition coil. In some systems, such as some **coil-on-plug** (**COP**) designs, the **powertrain control module** (**PCM**) does the actual switching.

Triggering is the term used to describe the sensor that activates (trips) the primary coil circuit. This triggering device determines *when* the power transistor turns the coil primary current on and off. When the switch turns off the primary coil current, a high-voltage spark occurs from the secondary winding of the coil.

The trigger wheel is made of steel with a low reluctance, which cannot be permanently magnetized. Therefore, it provides a low-resistance path for magnetic flux lines. The trigger wheel has as many teeth as the engine has cylinders.

As the trigger wheel rotates, its teeth come near the pole piece. Flux lines from the pole piece concentrate in the low-reluctance trigger wheel, increasing the magnetic field strength and inducing a positive voltage signal in the pickup coil. When the teeth and the pole piece are aligned, the magnetic lines of force from the permanent magnet are concentrated and the voltage drops to zero.

The reluctor continues and passes the pole piece, but now the voltage induced is negative, creating an ac voltage signal, Figure 11-5. The pickup coil is connected to the electronic control module, which senses this AC voltage, converts the signal to DC voltage and switches the primary current off, Figure 11-6. Each time a trigger wheel tooth comes near the pole piece, the control module is signaled to switch off the primary current. Solid-state circuitry in the module determines when the primary current is turned on again. Figure 11-7 shows the typical construction of a pulse generator for an 8-cylinder engine. These generators produce an AC signal voltage whose frequency and amplitude vary in direct proportion to rotational speed.

The terms "trigger wheel" and "pickup coil" describe the magnetic pulse generator. Various manufacturers have different names for these components. Other terms for the pickup coil are pole piece, magnetic pickup, or stator. The trigger wheel is often called the reluctor, armature, timer core, or signal rotor.

A **Hall Effect switch** also uses a stationary sensor and rotating trigger wheel, Figure 11-8. Unlike the magnetic pulse generator, it requires a small input voltage in order to generate an output



Figure 11-5. The pickup coil generates an AC voltage signal as the reluctor moves closer and then away from the magnetic field.

or signal voltage. Hall Effect is the ability to generate a small voltage signal in semiconductor material by passing current through it in one direction and applying a magnetic field to it at a right angle to its surface. If the input current is held steady and magnetic field fluctuates, the output voltage changes in proportion to field strength.

Most Hall Effect switches in distributors have a Hall element or device, a permanent magnet, and a ring of metal blades similar to a trigger wheel. Some blades are designed to hang down. These are typically found in Bosch and Chrysler systems, Figure 11-9, while others may be on a separate ring on the distributor shaft, typically found in GM and



Figure 11-6. Schematic of a typical magnetic pulse generator ignition system.



Figure 11-7. A magnetic pulse generator installed in the distributor housing. (Courtesy of Ford Motor Company)

Ford distributors. When the shutter blade enters the gap between the magnet and the Hall element, it creates a magnetic shunt that changes the field strength through the Hall element, thereby creating an analog voltage signal. The Hall element contains a logic gate that converts the analog signal into a digital voltage signal. This digital signal triggers the switching transistor. The transistor transmits a digital square waveform at varying frequency to the powertrain control module (PCM).

The Hall Effect switch requires an extra connection for input voltage; however, its output voltage does not depend on the speed of the rotating trigger wheel. Therefore, its main advantage over



Figure 11-8. Hall Effect ignition systems use a reference voltage to power the Hall device.



Figure 11-9. Shutter blades rotating through the Hall Effect switch air gap bypass the magnetic field around the pickup and drop the output voltage to zero.

the magnetic pulse generator is that it generates a full-strength output voltage signal even at slow cranking speeds. This allows precise switching signals to the ignition primary circuit and accurate and fine adjustments of the air-fuel mixture.

The **optical signal generator** uses the principle of light beam interruption to generate voltage signals. Many optical signal distributors contain a



Figure 11-10. This Nissan optical signal generator works by interrupting a beam of light passing from the LEDs to photodiodes.



Figure 11-11. Each row of slots in this Chrysler optical distributor disc acts as a separate sensor, creating signals used to control fuel injection, ignition timing, and idle speed.

pair of light-emitting diodes (LED) and photo diodes installed opposite each other, Figure 11-10. A disc containing two sets of chemically etched slots is installed between the LEDs and photo diodes. Driven by the camshaft, the disc acts as a timing member and revolves at half engine speed. As each slot interrupts the light beam, an alternating voltage is created in each photo diode. A hybrid integrated circuit converts the alternating voltage into on-off pulses sent to the PCM.

The high-data-rate slots, or outer set, are spaced at intervals of two degrees of crankshaft rotation, Figure 11-11. This row of slots is used for timing engine speeds up to 1,200 rpm. Certain slots in this set are missing, indicating the crankshaft position of the number one cylinder to the PCM. The low-data-rate slots, or inner set, consist of six slots correlated to the crankshaft topdead-center angle of each cylinder. The PCM uses this signal for triggering the fuel-injection system and for ignition timing at speeds above 1,200 rpm. This way, the optical signal generator acts both as the crankshaft position (CKP) sensor and engine speed (RPM) sensor, as well as a switching device.

MONITORING IGNITION PRIMARY CIRCUIT VOLTAGES

An ignition system voltage trace, both primary and secondary, is divided into three sections: firing, intermediate, and dwell. Deviations from a normal pattern indicate a problem. In addition, most scopes display ignition traces in three different patterns. Each pattern is best used to isolate and identify particular kinds of malfunctions. The three basic patterns are superimposed pattern, parade pattern, and stacked, or raster, pattern.

In a superimposed pattern, voltage traces for all cylinders are displayed one on top of another to form a single pattern. This display provides a quick overall view of ignition system operation and also reveals certain major problems. The parade pattern displays voltage traces for all cylinders one after another across the screen from left to right in firing order sequence. A parade display is useful for diagnosing problems in the secondary circuit. A raster pattern shows the voltage traces for all cylinders stacked one above another in firing order sequence. This display allows you to compare the time periods of the three sections of a voltage trace.

