VEHICLE SERVICING AND REPAIRING

NTQF Level - II

Learning Guide -41

Unit of Competence: - Test and Repair Engine Electrical Systems

Module Title: - Testing and Repairing Engine Electrical Systems

LG Code: EIS VSR2 M11LO2-LG-41

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LO2: Test engine electrical systems

Instruction Sheet	Learning Guide # 40

This learning guide is developed to provide you the necessary information regarding the following **content coverage** and topics –

- Engine electrical systems
- Identify faults
- Report diagnosis findings

This guide will also assist you to attain the learning outcome stated in the cover page. Specifically, upon completion of this Learning Guide, **you will be able to –**

- Engine electrical systems
- Identifying faults
- Reporting diagnosis findings

Learning Instructions:

1. Read the specific objectives of this Learning Guide.
2. Follow the instructions described in number 3 to 20.
3. Read the information written in the "Information Sheets 1". Try to understand what are being discussed. Ask you teacher for assistance if you have hard time understanding them.
4. Accomplish the "Self-check 1" **in page -.**
5. Ask from your teacher the key to correction (key answers) or you can request your teacher to correct your work. (You are to get the key answer only after you finished answering the Self-check 1).
6. If you earned a satisfactory evaluation proceed to "Information Sheet 2". However, if your rating is unsatisfactory, see your teacher for further instructions or go back to Learning Activity #1.
7. Submit your accomplished Self-check. This will form part of your training portfolio.

Information Sheet-1	engine electrical systems

1.1 CHARGING SYSTEM

PURPOSE

The primary purpose of a charging system is torecharge the battery. After the battery has suppliedthe high current needed to start the engine,the battery, even a good battery, has a low charge.The charging system recharges the battery bysupplying a constant and relatively low charge tothe battery.

OPERATION

Charging systems work on the principlesof magnetism to change mechanical energyinto electrical energy. This is done by inducingvoltage.Voltage is induced in a wire when it moves througha magnetic field. The wire or conductor becomes asource of electricity and has a polarity or distinct positive and negative ends. However, this polarity canbe switched depending on the relative direction ofmovement between the wire and magnetic field **(Figure19–1)**. This is why an AC generator producesalternating current **(Figure 19–2)**.

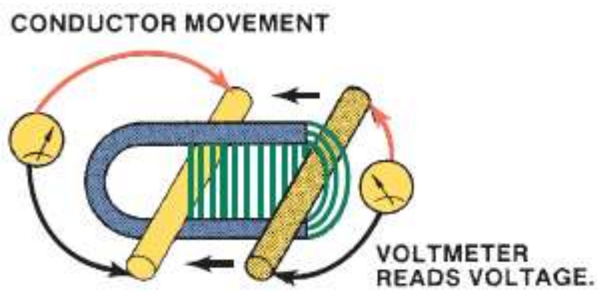


Figure 1.1-1 principles of magnetism

Figure 1.1-2 An AC generator

The charging system must meet the following criteria (when the engine is running):

- Supply the current demands made by all loads.
- Supply whatever charge current the battery demands.
- Operate at idle speed.
- Supply constant voltage under all conditions.
- Have an efficient power-to-weight ratio.
- Be reliable, quiet, and have resistance to contamination.

- Require low maintenance.
- Provide an indication of correct operation.

CHARGING VOLTAGES

The main consideration for the charging voltage is the battery terminal voltage when fully charged. If the charging system voltage is set to this value then there can be no risk of overcharging the battery. This is known as the constant voltage charging technique. The 14.2 ± 0.2 V is the accepted charging voltage for a 12 V system. Commercial vehicles generally employ two batteries in series ata nominal voltage of 24V; the accepted charge voltagewould therefore be doubled.

CHARGING SYSTEM COMPONENTS

- **BATTERY-** The battery supplies current to energize the alternator. During charging, the battery changes electrical energy from the alternator into chemical energy. The battery's active materials are restored. The battery also acts as a "shock absorber" or voltage stabilizer in the system to prevent damage to sensitive components in the vehicle's electrical system.
- **FUSING-** A fusible link as well as separate fuses are used to protect circuits in the charging system.
- **IGNITION SWITCH-** When the ignition switch is in the ON position, battery current energizes the alternator.
- **ALTERNATOR-** Mechanical energy is transferred from the engine to the alternator by a grooved drive belt on a pulley arrangement. Through electromagnetic induction, the alternator changes this mechanical energy into electrical energy. The alternating current generated is converted into direct current by the rectifier, a set of diodes which allow current to pass in only one direction.
- **ALTERNATOR BELT -** links the engine crankshaft pulley with alternator/ generator pulley to drive the alternator/ generator.
- **VOLTAGE REGULATOR -** Without a regulator, the alternator will always operate at its highest output. This may damage certain components and overcharge the battery. The regulator controls the alternator output to prevent overcharging or undercharging. On older models, this is a separate electromechanical component which uses a coil and contact points to open and close the circuit to the alternator. On most models today, this is a built-in electronic device.

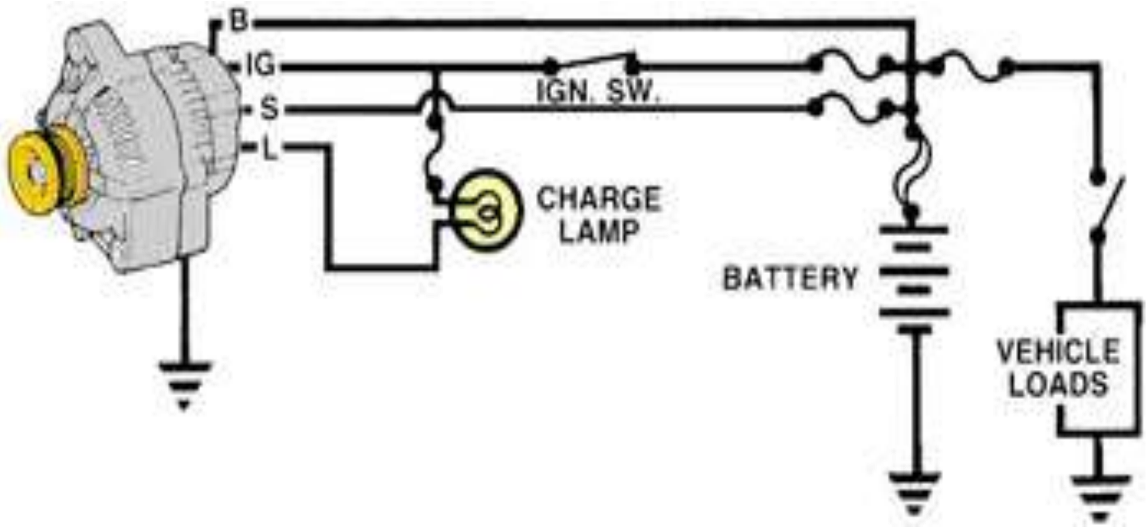


Figure 1.1-3CHARGING SYSTEM COMPONENTS

- **INDICATOR-** The charging indicator device most commonly used on cars today is a simple ON/OFF warning lamp. It is normally off. It lights when the ignition is turned "on" for a check of the lamp circuit. And, it lights when the engine is running if the charging system is undercharging. A voltmeter is used on current models to indicate system voltage. It is connected in parallel with the battery. An ammeter in series with the battery was used on older models.

AC GENERATOR CONSTRUCTION(ALTERNATORS) CONSTRUCTION

Rotor -The rotor assembly consists of a drive shaft,coil, and two pole pieces **(Figure 1.1-4)**. A pulleymounted on one end of the shaft allows the rotor tobe spun by a belt driven by the crankshaft pulley.

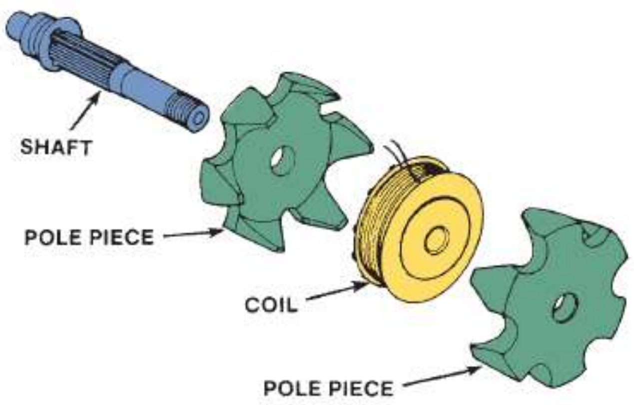


Figure 1.1-4the rotor is made up of a coil, polepieces, and a shaft.

The **rotor** is a rotating magnetic field inside thealternator. The field coil is simply a long length ofinsulated wire wrapped around an iron core. The coreis located between the two sets of **pole pieces**. Amagnetic field is formed by a small amount (4.0 to6.5 amperes) of current passing through the coil winding.As current flows through the coil, the core is magnetizedand the pole pieces assume the magneticpolarity of the end of the core that they touch. Thus,one pole piece has a north polarity and the other has

a south polarity. The extensions of the pole pieces,known as **fingers**, form the actual magnetic poles.

A typical rotor has fourteen poles, seven north andseven south, with the magnetic field between thepole pieces moving from the N poles to the adjacent
S poles **(Figure 1.1-5)**.

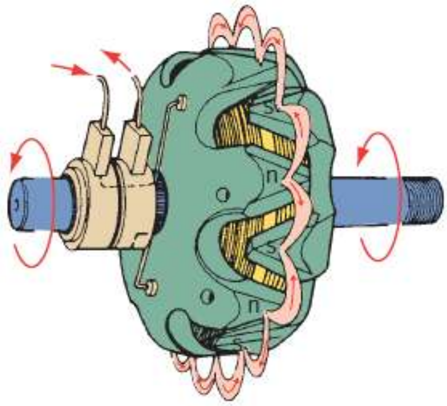


Figure 1.1-5the magnetic field moves from theN poles, or fingers, to the S poles.

Slip Rings and Brushes -Current to create the magneticfield is supplied to the coil from one of twosources: the battery or the AC generator itself. In eithercase, the current is passed through the AC generator'svoltage regulator before it is applied to the coil. Thevoltage regulator varies the amount of current supplied.Increasing field current through the coil increases the strength of the magnetic field. This, in turn, increases AC generator voltage output. Decreasingthe field current to the coil has the opposite effect.Output voltage decreases.

Slip rings and brushes **(Figure 1.1-6)** conductcurrent to the spinning rotor. Most AC generatorshave two slip rings mounted directly on the rotorshaft. They are insulated from the shaft and eachother. Each end of the **field coil** connects to one ofthe slip rings. A carbon brush located on each slipring carries the current to the field coil. Current istransmitted from the field terminal of the voltageregulator through the first brush and slip ring to thefield coil. Current passes through the field coil, the second slip ring and brush before returning toground.

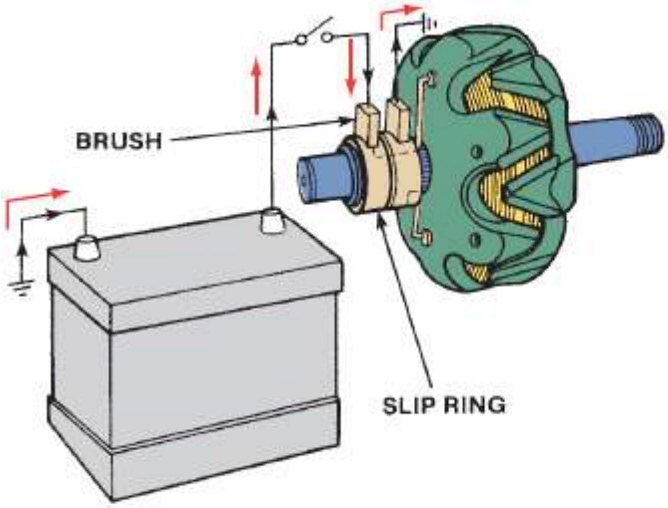


Figure 1.1-6 Current is carried by the brushes to the rotor windings via the slip rings.

Stator - The **stator** is the stationary member of thegenerator. It is made up of a number of conductors,or wires, into which the voltage is induced. MostAC generators use three windings to generate therequired amperage output. They can be arranged ineither a **delta** configuration**(Figure 1.3-7a)** or a **wye** configuration**(Figure 1.3-7b)**. Alternators use one or the other. Usually, awye winding is used in applications in which highcharging voltage at low engine speeds is required. ACgenerators with delta windings are capable of puttingout higher amperages at high speeds but low enginespeed output is poor.