All ignition waveforms contain a vast amount of information about circuit activity, mechanical condition, combustion efficiency, and fuel mixture. Electronic ignition system waveform patterns vary with manufacturer and ignition types; therefore, it is important to be able to recognize the normal waveform patterns and know how they relate to the particular system. The differences between the scope trace of breaker point and electronic ignition systems occur in the intermediate and the dwell sections, Figure 11-12. The most noticeable difference is that no condenser oscillations are present in the intermediate section of the waveform trace on electronic ignition systems. Also, the beginning of the dwell section in the breaker point system is the points closing, while on electronic ignition systems it is the current on signal from the switching device. Another difference is that the current limiting devices on



Figure 11-12. The primary superimposed pattern traces all the cylinders, one upon the other.

electronic ignition systems often display an abrupt rise in dwell voltage called a current limiting hump. These and other waveform characteristics are used to diagnose many primary circuit malfunctions.

With ignition scope experience and knowledge of waveform data, primary ignition traces are categorized according to the particular features of the ignition system. The GM HEI ignition system is capable of producing 30,000 volts of secondary voltage at the spark plug. The primary firing line measures approximately 250 volts, Figure 11-13. As the secondary firing voltage goes up or down, it performs the same in the primary firing voltage. Ford TFI systems display a dwell line with 4.25 milliseconds between the primary turn-on and the current limiting hump, Figure 11-14. The lowresistance coil of a TFI system produces current acceleration to about 6 amps before the current limiting restricts the current. Early electronic ignition systems display features not particular to the newer, more efficient ignition systems.

Observing Triggering Devices and Their Waveforms

The ignition scope has its place in diagnosing many primary ignition system malfunctions. Because the primary circuit deals with low voltage values, the lab scope is the best tool for diagnosing primary ignition system problems. A lab scope has greater resolution, which provides more clarity than an ignition scope. Many digital



Figure 11-13. The firing line on Ford electronic distributorless ignition system (EDIS) should be approximately 342 volts for the primary circuit.



Figure 11-14. Ford thick film integrated (TFI) ignition systems use low-resistance coils that allow current acceleration and produce a distinct current limiting hump in the dwell trace.

scopes are capable of storing waveform patterns for future review and comparison. Lab scopes are convenient because they observe other activity on the ignition primary circuit. The various primary circuit-switching devices also display voltage fluctuations during their prescribed trigger cycle that can be observed and diagnosed.

Magnetic pulse generators provide an AC voltage signal easily observed using a lab scope. The GM HEI ignition system magnetic pickup coil applies this ac symmetrical sine wave signal voltage to the "P" and "N" terminals on the HEI module, Figure 11-15. The solid-state circuitry inside the ignition module converts the AC signal to a DC square wave that peaks at 5.0 volts. These AC and DC voltage fluctuations are observed separately. While the engine is cranking, the AC voltage signal from the pickup coil is accessed from terminal "P," Figure 11-16. The square-wave signal HEI reference signal, is accessed from terminal "R." A dual-trace scope simultaneously displays the primary circuit voltage and the reference signal voltage, Figure 11-17.

A Hall Effect switching device requires a threewire circuit: power input, signal output, and ground. The Hall element receives an input voltage from the ignition switch or PCM, Figure 11-18. As the shutter blade opens and closes, so does the input signal ground circuit. This opening and closing transmits a digital square-wave signal to the PCM. Many ignition systems are designed with the Hall Effect square waves peaking at 5.0 volts. Others may use 7.0, 9.0, or some other voltage.

More complex Hall Effect ignition systems require more details. The Hall Effect TFI ignition system on many Ford vehicles uses a camshaft position (CMP) sensor, which is a Hall Effect device inside the distributor. The CMP sensor produces a digital profile ignition pickup (PIP) signal. The shutter blade passes over a smaller vane, which identifies the number one cylinder for fuel injector firing. This signal is called the Signature PIP. The PIP signal is sent from the CMP sensor to the PCM and the ignition control module (ICM). The computer uses this signal to calculate the spark angle data for the ignition control module to control ignition coil firing. The ICM acts as a switch to ground in the primary circuit. The falling edge of the SPOUT signal controls the battery voltage applied to the primary circuit. The rising edge of the SPOUT signal controls the actual switch opening, Figure 11-19. The PCM uses the inductive voltage spike when the primary field collapses and converts it into an ignition diagnostic monitor signal (IDM), Figure 11-20. This diagnostic monitor signal is used by the computer to observe the primary circuit. Because the ICM mounts on the exterior of the distributor, the various voltage waveforms are observed on a scope.

Optical ignition systems create distinct voltage signals. The Chrysler Optical ignition system on the 3.0L engine uses two photocells and two LEDs with solid-state circuitry to create two 5.0volt signals. The inner set, or low data, of slots signals TDC for each cylinder while the outer slots (high data) monitor every two degrees of crankshaft rotation, Figure 11-21. When observing the waveforms, if the low data rate or the high data rate signals fail on the high section, then the LED is most likely malfunctioning. If the signals fail on the low section, then the PCM is most likely not delivering the 5.0-volt reference signal.



Figure 11-15. Schematic of the GM HEI magnetic pulse generator ignition system.

If the low data signal is lost, the engine normally starts. If the high data signal is lost, the engine starts, but on default settings from the PCM, Figure 11-22.

PRIMARY AND SECONDARY CIRCUITS

The general operation of the ignition primary circuit and some of the system components have already been covered.

The secondary circuit must conduct surges of high voltage. To do this, it has large conductors

and terminals, and heavy-duty insulation. The secondary circuit in a distributor ignition system, Figure 11-23, consists of the:

- · Coil secondary winding
- Distributor cap and rotor
- Ignition cables
- Spark plugs

The secondary circuit in a distributorless ignition system (DIS), Figure 11-24, consists of the:

- Coil packs
- Ignition cables, where applicable
- Spark plugs

The secondary circuit in a coil over plug DIS consists of the same components as a DIS system except that each cylinder has its own separate coil



Figure 11-16. A lab scope displays an AC since wave during cranking on HEI Terminal "P."



Figure 11-17. The HEI primary circuit voltage trace is displayed on the top and the square-wave reference signal is displayed on the bottom of the scope screen.

and there are usually no ignition wires to the spark plugs, Figure 11-25. Also, the coil over plug system fires each cylinder sequentially rather than using the waste spark method.

IGNITION COILS

The ignition coil steps up voltage in the same way as a transformer. When the magnetic field of the coil primary winding collapses, it induces a high voltage in the secondary winding.



Figure 11-18. The lab scope displays the Hall Effect output signal transmitted to the PCM.

Coil Secondary Winding and Primary-to-Secondary Connections

Two windings of copper wire compose the ignition coil. The primary winding of heavy wires consists of 100 to 150 turns; the secondary winding is 15,000 to 30,000 turns of a fine wire. The ratio of secondary turns to primary turns is usually between 100 and 200. To increase the strength of the magnetic field, the windings are wrapped around a laminated core of soft iron, Figure 11-26.

The coil must be protected from the underhood environment to maintain its efficiency. Four coil designs are used:

- Oil-filled coil
- Laminated E-core coil
- DIS coil packs
- Coil over plug assemblies

Oil-filled Coil

In the oil-filled coil, the primary winding is wrapped around the secondary winding, which is wrapped around the iron core. The coil windings

DISTRIBUTOR IGNITION SCHEMATIC EXAMPLE



DISTRIBUTOR IGNITION SCHEMATIC (5.8./7.5. E AND F SERIES)

REMOTE IGNITION CONTROL MODULE



Figure 11-19. Schematic of the Ford TFI CCD ignition system on late-model trucks. (Courtesy of Ford Motor Company)



Figure 11-20. The IDM, SPOUT, and PIP signals are monitored to check power input, power output, and ground. **238**



Figure 11-21. In a Chrysler Optical Ignition system, the low data rate square wave looks different than the high data rate square wave.



Figure 11-22. The primary circuit voltage trace of a Chrysler Photo Optical Ignition system is displayed on the top while the CKP square wave is displayed on the bottom of the scope screen.

are insulated by layers of paper and the entire case is filled with oil for greater insulation. The top of the coil is molded from an insulating material such as Bakelite. Metal inserts for the winding terminals are installed in the cap. Primary and secondary terminals are generally marked with a + and -, Figure 11-27. Leads are attached with nuts and washers on some coils; others use pushon connectors. The entire unit is sealed to keep out dirt and moisture.

Laminated E-Core Coil

Unlike the oil-filled coil, the E-core coil uses an iron core laminated around the windings and pot-

ted in plastic, much like a small transformer, Figure 11-28. The coil is so named because of the "E" shape of the laminations making up its core. Because the laminations provide a closed magnetic path, the E-core coil has a higher energy transfer. The secondary connection looks much like a spark plug terminal. Primary leads are housed in a single snap-on connector that attaches to the coil's blade-type terminals. The Ecore coil has very low primary resistance and is used without a ballast resistor in Ford TFI and some GM HEI ignitions.

DIS Coil Packs

Distributorless ignitions use two or more coils in a single housing called a coil pack, Figure 11-29. Because the E-core coil has a primary and secondary winding on the same core, it uses a common terminal. Both ends of the E-core coil's primary winding connect to the primary ignition circuit; the open end of its secondary winding connects to the center tower of the coil, where the distributor high-tension lead connects.

Coil packs are significantly different, using a closed magnetic core with one primary winding for each two high-voltage outputs. The secondary circuit of the coil pack is wired in series. Each coil in the coil pack directly provides secondary voltage for two of the spark plugs, which are in series with the coil secondary winding. Coil pack current is limited by transistors called output drivers, which are located in the ignition module attached to the bottom of the pack. The output drivers open and close the ground path of the coil primary circuit. Other module internal circuits control timing and sequencing of the output drivers.



Figure 11-23. Typical early Chrysler electronic ignition system with a distributor, cap, and rotor.

Coil Over Plug Coil Assemblies

Each cylinder has its own separate coil and there are no ignition wires to the spark plugs on all coil over plug ignition systems. Each cylinder is fired only on its compression stroke.

Coil Voltage

A coil must supply the correct amount of voltage for any system. Since this amount of voltage varies, depending on engine and operating conditions, the voltage available at the coil is generally greater than what is required by the system. If it is less, the engine may not run.

Available Voltage

The ignition coil supplies much more secondary voltage than the average engine requires. The peak voltage that a coil produces is called its **available voltage.**

Three important coil design factors determine available voltage level:

- Secondary-to-primary turns ratio
- Primary voltage level
- Primary circuit resistance

The turns ratio is a multiplier that creates high secondary voltage output. The primary voltage level that is applied to a coil is determined by the ignition circuit design and condition. Anything affecting circuit resistance such as incorrect parts or loose or corroded connections, affects this voltage level. Generally, a primary circuit voltage loss of one volt may decrease available voltage by 10,000 volts.

If there were no spark plug in the secondary circuit, the coil secondary voltage would have no place to discharge quickly. That is, the circuit would remain open so there is no path to ground for the current to follow. As a result, the voltage oscillates in the secondary circuit and dissipates as heat. The voltage is completely gone in just a few milliseconds. Figure 11-30 shows the trace of this no-load, open-circuit voltage. This is called secondary voltage trace represents the maximum available voltage from that particular coil. Available voltage is usually between 20,000 and 50,000 volts.