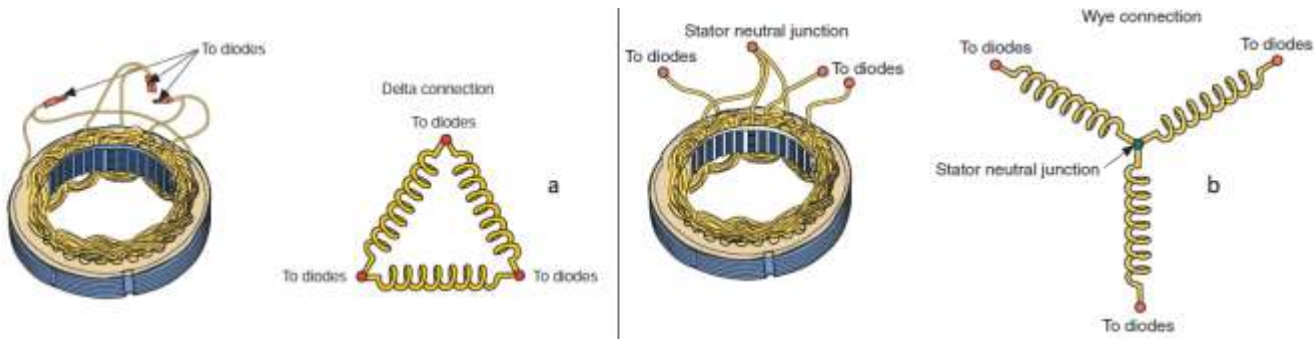


Figure 1.1-7a) delta-connected stator winding, **b)** wye-connected stator winding

The rotor rotates inside the stator. A small air gapbetween the two allows the rotor to turn without makingcontact with the stator.Alternating current produces positive and negativepulses. The resultant waveform is a sine wave,which can be observed on a scope. The waveformstarts at zero, goes positive, and then drops backto zero before turning negative. When the North Pole magnetic field cuts across the stator, a positivevoltage is generated. When the south polarity magneticfield cuts across the stator, a negative voltage isinduced. A single loop of wire energized by a singlenorth then a south result in a single-phase voltage.Remember that there are three overlapping statorwindings. This produces overlapping sine waves**(Figure 1.3-8)** or **three-phase voltage**.

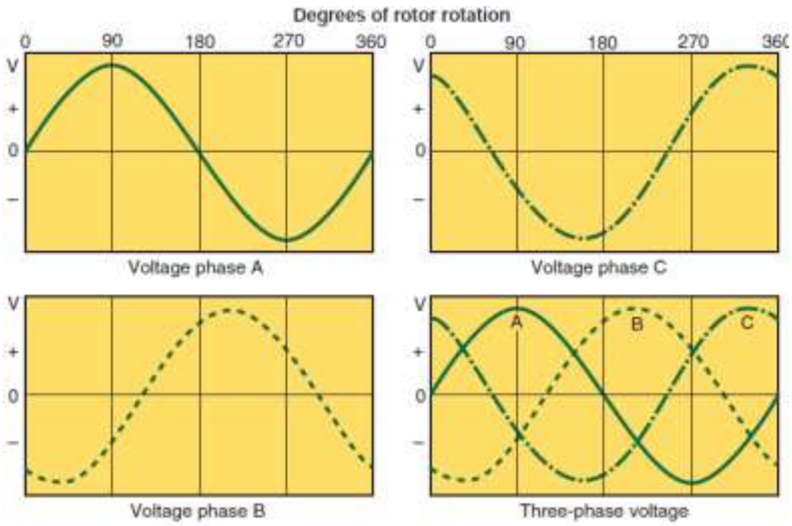


Figure 1.3-8the voltage produced in each stator winding is added together to create a three-phase voltage.

COOLING FANS

Behind the drive pulley on most ACgenerators is a cooling fan that rotates with therotor. This cooling fan draws air into the housing through the openings at the rear of the housing. Theair leaves through openings behind the cooling fan (**Figure 1.1-9**). The moving air pulls heat from thediodes and their heat decreases.

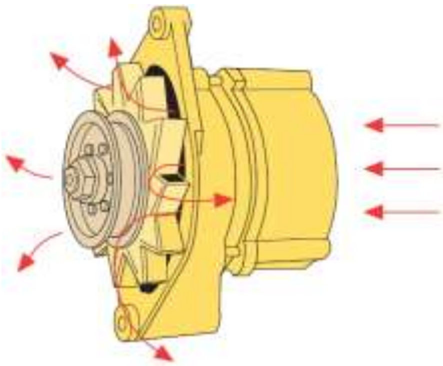


Figure 1.1-9alternator cooling fan

RECTIFICATION OF AC TO DC

Figure 1.1-10ashows that when AC passes through adiode, the negative pulses are blocked off to producethe scope pattern shown. If the diode is reversed, itblocks off current during the positive pulse and allowsthe negative pulse to flow **(Figure 1.1-10b)**. Becauseonly half of the AC current pulses (either the positiveor the negative) is able to pass, this is called **half-waverectification**.

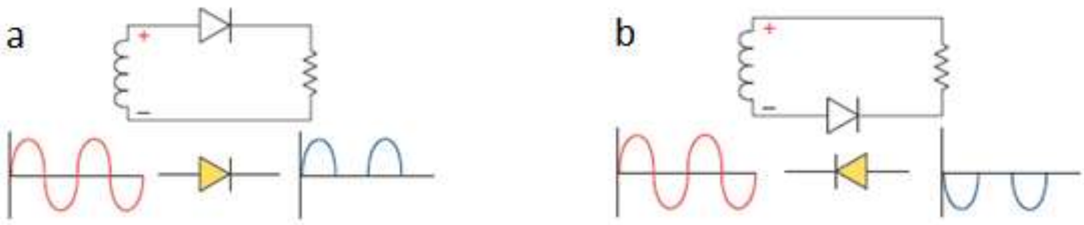


Figure 1.1-10a) Half-wave rectification, diode positively biased. **b)** Half-wave rectification, diode negatively biased.

By adding more diodes to the circuit, more of theAC is rectified. When all of the AC is rectified, **full-waverectification** occurs.

Full-wave rectification requires another circuitwith similar characteristics. **Figure 1.1-11a**shows a wye stator with two diodes attached to each winding. Onediode is insulated, or positive, and the other isgrounded, or negative. The center of the Y contains acommon point for all windings. It can have a connectionattached to it. It is called the stator neutral junction.At any time during the rotor movement, twowindings are in series and the third coil is neutral andinactive. As the rotor revolves, it energizes the differentsets of windings in different directions.

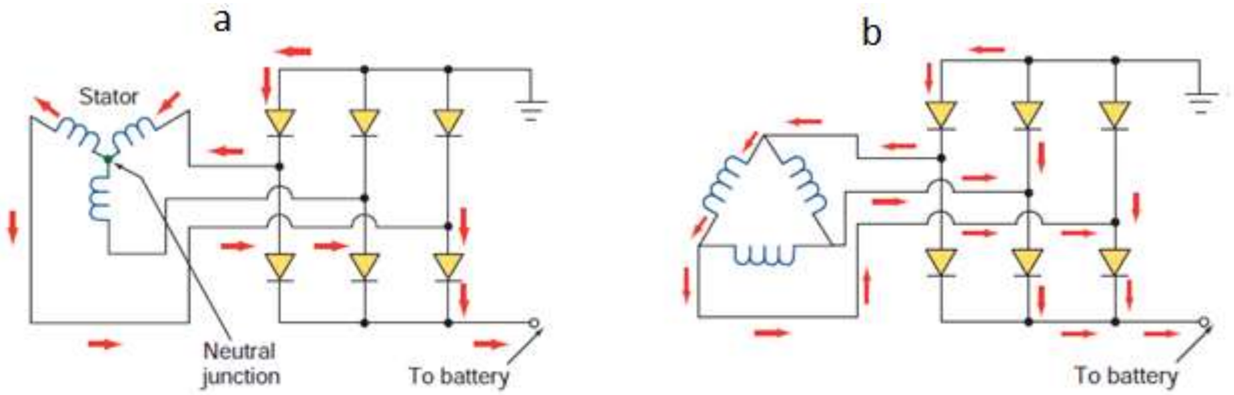


Figure 1.1-11a)a wye stator wired to six diodes.**B)** A delta stator wired to six diodes.

The diode action does not change when the statorand diodes are wired in a delta pattern. **Figure 1.1-11b**shows the major difference. Instead of having twowindings in series, the windings are in parallel. Thus,more current is available because the parallel pathsallow more current to flow through the diodes. Nevertheless,the action of the diodes remains the same.

Many AC generators have an additional set ofthree diodes called the **diode trio**. The diode trio isused to rectify current from the stator so that it canbe used to create the magnetic field in the rotor.Using the diode trio eliminates extra wiring. To control generator output, a voltage regulator regulatesthe current from the diode trio and to the rotor**(Figure 1.1-12)**.

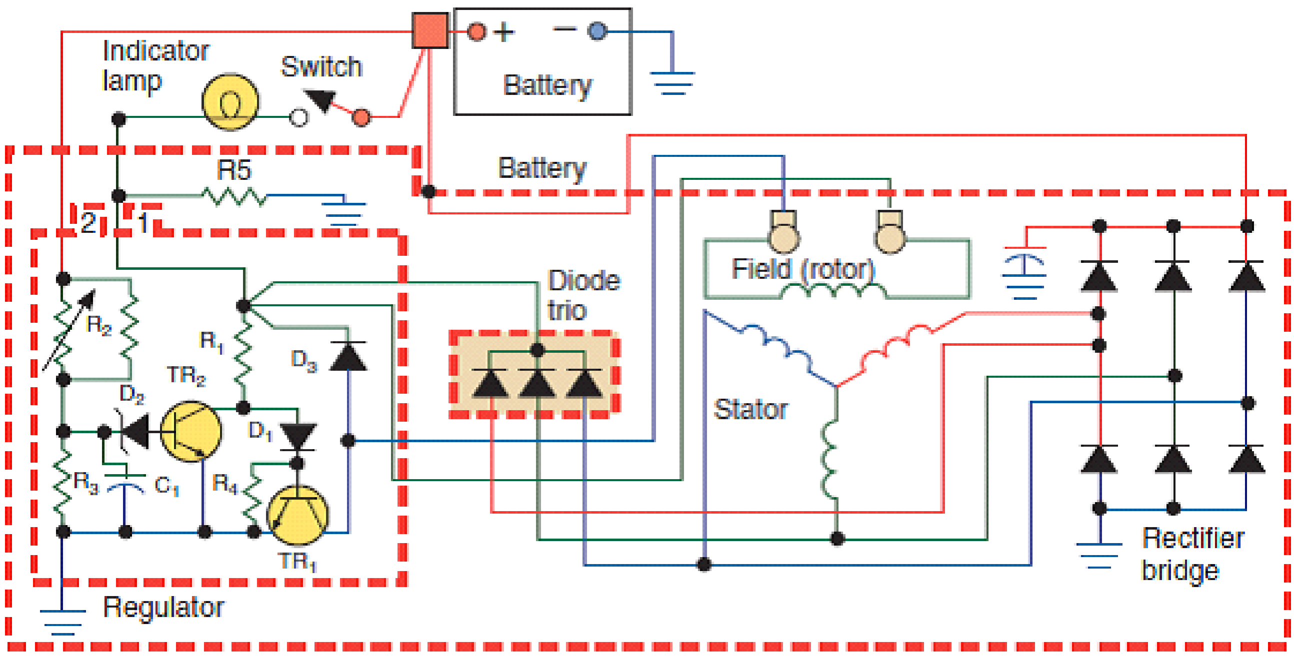


Figure 1.1-12 Wiring diagram of a charging circuit with a diode trio.

FACTORS CONTROLLING GENERATOR OUTPUT

Several factors determine the total output availablefrom a generator other than the type of stator winding.These include:

- The rotational speed of the rotor. Higher speedscan lead to higher output.
- The number of windings in the rotor. Increasedwindings will increase output.
- The current flow through the rotor windings.Increased current through the rotor will increaseoutput.
- The number of windings in the stator. An increasein the number of windings will increase output.

VOLTAGE REGULATION

The output from an AC generator can reach as highas 250 volts if it is not controlled. The battery andthe electrical system must be protected from this excessive voltage. Therefore, charging systems use a**voltageregulator**to control the generator's output.Voltage output is controlled by the voltage regulatoras it varies the strength of the magnetic field in therotor. Current output does not need to be controlled because an AC generator naturally limits the currentoutput. To ensure that the battery stays fully charged, most regulators are set for a system voltage between14.5 and 15.5 volts.

Voltage output is controlled by varying the field current through the rotor. The higher the field current, the higher the voltage output. By controlling the amount of resistance in series with the field coil, control of the field current and voltage output is obtained.

An input signal, called the **sensing voltage**, allows the regulator to monitor system voltage**(Figure 1.1-13)**. If the sensing voltage is below the regulator setting, an increase in field current is allowed, which causes an increase in voltage output. Higher sensing voltage will result in a decreasein field current and voltage output. The regulator will reduce the charging voltage until it is at a level to run the ignition system while putting a low charge on the battery. If a heavy load is turned on, such as the headlights, the additional draw will cause a decrease in battery voltage. The regulator will sense the low voltage and will increase current to the rotor. When the load is turned off, the regulator senses the rise in system voltage and reduces the field current.

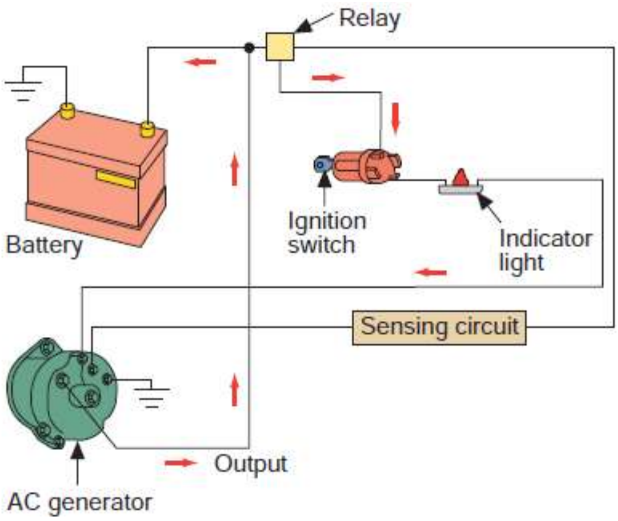


Figure 1.1-13the voltage regulator adjusts thegenerator’s output according to the voltage on the sensingcircuit.