Required Voltage

When there is a spark plug in the secondary circuit, the coil voltage creates an arc across the plug air gap to complete the circuit. Figure 11-31 compares a typical no-load oscillation to a typical secondary



Figure 11-24. Typical Ford EDIS ignition system with a coil pack and separate spark plug wires for the secondary system. (Courtesy of Ford Motor Company)

firing voltage oscillation. At about 15,000 volts, the spark plug air gap ionizes and becomes conductive. This is the ionization voltage level, also called the **firing voltage**, or **required voltage**.

As soon as a spark has formed, less voltage is required to maintain the arc across the air gap. This reduces the energy demands of the spark causing the secondary voltage to drop to the much lower spark voltage level. This is the inductive portion of the spark. **Spark voltage** is usually about one-fourth of the firing voltage level.

Figure 11-32 shows the entire trace of the spark. The spark duration or **burn time** of the trace indicates the amount of resistance and efficiency of the spark voltage. Burn time on most ignition systems is between 1.6 and 1.8 milliseconds. The traces



Figure 11-25. Typical coil over plug ignition system on a V-8 with a separate coil/spark plug assembly for each cylinder.





Figure 11-27. Many oil-filled coils are marked with the polarity of the primary leads.

Figure 11-26. The laminated iron core within the coil strengthens the coil's magnetic field.

shown are similar to the secondary circuit traces seen on an oscilloscope screen. High secondary resistance causes the spark voltage to increase and a quick burn time, or short spark duration. This occurs as the secondary system overcomes the resistance by reducing current and increasing voltage. This section of the waveform trace indicates secondary efficiency. When the secondary voltage falls below the inductive air-gap voltage level, the spark can no longer be maintained. The spark gap becomes nonconductive. The remaining secondary voltage oscillates in the secondary circuit, dissipating as heat. This is called secondary **voltage de**-



Figure 11-28. The E-core coil is used without a ballast resistor.



Figure 11-29. Typical DIS coil packs used on cylinder engines.

cay. At this time, the primary circuit closes and the cycle repeats, Figure 11-33.

It is a good idea to memorize the three most typical firing voltages and their respective air-gap settings. The firing voltage on the spark plug of 0.035 inch is about 6 to 8 kV; 0.045-inch air gap is 8 to 10 kV; and 0.060 air gap is 10 to 12 kV. There are many more plug air-gap settings but it is important to know the three most popular spark plug gap settings and their kilovolt requirements to compare to other systems. The scope pattern for the secondary circuit quickly shows the firing voltage, Figure 11-34.

Secondary ignition component failure due to wear is a common problem that results in high circuit resistance. Whether caused by a damaged plug wire, worn distributor cap, or excessive spark plug gap, this additional resistance disrupts



Figure 11-30. A secondary circuit no-load voltage trace.

current and alters the scope trace. Higher voltage, which is required to overcome this type of resistance, reduces current. The energy in the coil dissipates more rapidly than normal. As a result, high circuit resistance produces a high firing spike followed by high, short spark line.

Firing voltage for the DIS exhibits a slightly different waveform pattern than distributor ignition systems because of the design of the "waste spark" secondary system. Distributorless ignition systems pair two cylinders, called companion cylinders, and fire both spark plugs at the same time. One cylinder fires on the compression stroke, while the other cylinder fires on the exhaust stroke. The spark plugs are wired in series. One fires in the conventional method, from center electrode to ground electrode, while the other fires from ground electrode to center electrode. Every other cylinder has reverse polarity, Figure 11-35. The cylinder on the compression stroke requires more voltage to fire the air-fuel mixture than the other cylinder. The exhaust waste spark, or stroke pattern, shows less voltage because there is much less resistance across the spark plug gap of the waste spark, Figure 11-36. Also, the DIS fires once per engine revolution as opposed to every other revolution in a distributor

Figure 11-31. The dashed line shows no-load voltage; the solid line shows the voltage trace of firing voltage and spark voltage.

0.10

TIME IN MILLISECONDS

0.15

FIRING VOLTAGE

SPARK VOLTAGE

 $1000 \ \mu s = 1 \ ms$

0.20

NO-LOAD OSCILLATION



Figure 11-32. The voltage trace of an entire secondary ignition pulse.

engine. As a result, DIS plugs wear twice as fast as distributor ignition plugs.

Secondary waveform patterns should be viewed first to gather the most complete list of ignition and engine driveability problems. The secondary system clearly indicates the operating resistance—or the systems that are expending too much resis-



Figure 11-33. As the primary circuit opens and closes, the ignition cycle repeats.

tance. The secondary waveform patterns include data for resistance in three areas: the electrical resistance (air gaps and secondary circuit), the cylinder compression resistance (mechanical), and the combustion resistance (air-fuel ratio performance). The resistance expended by faulty secondary ignition wires, excessive spark plug and rotor air gaps, weak compression, incorrect valve timing, or poor air-fuel mixing may be detected on the secondary waveform pattern.

Some other conditions of high resistance that cause required voltage levels to increase are:

- Eroded electrodes in the distributor cap, rotor, or spark plug
- Damaged ignition cables
- Reversed plug polarity
- · High compression pressures
- Lean air-fuel mixture that is more difficult to ionize

Voltage Reserve

The physical condition of the automotive engine and ignition system affects both available and required voltage levels. Figure 11-37 shows available and required voltage levels in a particular ignition system under various operating conditions. **Voltage reserve** is the amount of coil voltage available in excess of the voltage required.

Under certain poor circuit conditions, there may be no voltage reserve. At these times, some spark plugs do not fire and the engine runs poorly or not at all. Ignition systems must be properly maintained to ensure that there is always some voltage reserve. Typically, an ignition system should have a voltage reserve of about 60 percent of available voltage under most operating conditions.

k٧

20

15

10

5

0

-10

-15

0

APPROX 30 μs

0.05

SECONDARY VOLTAGE

Ø



Figure 11-34. Normal secondary firing voltages for the secondary system with an 0.045-inch air gap.