Another input that affects voltage regulation is temperature. Because ambient temperature influences the rate of charge that a battery can accept, regulators are temperature compensated. Temperature compensation is required because the battery is more reluctant to accept a charge at lower ambient temperatures. The regulator will increase the voltage output to force a charge on the battery.

Electronic Regulators

Electronic regulators can be mounted outside the generator or be an integral part of the generator. Voltage output is controlled through the ground side of the field circuit (A-circuit control). Most electronic regulators have a zener diode that blocks current flow until a specific voltage is obtained,at which point it allows the current to flow. The schematicfor an electronic voltage regulator with a zenerdiode is shown in.

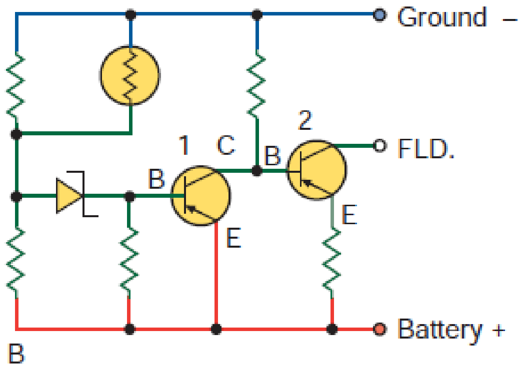


Figure 1.1-14 A simplified circuit of an electronicregulator with a zener diode.

The generator's output is controlled by pulsewidth modulation. This varies the amount of timethe field coil is energized in response to the vehicle'sneeds. For example, assume that a vehicle isequipped with a 100-ampere generator. If the electricaldemand placed on the charging systemrequires 50 amps, the regulator would energize thefield coil for 50% of the time. If the electricalsystem's demand were increased to 75 amps, theregulator would energize the field coil 75% of thecycle time.

Drive Belts

Drive belts have been used for many years. **V-belts** and **V-ribbed** (serpentine) **belts** are used to drivewater pumps, power steering pumps, air-conditioningcompressors, generators, and emission control pumps.

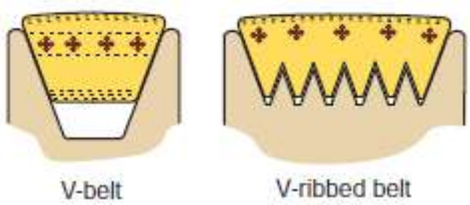
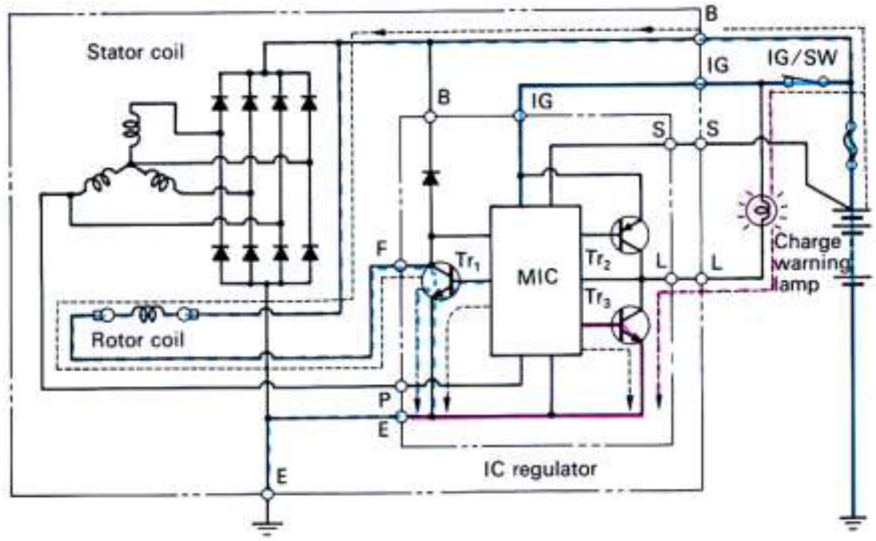


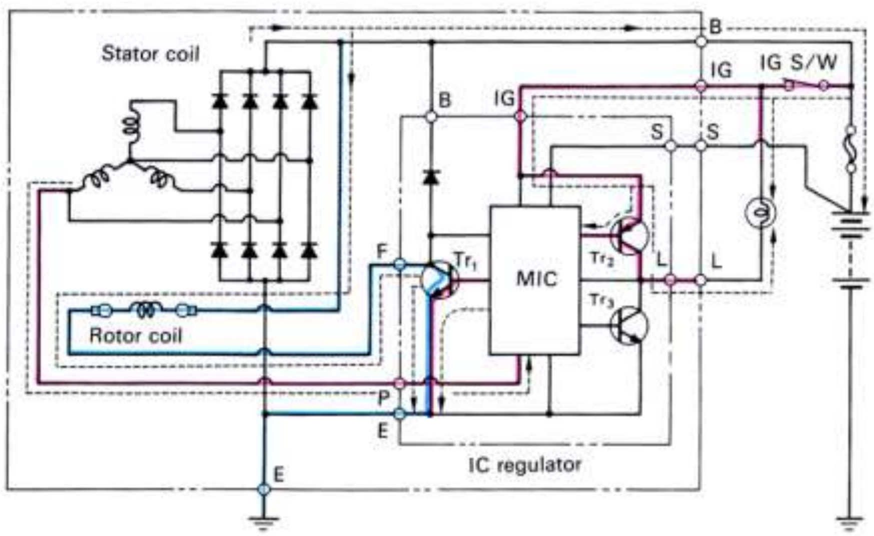
Figure 1.1-15A V-belt rides in a single groove, whereas a V-ribbed belt rides in several grooves.

OPERATING PRINCIPLES OF IC REGULATOR

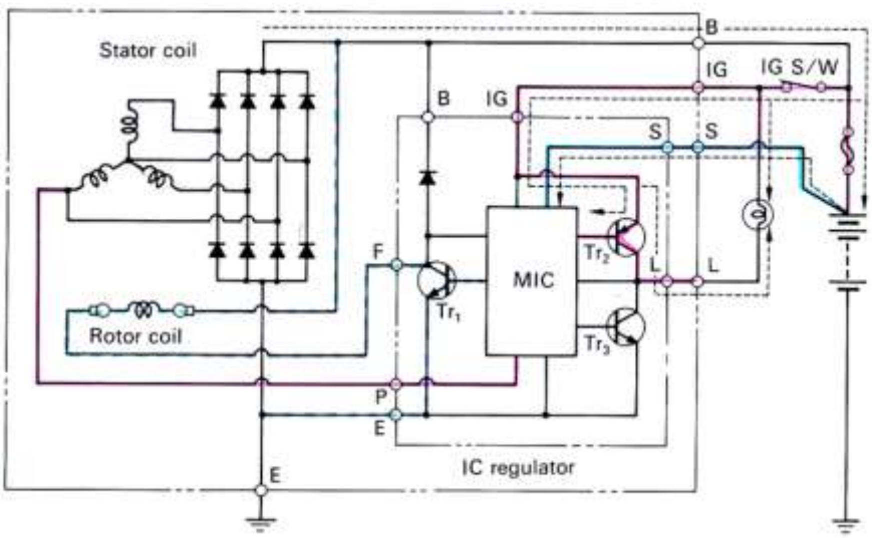
- **IGNITION SWITCH ON, ENGINE STOPPED**



- **GENERATION OF CURRENT BY ALTERNATOR (Less than standard voltage)**



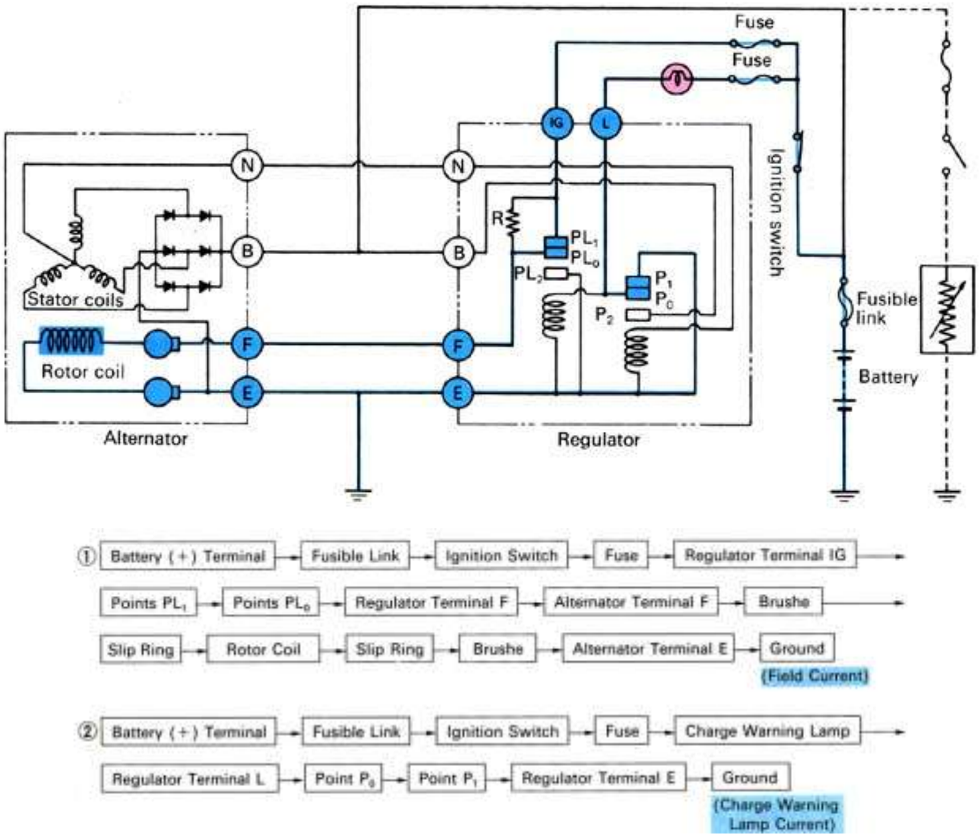
GENERATION OF CURRENT BY ALTERNATOR (Standard voltage reached)



OPERATING PRINCIPLES OF CONVECTIONAL REGULATOR

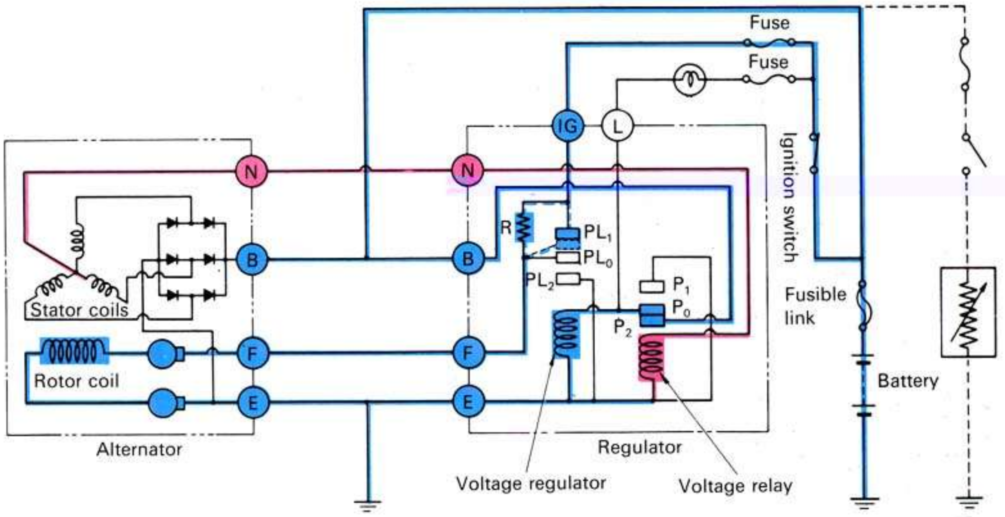
- **IGNITION SWITCH ON, ENGINE STOPPED**

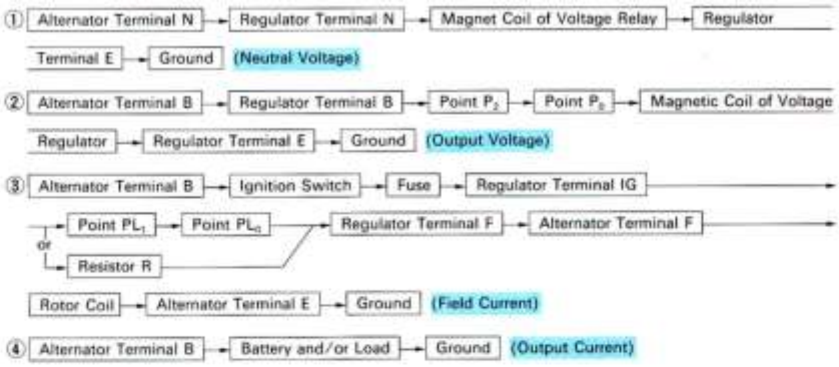
When the ignition switch is turned on field current from the battery flows to the rotor and excites the rotor coil. At the same time, battery current also flows to the charge warning lamp and the lamp comes on.