Figure 11-35. Although the current in the secondary windings of the DIS coil does not reverse, one spark plug fires with normal polarity, while the other spark plug fires with reverse polarity.

Coil Installations

Ignition coils are usually mounted with a bracket on a fender panel in the engine compartment or on the engine, Figure 11-38.

Some ignition coils have an unusual design and location. The Delco-Remy high energy ignition (HEI) electronic ignition system has a coil mounted in the distributor. The coil output terminal is connected directly to the center electrode of the distributor cap. The connections to the primary winding are made through a multiplug connector.

Many ignition systems manufactured in Asia have the coil inside the distributor along with the pickup coil, rotor, and module. Toyota mounts the ignition coil inside the distributor, Figure 11-39, but positions the module (igniter) on the bulkhead or shock tower for cooling purposes.

Distributorless ignitions use an assembly containing one or more separate ignition coils and an electronic ignition module, Figure 11-40. Control circuits in the module discharge each coil separately in sequence, with each coil serving two cylinders 360 degrees apart in the firing order.

In any system, the connections to the primary winding must be made correctly. If spark plug polarity is reversed, greater voltage is required to fire the plug. Plug polarity is established by the ignition coil connections.

One end of the coil secondary winding is connected to the primary winding, Figure 11-41, so the secondary circuit is grounded through the ignition primary circuit. When the coil terminals are properly connected to the battery, the grounded end of the secondary circuit is electrically positive. The other end of the secondary circuit, which is the center electrode of the spark plug, is electrically negative. Whether the secondary winding is grounded to the primary + or [-] terminal depends on whether the windings are wound clockwise or counterclockwise.



Figure 11-36. The cylinder with the greatest resistance (compression) exhibits high firing voltage while the cylinder with the least resistance (waste) exhibits the lower firing voltage.



Figure 11-37. Available and required voltage levels under different system conditions.

The secondary circuit must have negative polarity, or positive ground, for two main reasons. First, electrons flow more easily from negative to positive than they do in the opposite direction. Second, high temperatures of the spark plug center electrode increase the rate of electron movement, or current. The center electrode is much hotter than the side electrode because it cannot transfer heat to the cylinder head as easily. The electrons move quickly and easily to the side electrode when the air-fuel mixture is ignited. Although the secondary operates with negative polarity, it is a positive ground circuit.



Figure 11-38. A typical distributorless ignition system coil pack may be mounted on the engine in a location that provides easy access.

If the coil connections are reversed, Figure 11-42, spark plug polarity is reversed. The grounded end of the secondary circuit is electrically negative. The plug center electrode is electrically positive, and the side electrode is negative. When plug polarity is reversed, 20 to 40 percent more secondary voltage is required to fire the spark plug.

Coil terminals are usually marked BAT or +, and DIST or [-]. To establish the correct plug polarity with a negative-ground electrical system, the + terminal must be connected to the positive terminal of the battery through the ignition switch, starter relay, and other circuitry. The [-]coil terminal must be connected to the ignition control module.



Figure 11-39. Toyota mounts the ignition coil inside the distributor.

DISTRIBUTOR CAP AND ROTOR

The distributor cap and rotor, Figure 11-43, receive high-voltage current from the coil secondary winding. Current enters the distributor cap through the central terminal called the coil tower. The rotor carries the current from the coil tower to the spark plug electrodes in the rim of the cap.



Figure 11-40. The Buick C31 distributorless ignition uses a single coil pack with three coils, each of which serves two cylinders 360 degrees apart in the firing order.



Figure 11-41. When coil connections are made properly, the spark plug center electrode is electrically negative.

The rotor mounts on the distributor shaft and rotates with the shaft so the rotor electrode moves from one spark plug electrode to another in the cap to follow the designated firing order.

Distributor Rotor

A rotor is made of silicone plastic, **bakelite**, or a similar synthetic material that is a very good insulator. A metal electrode on top of the rotor conducts current from the carbon terminal of the coil tower.

The rotor is keyed to the distributor shaft to maintain its correct relationship with the shaft and



Figure 11-42. When coil connections are reversed, spark plug polarity is reversed.



Figure 11-43. A distributor rotor and a cutaway view of the distributor cap.

the spark plug electrodes in the cap. The key may be a flat section or a slot in the top of the shaft. Delco-Remy V-6 and V-8, shown at the left in Figure 11-44, are keyed in place by two locators and secured by two screws. On the right is shown







Figure 11-45. A Hall Effect triggering device attached to the rotor. (Courtesy of DaimlerChrysler Corporation)

a plug-on or push-on distributor rotor. Most other rotors are pressed onto the shaft by hand. The rotor in a Chrysler optically triggered distributor is retained by a horizontal capscrew.

Rotors used with Hall Effect switches often have the shutter blades attached, Figure 11-45, serving a dual purpose: In addition to distributing the secondary current, the rotor blades bypass the Hall Effect magnetic field and create the signal for the primary circuit to fire.

Rotor Air Gap

An air gap of a few thousandths of an inch, or a few hundredths of a millimeter, exists between the tip of the rotor electrode and the spark plug electrode of the cap. If they actually touch, both would wear very quickly. Because the gap cannot be measured when the distributor is assembled, it



Figure 11-46. Many Delco-Remy HEI electronic ignition systems used on V-6 and V-8 engines have a coil mounted in the distributor cap.

is usually described in terms of the voltage required to create an arc across the electrodes. Only about 3,000 volts are required to create an arc across some air gaps, but others require as much as 9,000 volts. As the rotor completes the secondary circuit and the plug fires, the rotor air gap adds resistance to the circuit. This raises the plug firing voltage, suppresses secondary current, and reduces RFI.

Distributor Cap

The distributor cap is also made of silicone plastic, Bakelite, or a similar material that resists chemical attack and protects other distributor parts. Metal electrodes in the spark plug towers and a carbon insert in the coil tower provide electrical connections with the ignition cables and the rotor electrode. The cap is keyed to the distributor housing and is held on by two or four springloaded clips or by screws.