- **ENGINE OPERATION (Low speed to middle)**

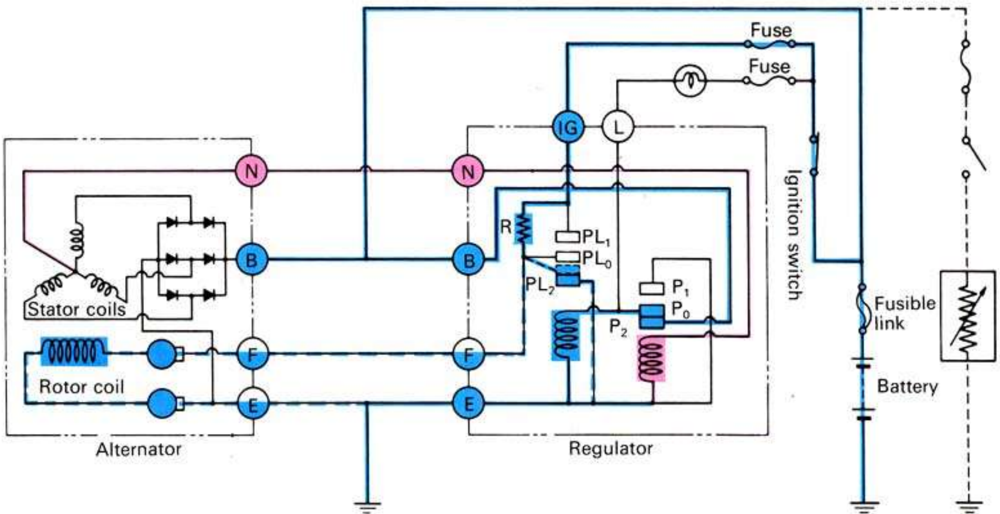
After the engine is started and the rotor is turning, Voltage is generated in the stator coil, and neutral voltage is applied to the voltage relay so the charge warning lamp goes out. At the same time; output voltage is acting on the voltage regulator. Field current to the rotor is controlled in accordance with the output voltage acting on the voltage regulator. Thus depending on the condition of point PL_0, the field current either passes through or does not pass through the resistor (R).

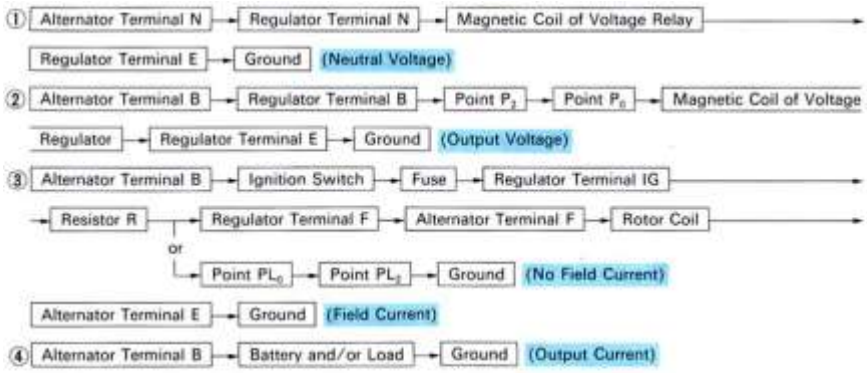




- **ENGINE OPERATING (Middle speed to high speed)**

As engine RPM increases, the voltage generated by the stator coil rises and the pulling force of the magnetic coil becomes stronger with a stronger pulling force, field current to the rotor will flow intermittently. In other words moving point PL_0 of the voltage regulator intermittently makes contact with point PL_2.





ADVANCED CHARGING SYSTEM TECHNOLOGY

An intelligent power management system, however, may become more financially attractive as electronic components continue to become cheaper. This technique works by switching off headlights and fog lights when the vehicle is not moving. The cost of this system may be less than increasing the size of the alternator. **Figure 1.1-16** shows the operating principle of this system. A speed sensor signal is used via an electronic processing circuit to trigger number of relays. The relays can be used to interrupt the chosen lighting circuits. An override switchis provided, for use in exceptional conditions.

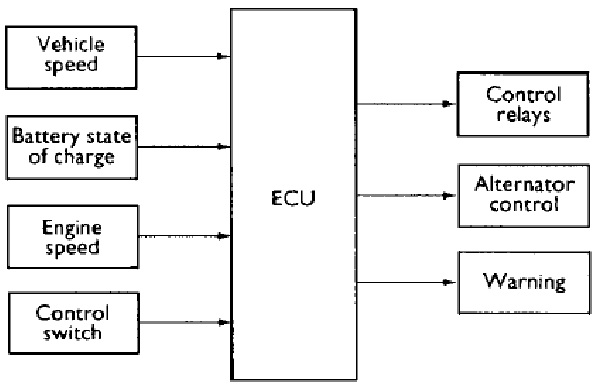


Figure 1.1-16 Operating principles of a power managementsystem

Increased idle speed may not be practical inview of the potential increase in fuel consumptionand emissions. It is nonetheless an option, but maybe more suitable for diesel-engine vehicles. Some existing engine management systems, however, are provided with a signal from the alternator when power demand is high. The engine management system can then increase engine idle speed both to prevent stalling and ensure a better alternator output.

NEW DEVELOPMENTS

In the quest to improve fuel economy, decrease emissionlevels, and make vehicles more reliable, engineershave applied advanced electronics to startersand generators.

MOTOR/GENERATORS

Keep in mind that the main difference between agenerator and a motor is that a motor has two magneticfields that oppose each other, whereas a generatorhas one magnetic field and wires are movedthrough that field.

Using electronics to control thecurrent to and from the battery, a generator canalso work as a motor. These units are called starter/generators or motor/generators. The construction ofa motor/generator may be based on two sets of windingsand brushes, a brushless design with a permanentmagnet, or switched reluctance **(Figure 1.1-27)**.

A motor/generator can be mounted externally tothe engine and connected to the crankshaft by a drivebelt. Belt-driven motor/generators have a belt tensionerthat is mechanically or electrically controlledto allow it to drive or be driven by the engine’s crankshaft.

Figure 1.1-18 An integrated motor/generator assembly built into the flywheel.

Figure 1.1-17A switched reluctance motor/ generator.

One system uses an electromagnetic clutch fittedto the crankshaft pulley. The clutch is engaged toallow the motor/generator to work as a generator oras a starter motor. When the engine is stopped, thecrank pulley clutch disengages. Motor/generatorscan also be directly mounted to the crankshaftbetween the engine and transmission or integratedinto the flywheel **(Figure 1.1-18)**. The most commonhybrid vehicles have two motor/generators: one thatserves as the engine starting motor and a generatorand the other as a traction motor and generator.

Charging System Troubleshooting Chart

Symptom	Possible Cause	Corrective Action
Batteries not charging	1. Insufficient belt tension, worn belt 2. Defective battery(s) or battery connections 3. Blown fuse or fusible link 4. Defective wiring 5. Faulty alternator 6. Excessive electrical load	1. Tighten or replace 2. Check battery and battery terminal connections 3. Check fuse and fusible link; replace as needed 4. Check voltage drop 5. Replace alternator 6. Reduce load by turning off all unnecessary accessories

Symptom	Possible Cause	Corrective Action
Constantly overcharging (battery electrolyte is depleted in a short time)	Battery Poor contact at voltage detection point of alternator Faulty voltage regulator	Faulty battery; replace Clean contact area Replace alternator
Abnormal Noise	Insufficient belt tension Faulty bearing	Tighten or replace Replace alternator

1.2 STARTING SYSTEM

GENERAL

Starting the engine is possibly the most important function of the vehicle's electrical system. The starting system performs this function by changing electrical energy from the battery to mechanical energy in the starting motor. This motor then transfers the mechanical energy, through gears, to the flywheel on the engine's crankshaft. During cranking, the flywheel rotates and the air-fuel mixture is drawn into the cylinders, compressed, and ignited to start the engine. Most engines require a cranking speed of about 200 rpm.

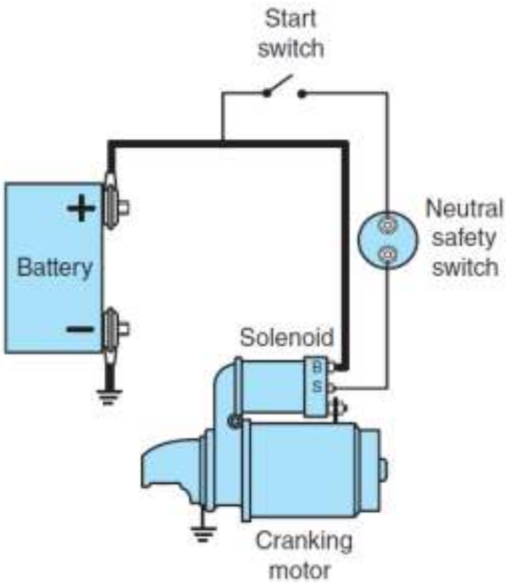


Figure 1.2-1 an illustration of a basic starting system circuit.

DC MOTOR

Introduction

A **DC motor** is any of a class of rotary electrical machines that converts direct current electrical energy into mechanical energy. The most common types rely on the forces produced by magnetic fields. Nearly all types of DC motors have some internal mechanism, either electromechanical or electronic; to periodically change the direction of current flow in part of the motor. The operation of all electric motors is based on the basic principles of magnetism.

BASICS OF ELECTROMAGNETISM

Electricity and magnetism are related. One canbeused to create the other. Current flowing through awire creates a magnetic field around the wire. Movinga wire through a magnetic field creates current flow in the wire.

MAGNETISM

A substance is said to be a magnet if it has the propertyof magnetism—the ability to attract such substances as iron, steel, nickel, or cobalt. A magnet has two points of maximum attraction, one at each end of the magnet. These points are designated the north pole and the south pole **(Figure 1.2-2A)**. When twomagnets are brought together, opposite poles attract **(Figure 1.2-2B)**, while similar poles repel each other **(Figure 1.2-2C)**.

A magnetic field, called a **flux field**, exists around every magnet. The field consists of imaginary lines along which the magnetic force acts. These lines emerge from the north pole and enter the south pole, returning to the north pole through the magnet itself.
All lines of force leave the magnet at right angles to the magnet. None of the lines cross each other and all are complete.

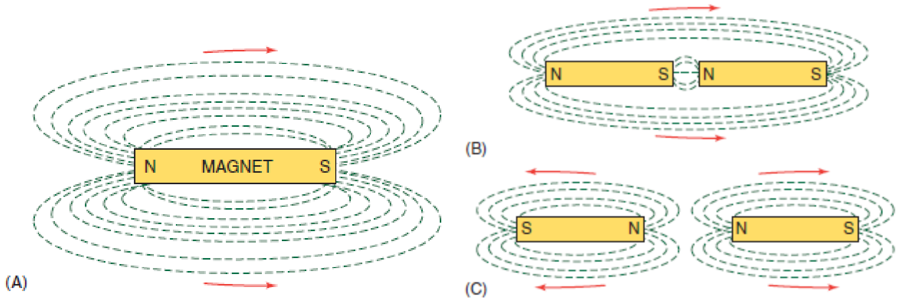


Figure 1.2-2(A) In a magnet, lines of force emergefrom the north pole and travel to the south pole before passing through the magnet back to the north pole. (B) Unlike poles attract, while (C) similar poles repel each other.

ELECTROMAGNETS

Magnets can occur naturally in the form of a mineralcalled magnetite. Artificial magnets can be made by inserting a bar of magnetic material inside a coil of insulated wire and passing current through the coil. Another way of creating a magnet is by stroking the magnetic material with a bar magnet. Both methods force the randomly arranged molecules of the magnetic material to align themselves along north and south poles.
Artificial magnets can be either temporary or permanent.Temporary magnets are usually made of soft iron. They are easy to magnetize but quickly lose theirmagnetism when the magnetizing force is removed.Permanent magnets are difficult to magnetize. However,once magnetized they retain this property for very long periods.

The earth is a very large magnet, having a North Pole and a South Pole, with lines of magnetic force running between them. This is why a compass always aligns itself to straight north and south.

In 1820, a simple experiment discovered theexistence of a magnetic field around a current carrying wire. When a compass was held over the wire, its needle aligned itself at right angles to the wire **(Figure 1.2-3)**. The lines of magnetic force are concentric circles around the wire. The density of these circular lines of force is very heavy near the wire and decreases farther away from the wire. As is also shown in the same figure, the polarity of a current-carrying wire's magnetic field changes depending on the direction the current is flowing through the wire. These magnetic lines of force or flux lines do not move or flow around the wire. They simply have a direction as shown by their effect on a compass needle.

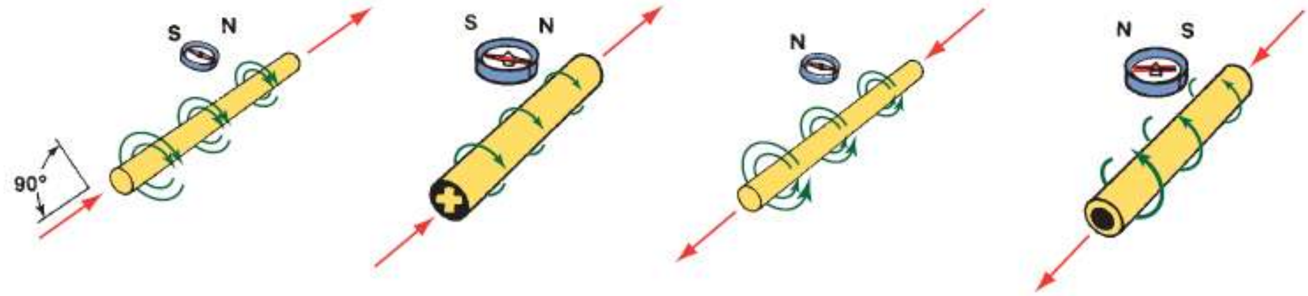


Figure 1.2-3when current is passed through aconductor such as a wire; magnetic lines of force are generated around the wire at right angles to the direction of the current flow.

- **Flux Density: -** The more flux lines, the stronger the magnetic field at that point. Increasing current will increase **flux density**. Also, two conducting wires lying side by side carrying equal currents in the same direction create a magnetic field equal in strength to one conductor carrying twice the current. Therefore, adding more wires increases the magnetic field **(Figure 1.2-4)**.

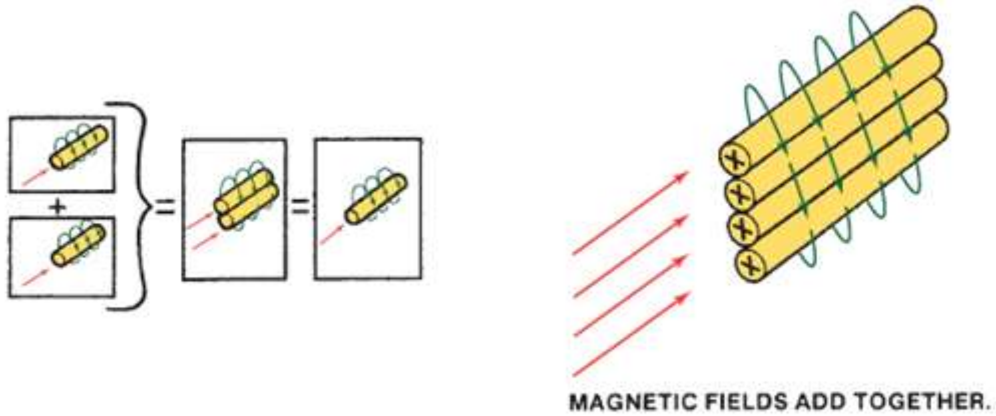


Figure 1.2-4increasing the number of conductorscarrying current in the same direction increases the strength of the magnetic field around them.

- **Coils: -** Looping a wire into a coil concentrates the lines of flux inside the coil. The resulting magnetic field is the sum of the single-loop magnetic fields **(Figure 1.2-5)**. The overall effect is the same as placing many wires side by side, each carrying current in the same direction.

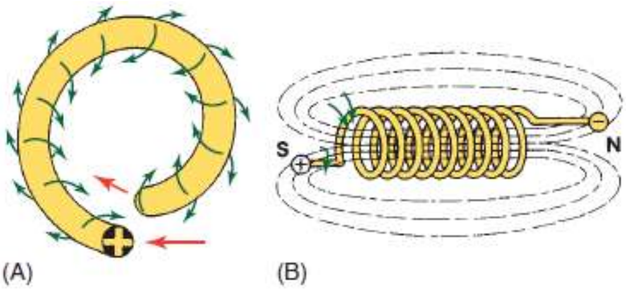


Figure 1.2-5(A) Forming a wire loop concentrates the lines of force inside the loop. **(B)** The magnetic field of a wire coil is the sum of all the single-loop magnetic fields.

MAGNETIC CIRCUITS AND RELUCTANCE

Just as current can only flow through a complete circuit, the lines of flux created by a magnet can only occupy a closed magnetic circuit. The resistance that a material offers to the passage of magnetic flux lines is called **reluctance**. Magnetic reluctance can be compared to electrical resistance.

Reconsider the coil of wire shown in **Figure 1.2-5**. The air inside the coil has very high reluctance and limits the magnetic strength produced. However, if an iron core is placed inside the coil, magnetic strength increases tremendously. This is because the iron core has a very low reluctance **(Figure 1.2-6)**.

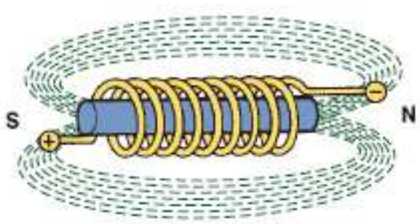


Figure 1.2-6electromagnetism

When a coil of current-carrying wire is woundaround an iron core, it becomes a usable electromagnet. The strength of an electromagnet's magnetic field is directly proportional to the number of turns of wire and the current flowing through them.

The equation for an electromagnetic circuit is similar to Ohm's law for electrical circuits. It states that the number of magnetic lines is proportional to the ampere-turns divided by the reluctance.

To summarize:

- The magnetic polarity of the coil depends on the direction of current flow through the loop.
- Field strength increases if current through the coil increases.
- Field strength increases if the number of coil turns increases.
- If reluctance increases, field strength decreases.

OPERATING PRINCIPLE OFMOTORS

An electric motor converts electric energy intomechanical energy. Through the years, electric motors have changed substantially in design; however, the basic operational principles have remained the same. That principle is easily observed by taking two bar magnets and placing them end to end with each other. If the ends have the same polarity, they will push away from each other. If the ends have the opposite polarity, they will move toward each other and form one magnet.

If we put a pivot through the center of one of the magnets to allow it to spin and moved the other magnet toward it, the first magnet will either rotate away from the second or move toward it **(Figure 1.2-7)**. This is basically how a motor works. Although we do not observe a complete rotation, we do see part of one, perhaps a half turn. If we could change the polarity of the second magnet, we would get another half turn. So in order to keep the first magnet spinning, we need to change the polarity immediately after it moves halfway. If we continued to do this, we would have a motor.

In a real motor, an electromagnet is fitted on ashaft. The shaft is supported by bearings or bushings to allow it to spin and to keep it in the center of the motor. Surrounding, but not touching, this inner magnet is a stationary permanent magnet or an electromagnet. Actually, there is more than one magnet or magnetic field in both components. The polarity of these magnetic fields is quickly switched and we have a constant opposition and attraction of magnetic fields. Therefore, we have a constantly rotating inner magnetic field, the shaft of which can do work due to the forces causing it to rotate. The torque of a motor varies with rotational speed, motor design, and the amount of current draw the motor has. The rotationalspeed depends on the motor’s current draw, thedesign of the motor, and the load on the motor’s rotating shaft.

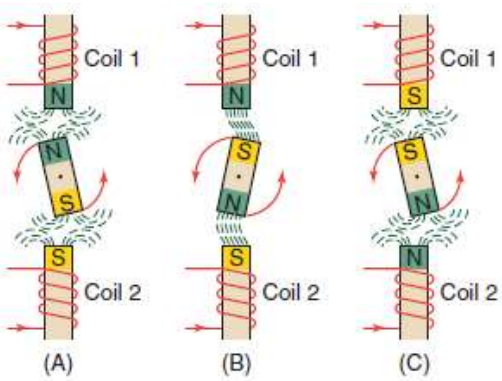


Figure 1.2-7(A) Like poles repel. (B) Unlike poles are attracted to each other. Then if we change the polarity of the coils, (C) the like poles again repel.

The basic components of a motor are the stator orfield windings, which are the stationary parts of the motor, and the rotor or armature, which is the rotating part **(Figure 1.2-8)**. The field windings are comprised of slotted cores made of thin sections of soft iron wound with insulated copper wire to form one or more pairs of magnetic poles. Some motors have the field windings wound around iron anchors, called pole shoes. The armature is comprised of loops of current-carrying wire. The loops are formed around a metal with low reluctance to increase the magnetic field. The magnetic fields around the armature are pushed away by the magnetic field of the field windings, causing the armature to rotate away from the windings' fields.

The field windings or the armature may be made with permanent magnets rather than electromagnets. Both cannot be permanent magnets. An electromagnet allows for a change in the polarity of the magnetic fields, which keeps the armature spinning. Changing the direction of current flow changes the magnetic polarities.

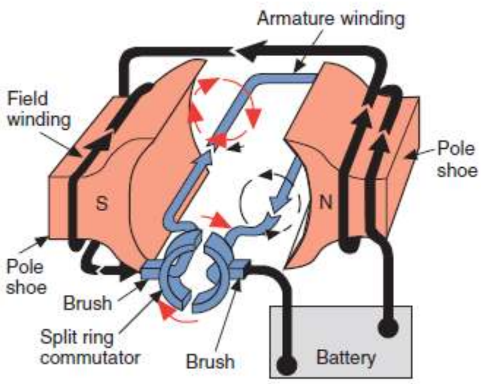


Figure 1.2-8A simple electric motor

STARTING MOTORS

The starting motor **(Figure 1.2-9)** is a special type ofelectric motor designed to operate under great electrical loads and to produce great amounts of torque for short periods.

Figure 1.2-9A cutaway of a starter motor.

All starting motors are generally the same in design and operation. Basically the starter motor consists of housing, field coils (windings), an armature, a commutator with brushes, and end frames **(Figure 1.2-10)**.

The **starter housing** or **starter frame** encloses theinternal parts and protects them from damage, moisture, and foreign materials. The housing also supports the fieldcoils.

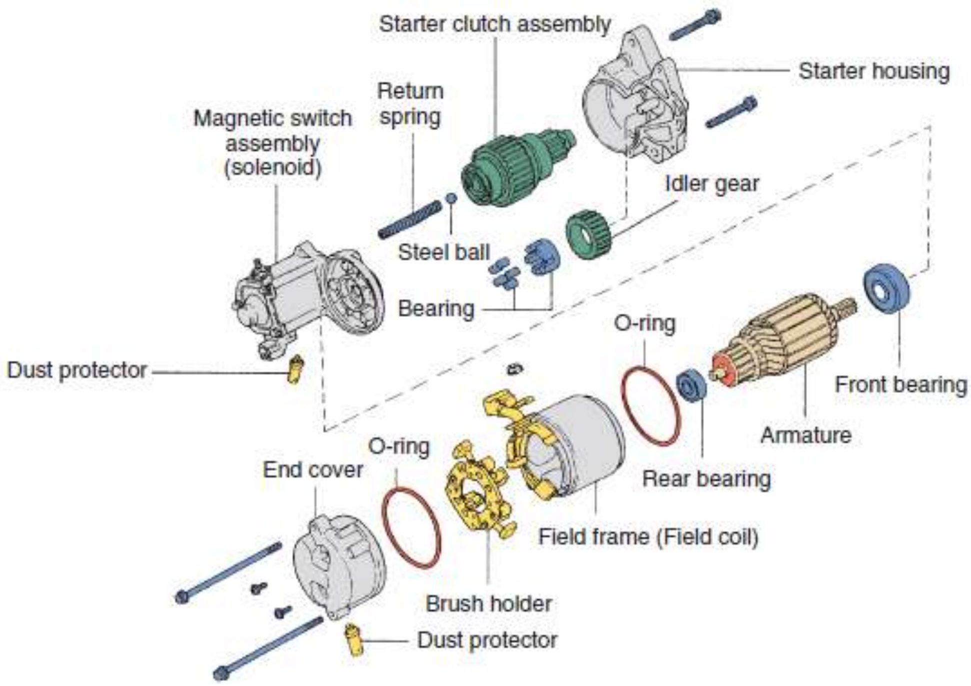


Figure 1.2-10A typical starter motor assembly

The **field coils** and their **pole shoes (Figure 1.2-11a)** are securely attached to the inside of the housing. Thefield coils are insulated from the housing but are connectedto a terminal that protrudes through the outersurface of the housing.

The field coils and pole shoes are designed to produce strong stationary electromagnetic fields within the starter when current flows to it. The magnetic fields are concentrated at the pole shoe. The coils are wound around respective pole shoes in opposite directions to create opposing magnetic fields.

The field coils connect in series with the armature winding through the starter **brushes**. This permits all current passing through the field coil circuit to also pass through the armature windings.

The **armature** is the rotating part of a starter. It is located between the starter drive and commutator end frames and the field windings. Current passing through the armature produces a magnetic field ineach of its conductors. The reaction between thearmature'smagnetic field and the magnetic fields produced by the field coils causes the armature to rotate **(Figure 1.2-11b)**. This is the mechanical energy that is then used to crank the engine.

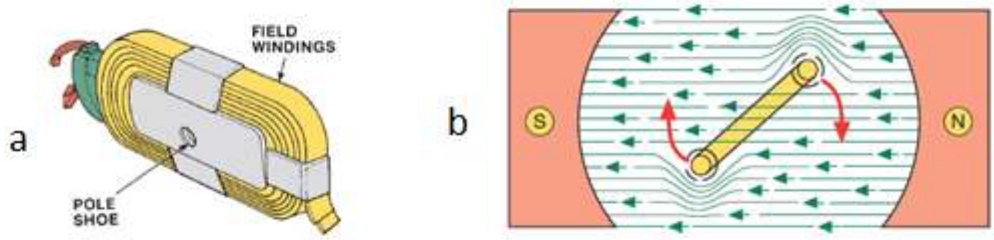


Figure 1.2-11a) field coil and pole shoe, **b)** rotation of the conductor is in the direction of the weaker magnetic field.

The armature has two main components: the armature windings and the **commutator**. Both mount to the armature shaft **(Figure 1.2-12)**. The armature windings are made of heavy flat copper strips or wires that form a single loop and can handle the heavy current flow. The sides of these loops fit into slots in the armature core or shaft, but they are insulated from it.

The coils connect to each other and to the commutator so that current from the field coilsflowsthrough all of the windings at the same time. Thisaction generates a magnetic field around each armature winding, resulting in a repulsion force all around the conductor. This repulsion force causes the armature to turn.

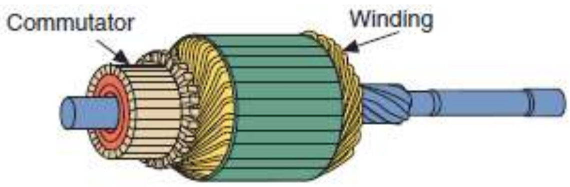


Figure 1.2-12 the armature of a starter motor

The commutator assembly is made up of heavy copper segments separated from each other and the armature shaft by insulation. The commutator segments connect to the ends of the armature windings.