Delco-Remy HEI distributor caps with an integral coil, Figure 11-46, are secured by four springloaded clips. When removing this cap, ensure that all four clips are disengaged and clear of the housing. Then lift the cap straight up to avoid bending the carbon button in the cap and the spring that connects it to the coil. If the button and spring are distorted, arcing can occur that will burn the cap and rotor.



Figure 11-47. Chrysler 4 cylinder distributors have used positive locking terminal electrodes as part of the ignition cable since 1980. (Courtesy of DaimlerChrysler Corporation)

Positive-engagement spark plug cables are used with some Chrysler and Ford 4-cylinder ignition systems. There are no electrodes in distributor caps used with these cables. A terminal electrode attached to the distributor-cap end of the cable locks inside the cap to form the distributor contact terminal. The secondary terminal of the cable is pressed into the cap, Figure 11-47.



Figure 11-48. Spark plug cable installation order for Ford V-8 EEC systems. (Courtesy of Ford Motor Company)

Ford distributors used with some electronic engine control (EEC) systems have caps and rotors with the terminals on two levels to prevent secondary voltage arcing. Spark plug cables are not connected to the caps in firing order sequence, but the caps are numbered with the engine cylinder numbers, Figure 11-48. The caps have two sets of numbers, one set for 5.0-liter standard engines, and the other for 5.7-liter and 302-cid high-performance engines. Cylinder numbers must be carefully checked when changing spark plug cables.

Distributor caps used on some late-model Ford and Chrysler vehicles have a vent to prevent the buildup of moisture and reduce the accumulation of ozone inside the cap.

IGNITION CABLES

Secondary ignition cables carry high-voltage current from the coil to the distributor and from the distributor to the spark plugs. They use heavy insulation to prevent the high-voltage current from jumping to ground before it reaches the spark plugs. Ford, GM, and some other electronic ignitions use an 8-mm cable; all others use a 7-mm cable.

Conductor Types

Spark plug cables originally used a solid steel or copper wire conductor. Cables manufactured with these conductors were found to cause radio and television interference. While this type of cable is still made for special applications such as racing, most spark plug cables have been made of high-resistance, nonmetallic conductors for the past 30 years. Several nonmetallic conductors may be used, such as carbon, and linen or fiberglass strands impregnated with graphite. The nonmetallic conductor acts as a resistor in the secondary circuit and reduces RFI and spark plug wear due to high current. Such cables are often called **television-radio-suppression** (**TVRS**) cables, or just suppression cables.

When replacing spark plug cables on vehicles with computer-controlled systems, ensure that the resistance of the new cables is within the original equipment specifications to avoid possible electromagnetic interference with the operation of the computer.

Terminals and Boots

Secondary ignition cable terminals are designed to make a strong contact with the coil and distributor electrodes. They are, however, subject to corrosion and arcing if not firmly seated and protected from the elements.

Positive-engagement spark plug cable terminals, Figure 11-49, lock in place inside the distributor cap and cannot accidentally come loose. They can only be removed when the cap is off the distributor. The terminal electrode is then compressed with pliers and the wire is pushed out of the cap.

The ignition cables must have special connectors, often called spark plug boots, Figure 11-50. The boots provide a tight and well-insulated contact between the cable and the spark plug.

SPARK PLUGS

Spark plugs allow the high-voltage secondary current to arc across a small air gap. The three basic parts of a spark plug, Figure 11-51, are:

- A ceramic core, or insulator, that insulates the center electrode and acts as a heat conductor.
- Two electrodes, one insulated in the core and the other grounded on the shell.
- A metal shell that holds the insulator and electrodes in a gas-tight assembly and has threads to hold the plug in the engine.

The metal shell grounds the side electrode against the engine. The other electrode is encased in the ceramic insulator. A spark plug boot and cable are attached to the top of the plug. High-voltage current travels through the center of the plug and arcs from the tip of the insulated electrode to the side



Figure 11-49. Positive locking terminal electrodes are removed by compressing the wire clips with pliers and removing the wire from the cap.



Figure 11-50. Ignition cables, terminals, and boots work together to carry the high-voltage secondary current.

electrode and ground. This spark ignites the airfuel mixture in the combustion chamber to produce power.

The burning gases in the engine can corrode and wear the spark plug electrodes. Electrodes are made of metals that resist this attack. Most electrodes are made of high-nickel alloy steel, but platinum and silver alloys are also used.

Spark Plug Firing Action

The arc of current across a spark plug air gap provides two types of discharge:

- Capacitive
- Inductive.



Figure 11-51. A cutaway view of the spark plug.

When a high-voltage surge is first delivered to the spark plug center electrode, the air-fuel mixture in the air gap cannot conduct an arc. The spark plug acts as a capacitor, with the center electrode storing a negative charge and the grounded side electrode storing a positive charge. The air gap between the electrodes acts as a dielectric insulator. This is the opposite of the normal negativeground polarity, and results from the polarity of the coil secondary winding.

Secondary voltage increases, and the charges in the spark plug strengthen until the difference in potential between the electrodes is great enough to ionize the spark plug air gap. That is, the air-fuel mixture in the gap is changed from a nonconductor to a conductor by the positive and negative charges of the two electrodes. The dielectric resistance of the air gap breaks down and current travels between the electrodes. The voltage level at this instant is called ionization voltage. The current across the spark plug air gap at the instant of ionization is the capacitive portion of the spark. It flows from negative to positive and uses the energy stored in the plug itself when the plug was acting as a capacitor, before ionization. This is the portion of the spark that starts the combustion process within the engine.

The ionization voltage level is usually less than the total voltage produced in the coil secondary winding. The remainder of the secondary voltage (voltage not needed to force ionization) is dissipated as current across the spark plug air gap. This is the inductive portion of the spark discharge, which causes the visible flash or arc at the plug. It contributes nothing to the combustion of the air-fuel mixture, but is the cause of electrical interference and severe electrode erosion. High-resistance cables and spark plugs suppress this inductive portion of the spark discharge and reduce wear.

SPARK PLUG CONSTRUCTION Spark Plug Design Features

Spark plugs are made in a variety of sizes and types to fit different engines. The most important differences among plugs are:

- Reach
- Heat range
- Thread and seat
- Air gap

These are illustrated in Figure 11-52.

Reach

The **reach** of a spark plug is the length of the shell from the seat to the bottom of the shell, including both threaded and unthreaded portions. If an incorrect plug is installed and the reach is too short, the electrode will be in a pocket and the spark will not ignite the air-fuel mixture very well, Figure 11-53.

If the spark plug reach is too long, the exposed plug threads could get hot enough to ignite the airfuel mixture at the wrong time. It may be difficult to remove the plug due to carbon deposits on the plug threads. Engine damage can also result from interference between moving parts and the exposed plug threads.

Heat Range

The **heat range** of a spark plug determines its ability to dissipate heat from the firing end. The length of the lower insulator and conductivity of the center electrode are design features that primarily control the rate of heat transfer, Figure 11-54. A "cold" spark plug has a short insulator tip that provides a short path for heat to travel, and permits the heat to rapidly dissipate to maintain a lower firing tip temperature. A "hot" spark plug has a long insulator tip that creates a longer path for heat to travel. This slower heat transfer maintains a higher firing tip temperature.

Engine manufacturers choose a spark plug with the appropriate heat range required for the normal or expected service for which the engine was designed.



Figure 11-52. The design features of a spark plug.





Proper heat range is an extremely important factor because the firing end of the spark plug must run hot enough to burn away fouling deposits at idle, but must also remain cool enough at highway speeds to avoid preignition. It is also an important factor in the amount of emissions an engine will produce.

Current spark plug designations use an alphanumeric system that identifies, among other factors, the heat range of a particular plug. Spark



Figure 11-54. Spark plug heat range.



Figure 11-55. Spark plug thread and seat types.

plug manufacturers are gradually redesigning and redesignating their plugs. For example, a typical AC-Delco spark plug carries the alphanumeric designation R45LTS6; the new all-numeric code for a similar AC spark plug of the same length and gap is 41-600. This makes it more difficult for those who attempt to correct driveability problems by installing a hotter or colder spark plug than the manufacturer specifies. Eventually, it no longer will be possible for vehicle owners to affect emissions by their choice of spark plugs.

Thread and Seat

Most automotive spark plugs are made with one of two thread diameters: 14 or 18 millimeters, Figure 11-55. All 18-mm plugs have tapered seats that match similar tapered seats in the cylinder head. The taper seals the plug to the engine without the use of a gasket. The 14-mm plugs are made either with a flat seat that requires a gasket or with a tapered seat that does not. The gaskettype, 14-mm plugs are still quite common, but the 14-mm tapered-seat plugs are now used in most late-model engines. A third thread size is 10 millimeters; 10-mm spark plugs are generally used on motorcycyles, but some automotive engines also use them; specifically, Jaguar's V-12 uses them as well.

The steel shell of a spark plug is hex-shaped so a wrench fits it. The 14-mm, tapered-seat plugs have shells with a 5/8-inch hex; 14-mm gasketed and 18-mm tapered-seat plugs have shells with a 13/16-inch hex. A 14-mm gasket plug with a 5/8-inch hex is used for special applications, such as a deep recessed with a small diameter opening.

Air Gap

The correct spark plug air gap is important to engine performance and plug life. A gap that is too narrow causes a rough idle and a change in the exhaust emissions. A gap that is too wide requires higher voltage to jump it; if the required voltage is greater than the available ignition voltage, misfiring results.

Special-Purpose Spark Plugs

Specifications for all spark plugs include the design characteristics just described. In addition, many plugs have other special features to fit particular requirements.

Resistor-Type Spark Plugs

This type of plug contains a resistor in the center electrode, Figure 11-56. The resistor generally has a value of 7,500 to 15,000 ohms and is used to reduce RFI. **Resistor-type spark plugs** can be used in place of nonresistor plugs of the same size, heat range, and gap without affecting engine performance.

Extended-Tip Spark Plugs

Sometimes called an **extended-core spark plug,** this design uses a center electrode and insulator that extend farther into the combustion chamber, Figure 11-57. The extended-tip operates hotter under slow-speed driving conditions to burn off combustion deposits and cooler at high speed to prevent spark plug overheating.



Figure 11-56. A resistor-type spark plug.



Figure 11-57. A comparison of a standard and an extended-core spark plug.

Wide-Gap Spark Plugs

The electronic ignition systems on some late-model engines require spark plug gaps in the 0.045- to 0.080-inch (1.0- to 2.0-mm) range. Plugs for such systems are made with a wider gap than other plugs. This wide gap is indicated in the plug part number. Do not try to open the gap of a narrow-gap plug to create the wide gap required by such ignitions.

Copper-Core Spark Plugs

Many plug manufacturers are making plugs with a copper segment inside the center electrode. The copper provides faster heat transfer from the electrode to the insulator and then to the cylinder head and engine coolant. Cooper-core plugs are also extended-tip plugs. This combination results in a more stable heat range over a greater range of engine temperatures and greater resistance to fouling and misfire.

Platinum-Tip Spark Plugs

Platinum-tip plugs are used in some late-model engines to increase firing efficiency. The plat-



Figure 11-58. A long-reach, short-thread spark plug.

inum center electrode increases electrical conductivity, which helps prevent misfiring with lean mixtures and high temperatures. Since platinum is very resistant to corrosion and wear from combustion chamber gases and heat, recommended plug life is twice that of other plugs.