Starter motors have two to six brushes that ride on the commutator segments and carry the heavy current from the stationary field coils to the rotating armature windings. Each end of the armature windings is connected to one segment of the commutator. Carbon brushes are connected to one terminal of the power supply. The brushes contact the commutatorsegments conducting current to and from the armaturecoils.

The brushes mount on and operate in some type of holder, which may be a pivoting arm design inside the starter housing or frame **(Figure 1.2-13)**. However, in many starters the brush holders are secured to the starter's end frame. Springs hold the brushes against the commutator with the correct pressure.Finally, alternate brush holders are insulated fromthe housing or end frame. Those between the insulatedholders are grounded.

The **end frame** is a metal plate that bolts to the commutator end of the starter housing. It supports the commutator end of the armature with a bushing or bearing.

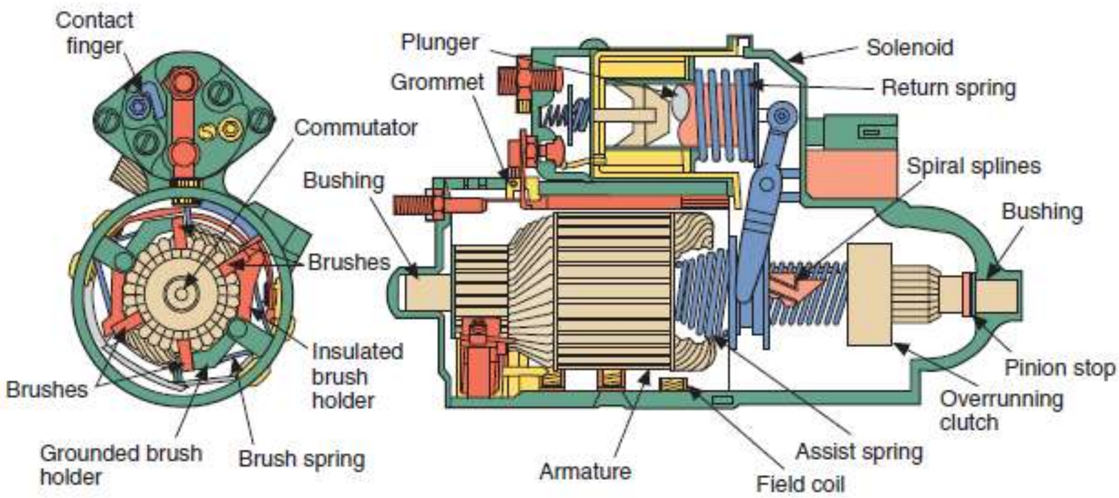


Figure 1.2-13 the location of the starter motor brushes and commutator

OPERATING PRINCIPLES

The starter motor converts current into torquethrough the interaction of magnetic fields. The magnetic field developed at the field windings and the armature has opposite polarities. When the armature windings are placed inside the field windings, part of the armature coil is pushed in one direction as the field opposes the field in the windings. This causes the armature to begin to rotate. As the armature moves, the contact between a brush and commutator segment is broken and the brush contacts a new segment. This causes a reverse in the polarity of the magnetic field around the armature. The new opposition of magnetic fields causes the armature to rotate more. This process continues and the armature continues to rotate until current stops flowing to the armature.

Many armature segments are used. This provides for a uniform turning motion because as one segment rotates past a brush, another immediately takes its place. This also provides for constant torque.

The number of coils and brushes may differ among starter motor models. The armature may be wired in series with the field coils (**series motor**); the field coils may be wired parallel or shunted across the armature (**shunt motors**); or a combination ofseries and shunt wiring (**compound motors**) may be used **(Figure 1.2-14)**.

A series motor develops its maximum torque at startup and develops less torque as speed increases. It is ideal for applications involving heavy starting loads.

Shunt or parallel-wound motors develop considerably less startup torque but maintain a constant speed at all operating loads. Compound motors combine the characteristics of good starting torque with constant speed. This design is particularly useful for applications in which heavy loads are suddenly applied. In a starter motor, a shunt coil is frequently used to limit the maximum free speed at which the starter can operate.

Figure 1.2-14 Starter motors are grouped accordingto how they are wired: **(A)** in series, **(B)** in parallel (shunt), or **(C)** a compound motor using both series and shunt coils.

PERMANENT MAGNET MOTORS

A recent change instarter and accessory motors is the use of permanent magnets instead of electromagnets as field coils. Electrically, this type of motor is simpler. It does not require current for field coils. Current is delivered directly to the armature through the commutator and brushes **(Figure 1.2-15)**. With the exception of no electromagnets in the fields, this functions exactly as the other motors. Maintenance and testing procedures are the same as forother designs. Notice the use of a planetary gearreduction assembly on the front of the armature. This allows the armature to spin with increased torque, resulting in improved starter cold-cranking performance.

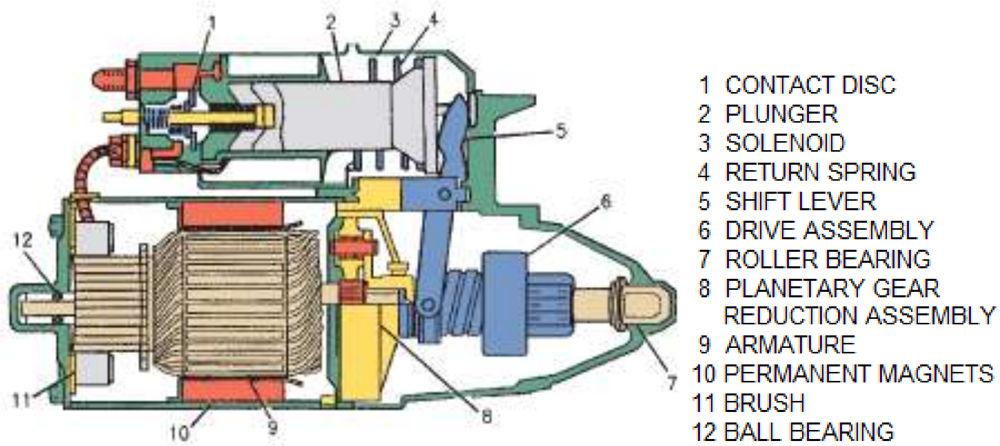


Figure 1.2-15 permanent magnettype starter assembly.

- **Counter EMF: -**The amount of torque from a startingmotor depends on a number of things. One of themost important is current draw. The slower themotor turns, the more current it will draw. This iswhy a starter motor will draw large amounts of currentwhen the engine is difficult to crank. A motorneeds more torque to crank a difficult-to-start engine.The relationship between current draw and motorspeed is explained by the principles of **counter EMF(CEMF)**. Electromotive force (EMF) is another namefor voltage.

When the armature rotates within the field windings, conditions exist to induce a voltage in the armature. Voltage is induced anytime a wire is passed through a magnetic field. When the armature, which isa structure with many loops of wire, rotates past thefield windings, a small amount of voltage is induced**(Figure 1.2-16)**. This voltage opposes the voltagesupplied by the battery to energize the armature.As a result, less current is able to flow through thearmature.

The faster the armature spins, the more inducedvoltage is present in the armature. The more voltage induced in the armature, the more opposition there is to normal current flow to the armature. The induced voltage in the armature opposes or is counter to the battery’s voltage. This is why the induced voltage is called CEMF.
The effects of CEMF are quite predictable. When the armature of the motor turns slowly, low amountsof voltage are induced and, therefore, low amounts ofCEMF are present. The low CEMF permits higher currentflow. In fact, the only time a starter motor draws its maximum amount of current is when the armature is not rotating.

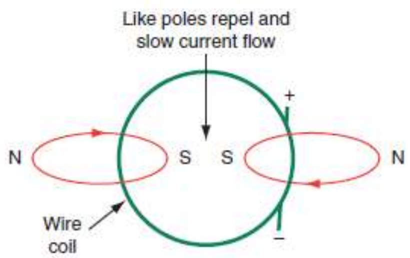


Figure 1.2-16 A magnetic field forms around acurrent-carrying conductor according to the direction of current flow. When a wire is formed into a coil, there are repelling poles that result in CEMF.

STARTING SYSTEM OPERATION

The starting system is designed to turn or crank theengine until it can operate under its own power. To do this, the starter motor is engaged to the engine’s flywheel. As it spins, it turns the engine’s crankshaft. The sole purpose of the starting system is to crank the engine fast enough to run. The engine’s ignition and fuel system provide the spark and fuel for engine operation, but they are not considered part of the starting system. They do affect how well an engine starts.

SHOP TALK

A diesel engine does not have an ignition system. These engines run on the heat of compression. When they are cold and are being started, glow plugs are energized to heat the air-fuel mixture in the cylinders. Glow plugs are simple heaters and do not function as a spark plug. Once the engine is running and warmed up, the glow plug circuit is shut down. If the glow plug circuit is not operating properly, the engine may have a difficult time starting or it may not start at all.

A typical starting system has six basic componentsand two distinct electrical circuits. The components are the battery, ignition switch, battery cables, magnetic switch (either an electrical relay or a solenoid), starter motor, and the starter safety switch.

The starter motor draws a great deal of current from the battery. A large starter motor might require 250 or more amperes of current. This current flows through the large cables that connect the battery to the starter and ground.

The driver controls the flow of this current using the ignition switch normally mounted on the steering column. The battery cables are not connected to the switch. Rather, the system has two separate circuits: thestarter circuit and the control circuit **(Figure 1.2-17)**.The starter circuit carries the heavy current from thebattery to the starter motor through a magnetic switchin a relay or solenoid. The control circuit connects batterypower at the ignition switch to the magnetic switch,which controls the high current to the starter motor.

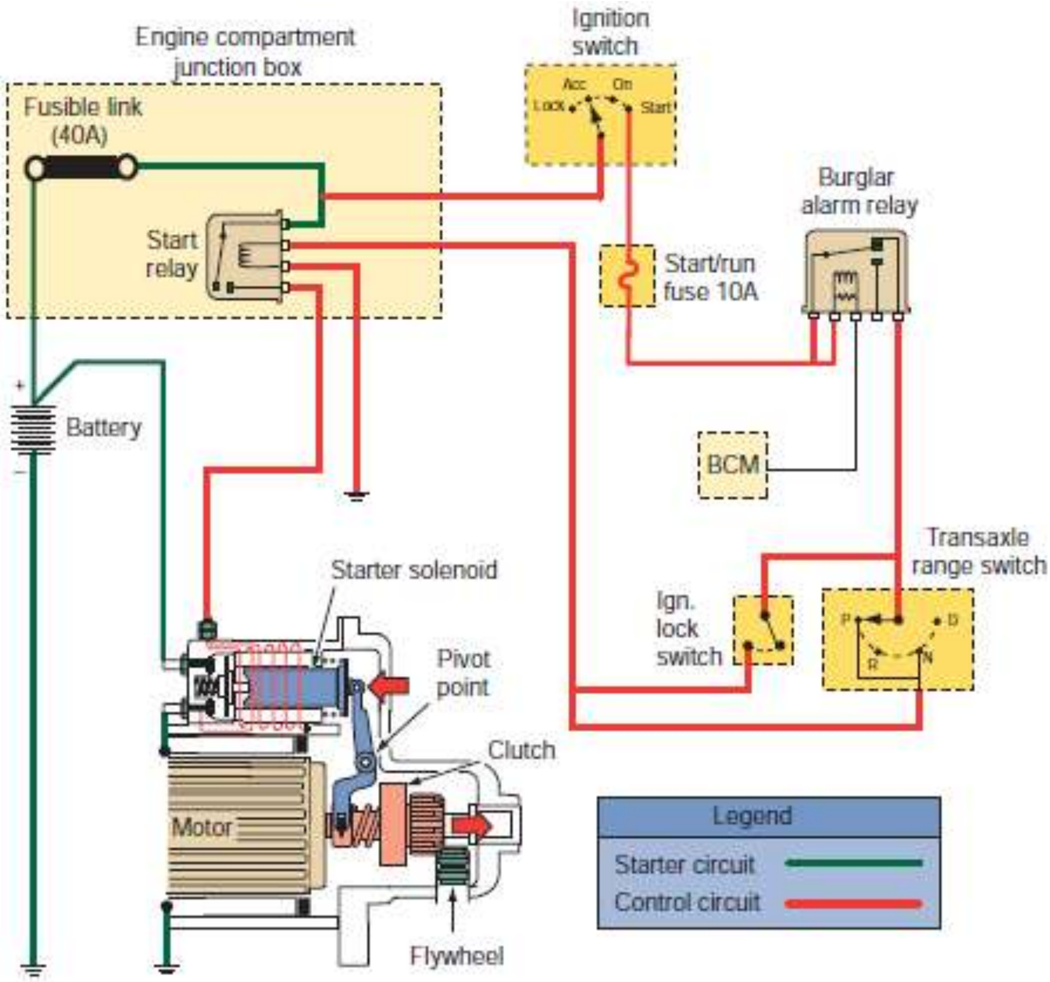


Figure 1.2-17 the starting system is made up of two separate systems: the starter and control systems.

STARTER CIRCUIT

The starter circuit carries the high current flow within the system and supplies power for the actual engine cranking. Components of the starter circuit are the battery, battery cables, magnetic switch or solenoid, and the starter motor.

- **BATTERY AND CABLES -** Many of the problems associated with the startingsystem can be solved by troubleshooting the batteryand its related components.

The starting circuit requires two or more heavy gauge cables. One of these cables connects between the battery's negative terminal and the engine block or transmission case. The other cable connects the battery's positive terminal with the solenoid. On vehicles equipped with a **starter relay**, two positive cables are needed. One runs from the positive battery terminal to the relay and the second from the relay to the starter motor terminal. In any case, these cables carry the required heavy current from the battery to the starter and from the starter back to the battery.

Cables must be heavy enough to comfortably carry the required current load. Cranking problems can be created when undersized cables are installed. With undersized cables, the starter motor does not develop its greatest turning effort and even a fully charged battery might be unable to start the engine.

- **MAGNETIC SWITCHES -** Every starting system contains some type of magneticswitch that enables the control circuit to open andclose the starter circuit. This magnetic switch canbeone of several designs.

- **Solenoid -**The solenoid-actuated starter is by far themost common starter system used. A solenoid is anelectromechanical device that uses the movement ofa plunger to exert a pulling or holding force. As showninFigure 1.2-18, the solenoid mounts directly on top of the starter motor.

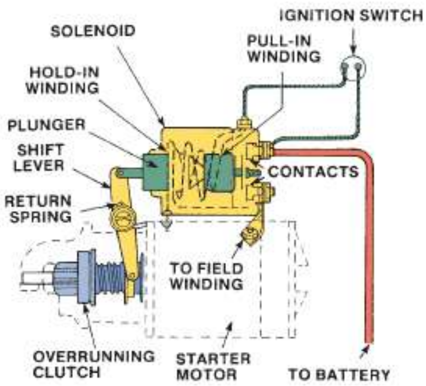


Figure 1.2-18 example of a solenoid-actuated starter where the solenoid mounts directly to the starter motor.

In this type of starting system, the solenoid usesthe electromagnetic field generated by its coil to perform two distinct jobs.

The first is to push the drive pinion of the starter motor into mesh with the engine’s flywheel. This is the solenoid’s mechanical function. The second job is to act as an electrical relay switch to energize the motor once the drive pinion is engaged. Once the contact points of the solenoid are closed, full battery current flows to the starter motor.

The solenoid assembly has two separate windings:a**pull-in winding** and a **hold-in winding**. The two windings have approximately the same number of turns but are wound from different size wire. Together these windings produce the electromagnetic force needed to pull the plunger into the solenoid coil. The heavier pull-in windings draw the plunger into the solenoid, while the lighter-gauge windings produce enough magnetic force to hold the plunger in this position.

Both windings are energized when the ignition switch is turned to the start position. When the plunger disc makes contact with this solenoid terminal, the pull-in winding is deactivated. At the same time, the plunger contact disc makes the motor feed connection between the battery and the starting motor, directing current to the field coils and starter motor armature for cranking power.

As the solenoid plunger moves, the shift fork alsopivots on the pivot pin and pushes the starter drive pinion into mesh with the flywheel ring gear. When the starter motor receives current, its armature starts to turn. This motion is transferred through an overrunning clutch and pinion gear to the engine flywheel and the engine is cranked.

With this type of solenoid-actuated direct drivestarting system, teeth on the **pinion gear** may not immediately mesh with the flywheel ring gear. If this occurs, a spring located behind the pinion compresses so the solenoid plunger can complete its stroke. When the starter motor armature begins to turn, the pinion teeth quickly line up with the flywheel teeth and the spring pressure forces them to mesh.

- **Starter Relay -** Starter relays **(Figure 1.2-19)** are similarto starter solenoids. However, they are not used tomove the drive pinion into mesh. They are used as anelectrical relay or switch. When current from the ignitionswitch arrives at the relay, a strong magnetic fieldis generated in the relay’s coil. This magnetic forcepulls the plunger contact disc up against the batteryterminal and the starter terminal of the relay, allowingfull current flow to the starter motor.

Figure 1.2-19 Starter relay/solenoid mounted on a vehicle.

A secondary function of the starter relay is to providean alternate electrical path to the ignition coilduring cranking. This current flow bypasses the resistancewire (or ballast resistor) in the ignition primarycircuit. This is done when the plunger disc contactsthe ignition by-pass terminal on the relay. Not all systemshave an ignition by-pass setup.
All positive engagement starters use a relay inseries with the battery cables to deliver currentthrough the shortest possible battery cables. Somevehicles use both a starter relay

and a starter **motormountedsolenoid**. The relay controls current flow tothe solenoid, which in turn controls current flow tothe starter motor. This reduces the amount of currentflowing through the ignition switch. In otherwords, it takes less current to activate the relay thanto activate the solenoid.

- **STARTER DRIVES -** The starter drive is the device that couples the armaturewith the flywheel. A pinion gear at one end of thearmature meshes with the teeth on the outside of theflywheel**(Figure 1.2-20a)**. The spinning armature thenturns the flywheel. To prevent damage to the piniongear or the ring gear on the flywheel, the pinion mustmesh with the ring gear before the armature beginsto spin. To help ensure smooth engagement, theend of the pinion gear is tapered **(Figure 1.2-20b)**. Todisengage the pinion from the flywheel, the pinion ismounted to the armature via an overrunning clutch.

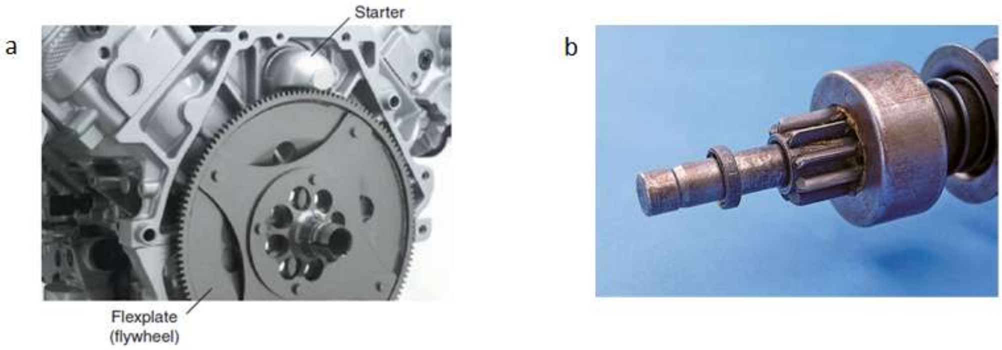


Figure 1.2-20a) Starter drive pinion gear is used to turn the engine's flywheel, **b)** the pinion gear teeth are tapered toallow for smooth engagement**.**

- **Overrunning Clutch -**Once the engine starts, its speed increases. If the starter motor remains connected to the engine through the flywheel, it will spin at very high speeds, destroying the armature and other parts.

  To prevent this, the starter drive must be disengaged as soon as the engine turns faster than the starter. In most cases, the pinion remains engaged until current stops flowing to the starter. To prevent the armature from spinning at engine speed, an overrunning clutch**(Figure 1.2-21)** is used.

  The clutch housing is internally splined to the armature shaft. The drive pinion turns freely on the armature shaft within the clutch housing. When the clutch housing is driven by the armature, the spring-loaded rollers are forced into the small ends of their tapered slots and wedged tightly against the pinion barrel. This locks the pinion and clutch housing solidly together, permitting the pinion to turn the flywheel and, thus, crank the engine.

When the engine starts, the flywheelspins the pinion faster than the armature.Thisreleases the rollers, unlocking the pinion gear fromthe armature shaft. The pinion then freely spins onthe armature shaft. Once current flow is stopped, thepinion is then pulled away from the flywheel. Theoverrunning clutch is moved in and out of mesh bythe starter drive linkage.

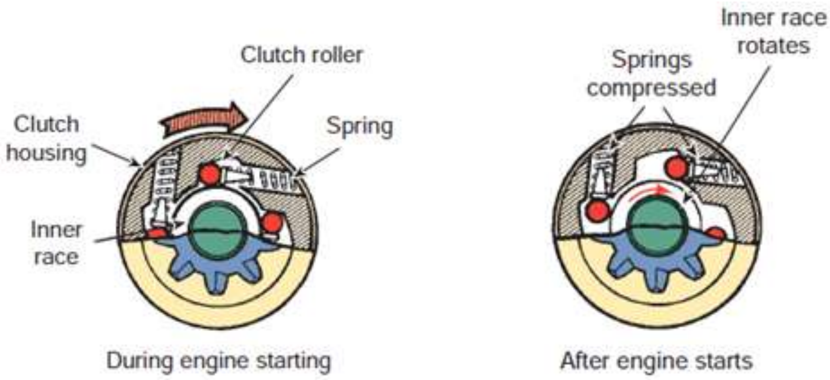


Figure 1.2-21 When the engine starts, the flywheel spins the pinion gear faster, which releases the rollers fromthe wedge

- **Gear Reduction Drive -**The armature of some starter motors does not directly drive the starter drive gear. Rather it drives a small gear that is permanently meshed with a larger gear **(Figure 1.2-22)**. This provides for a gear reduction and allows a small, high-speed motor to provide high torque at a satisfactory cranking speed. This starter design also tends to require lower current during engine startup. Some starters use a planetary gear-set for gear reduction.

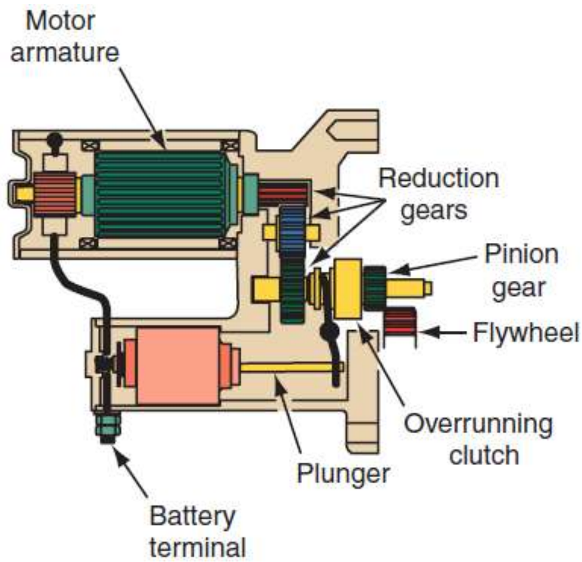


Figure 1.2-22gear reduction-drive starter.

PLANETARY-TYPE STARTER MOTOR

The planetary type starter uses a planetary gear to reduce the rotational speed of the armature, as with the reduction type and the pinion gear meshes with the ring gear via a drive lever, as with the conventional type.

Speed Reduction Mechanism

Reduction of the armature shaft'sspeed is accomplished by threeplanetary gears and 1 internal gear**(Figure 1.2-23)**.When the armature shaft turns, theplanetary gears turn in the oppositedirection, which attempts to cause theinternal gear to turn. However, sincethe internal gear is fixed, theplanetary gears themselvesareforced to rotate inside the internalgear.

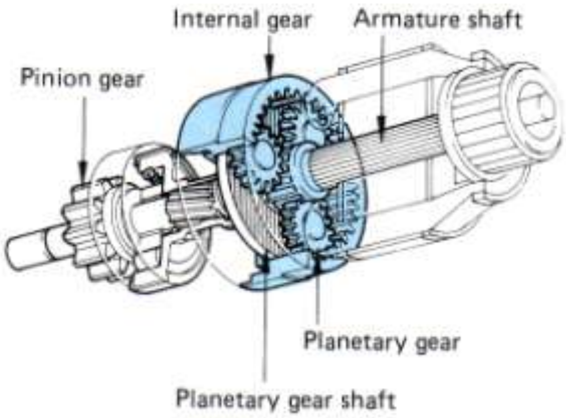


Figure 1.2-23 Planetary starter speed reduction mechanism.

Since the planetary gears aremounted on the planetary gear shaft,the rotation of the planetary gears causes the planetary gear shaft to turn also. Thegear ratio of the armature shaft gear to the planetary gears and internal gear is11:15:43, which results in a reduction ratio of approximately 5, reducing the rotationalspeed of the pinion gear to approximately 1/5 of its original speed.

Damping Device

The internal gear is normally fixed, but if too much torque is applied to the starter, the internal gear is caused to rotate, allowing the excess torque to escape and preventing damage to the armature and other parts. The internal gear is engagedwith a clutch plate and the clutchplateis pushed by a spring washer. If excess torque is brought to bear on the internal gear, the clutch plate overcomes the pushing force of the spring washer and turns, causing the internal gear to rotate. In this way, the excess torque is absorbed.

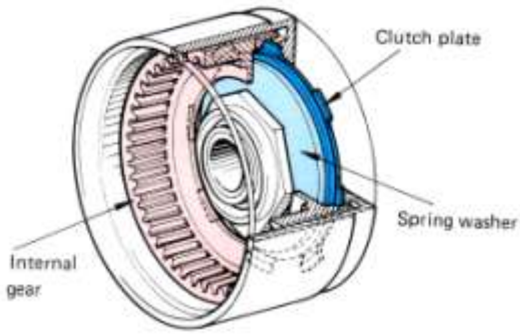


Figure 1.2-24 Damping Device

CONTROL CIRCUIT

The control circuit allows the driver to use a smallamount of battery current to control the flow of a largeamount of current in the starting circuit.

The entire circuit usually consists of an ignitionswitch connected through normal-gauge wire to thebattery and the magnetic switch (solenoid or relay).When the ignition switch is turned to the start positiona small amount of current flows through the coilof the magnetic switch, Closing it and allowing fullcurrent to flow directly to the starter motor. The ignitionswitch performs other jobs besides controllingthe starting circuit. It normally has at least four separatepositions: accessory, off, on (run), and start.

- **STARTING SAFETY SWITCH -** The **starting safety switch**, often called the **neutralsafety switch**, is a normally open switch that preventsthe starting system from operating when the transmissionis in gear. Starting safety switches can belocated between the ignition switch and the relay orsolenoid or the relay and ground.