Long-Reach, Short-thread Spark Plugs

Some late-model GM engines, Ford 4-cylinder engines, and Ford 5.0-liter V-8 engines use 14-mm, tapered-seat plugs with a 3/4-inch reach but have threads only for a little over half of their length, Figure 11-58. The plug part number includes a suffix that indicates the special thread design, although a fully threaded plug can be substituted if necessary.

Advanced Combustion Igniters

This extended-tip, copper-core, platinum-tipped spark plug was introduced by GM in 1991. It combines all the attributes of the individual plug designs described earlier and uses a nickel-plated shell for corrosion protection. This combination delivers a plug life in excess of 100,000 miles (160,000 km). No longer called a spark plug, the GM advanced combustion igniter (ACI) has a smooth ceramic insulator with no cooling ribs. The insulator is coated with a baked-on boot release compound that prevents the spark plug wire boot from sticking and causing wire damage during removal.

SUMMARY

Through electromagnetic induction, the ignition system transforms the low voltage of the battery into the high voltage required to fire the spark plugs. Induction occurs in the ignition coil where current travels through the primary winding to build up a magnetic field. When the field rapidly collapses, high voltage is induced in the coil secondary winding. All domestic original-equipment ignitions are the battery-powered, inductivedischarge type.

The ignition system is divided into two circuits: primary and secondary. The primary circuit contains the battery, the ignition switch, the coil primary winding, a switching device, and signal devices to determine crankshaft position.

For over sixty years, mechanical breaker points were used as the primary circuit-switching device. Solid-state electronic components replaced breaker points as the switching device in the 1970s. The two most common solid-state switching devices are the magnetic pulse generator and the Hall Effect switch.

The breaker points are a mechanical switch that opens and closes the primary circuit. The time period when the points are closed is called the dwell angle. The dwell angle varies inversely with the gap between the points when they are open. As the gap decreases, the dwell increases. The ignition condenser is a capacitor that absorbs primary voltage when the points open. This prevents arcing across the points and premature burning.

Three types of common ignition electronic signal devices are the magnetic pulse generator, the Hall Effect switch, and the optical signal generator. The magnetic pulse generator creates an ac voltage signal as the reluctor continually passes the pole piece, changing the induced voltage to negative. The Hall Effect switch uses a stationary sensor and rotating trigger wheel just like the magnetic pulse generator. Its main advantage over the magnetic pulse generator is that it can generate a full-strength output voltage signal even at slow speeds. The optical signal generator acts both as the crankshaft position CKP sensor and TDC sensor, as well as a switching device. It uses light beam interruption to generate voltage signals.

The ignition secondary circuit generates the high voltage and distributes it to the engine to ignite the combustion charge. This circuit contains the coil secondary winding, the distributor cap and rotor, the ignition cables, and the spark plugs.

The ignition coil produces the high voltage necessary to ionize the spark plug gap through electromagnetic induction. Low-voltage current in the primary winding induces high voltage in the secondary winding. A coil must be installed with the same primary polarity as the battery to maintain proper secondary polarity as the battery to maintain proper secondary polarity at the spark plugs.

Available voltage is the amount of voltage the coil is capable of producing. Required voltage is the voltage necessary to ionize and fire the spark plugs under any given operating condition. Voltage reserve is the difference between available voltage and required voltage. A welltuned ignition system should have a 60-percent voltage reserve.

The spark plugs allow the high voltage to arc across an air gap and ignite the air-fuel mixture in the combustion chamber. Important design features of a spark plug are its reach, heat range, thread and seat size, and the air gap. Other special features of spark plugs are the use of resistors, extended tips, wide gaps, and copper cores. For efficient spark plug firing, ignition polarity must be established so that the center electrode of the plug is negative and the ground electrode is positive.

Review Questions

Choose the letter that represents the best possible answer to the following questions:

- 1. The voltage required to ignite the air-fuel mixture ranges from:
 - a. 5 to 25 volts
 - b. 50 to 250 volts
 - c. 500 to 2,500 volts
 - d. 5,000 to 40,000 volts
- 2. Which of the following does *not* require higher voltage levels to cause an arc across the spark plug gap?
 - a. Increased spark plug gap
 - b. Increased engine operating temperature
 - c. Increased fuel in air-fuel mixture
 - d. Increased pressure of air-fuel mixture
- 3. Voltage induced in the secondary winding of the ignition coil is how many times greater than the self-induced primary voltage?
 - a. 1 to 2
 - b. 10 to 20
 - c. 100 to 200
 - d. 1,000 to 2,000
- 4. The two circuits of the ignition system are:
 - a. The "Start" and "Run" circuits
 - b. The point circuit and the coil circuit
 - c. The primary circuit and the secondary circuit
 - d. The insulated circuit and the ground circuit
- 5. Which of the following components is part of both the primary and the secondary circuits?
 - a. Ignition switch
 - b. Distributor rotor
 - c. Switching device
 - d. Coil
- 6. Which of the following is true of the coil primary windings?
 - a. They consist of 100 to 150 turns of very fine wire.
 - b. The turns are insulated by a coat of enamel.
 - c. The negative terminal is connected directly to the battery.
 - d. The positive terminal is connected to the switching device and to ground.

- 7. The voltage delivered by the coil is:
 - a. Its full voltage capacity under all operating conditions
 - b. Approximately half of its full voltage capacity at all times
 - c. Only the voltage necessary to fire the plugs under any given operating condition
 - d. Its full voltage capacity only while starting
- 8. The voltage reserve is the:
 - a. Voltage required from the coil to fire a plug
 - b. Maximum secondary voltage capacity of the coil
 - c. Primary circuit voltage at the battery side of the ballast resistor
 - d. Difference between the required voltage and the available voltage of the secondary circuit
- 9. Which of the following are basic parts of a spark plug?
 - a. Plastic core
 - b. Paper insulator
 - c. Fiberglass shell
 - d. Two electrodes
- **10.** In the illustration below, the dimension arrows indicate the:



- a. Heat range
- b. Resistor portion of the electrode
- c. Extended core length
- d. Reach