  The safety switch used with an automatic transmissionis normally called a park/neutral positionswitch**(Figure 1.2-25)**. The switch contacts are wiredin series with the control circuit so that no current canflow through the relay or solenoid unless the shiftlever is in neutral or park. The switch is normallymounted on the transmission housing.

  Mechanical safety switches for automatic transmissionsphysically block the movement of theignition key when the transmission is in a gear. Theignition key can only be turned when the shiftselector is in park or neutral. These are called interlocksystems.

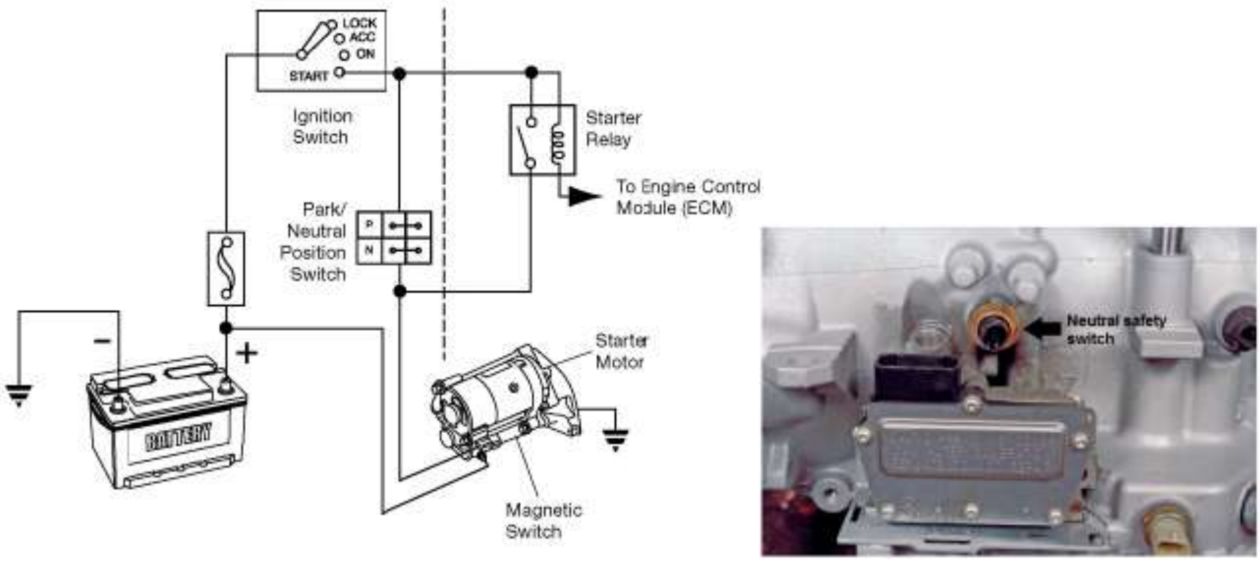


Figure 1.2-25 safety switch used with an automatic transmission.

The safety switches used with manual transmissionsare usually controlled by the clutch pedal. Theclutch start switch serves the same purpose as a park/ neutral position switch. The clutch start switch keepsthe starter control circuits open until the clutch pedalis depressed **(Figure 1.2-26)**.

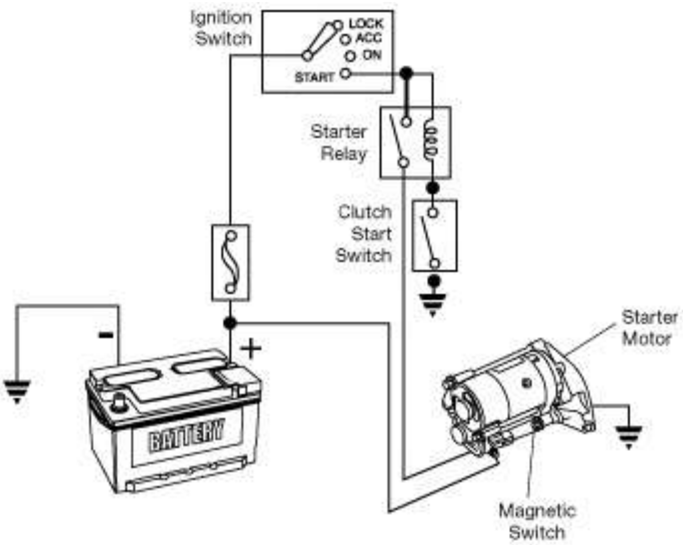


Figure 1.2-26 safety switches used with manual transmissions

Clutch start cancel switch

In some off-road situations it is advantageous to start a manual transmission vehicle while in gear with the clutch engaged. The driver controlled safety cancel switch allows the driver to bypass the clutch safety switch to make this possible**(Figure 1.2-27)**. This feature is only available on some models.

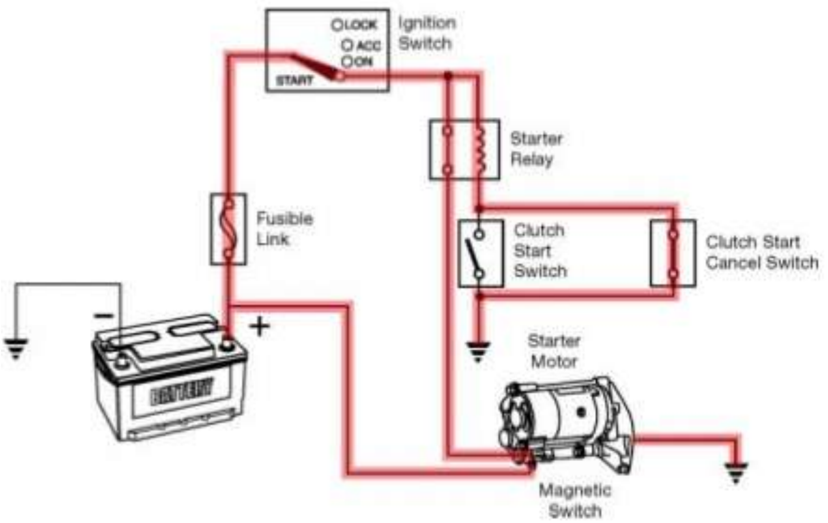


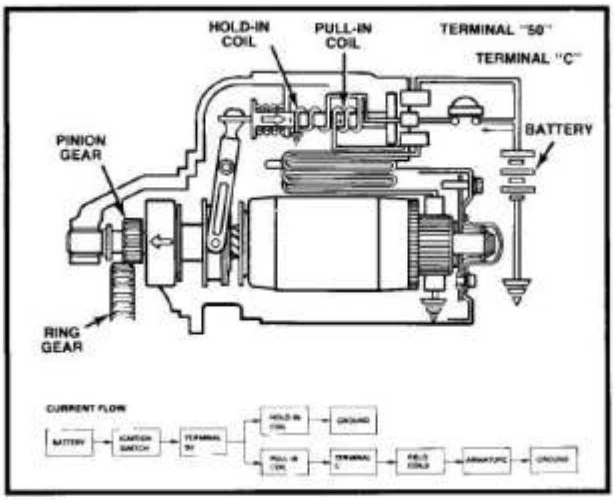
Figure 1.2-27 Clutch start cancel switch

STARTER MOTOR OPERATION

A. CONVENTIONAL STARTER MOTOR

IGNITION SWITCH IN "ST"

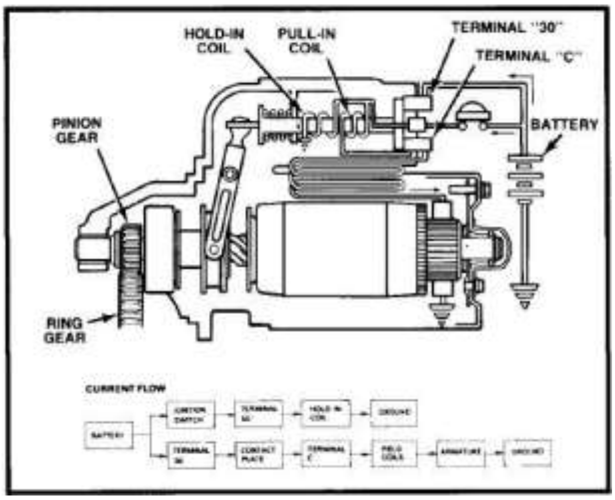
- Current flows from the battery through terminal "50" to the hold-in and pull-in coils. Then, from the pull-in coil, current flows through terminal "C" to the field coils and armature coils.
- Voltage drop across the pull-in coil limits the current to the motor, keeping its speed low.
- The solenoid plunger pulls the drive lever to mesh the pinion gear with the ring gear.
- The screw spline and low motor speed help the gears mesh smoothly.



PINION AND RING GEARS ENGAGED

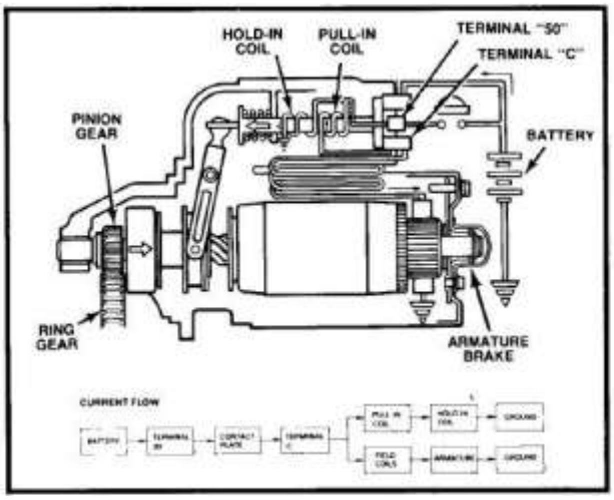
- When the gears are meshed, thecontact plate on the plunger turns on themain switch by closing the connection between terminals "30" and "C."

- More current goes to the motor and itrotates with greater torque (crankingpower).
- Current no longer flows in the pull-incoil. The plunger is held in position bythe hold-in coil's magnetic force.



IGNITION SWITCH IN “ON”

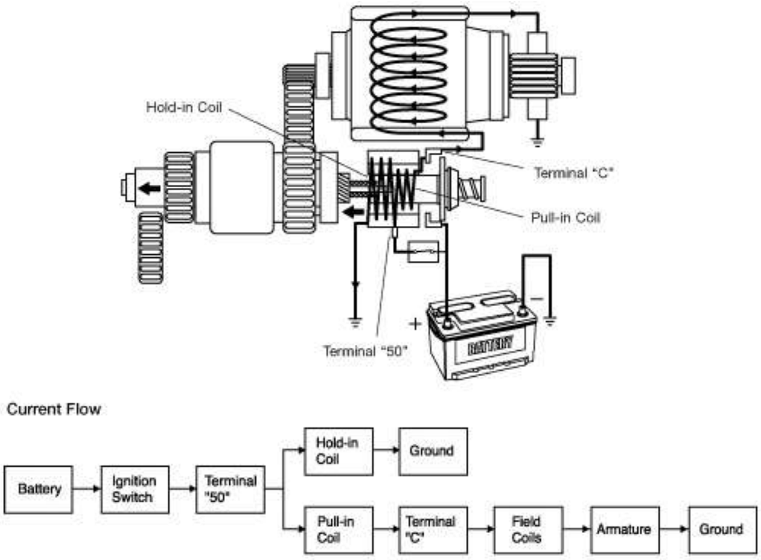
- Current no longer flows to terminal “50,”but the main switch remains closed to allow current flow from terminal “C” through the pull-in coil to the hold-in coil.
- The magnetic fields in the two coils cancel each other, and the plunger is pulled back by the return spring.
- The high current to the motor is cut off and the pinion gear disengages from the ring gear.
- A spring-loaded brake stops the armature.



A. GEAR-REDUCTION STARTER MOTOR

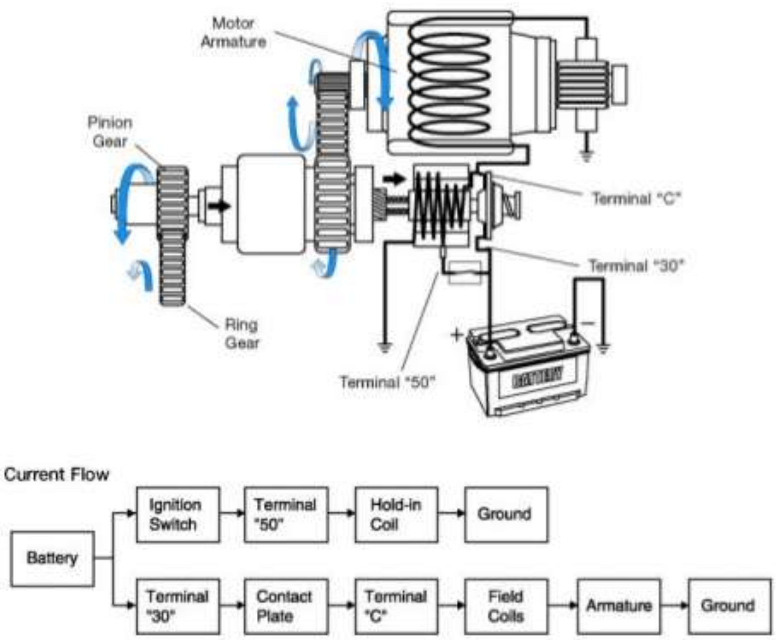
IGNITION SWITCH IN “ST”

1. Current flows from the battery through terminal "50" to the hold-in and pull-incoils. Then, from the pull-in coil, current flows through terminal "C" to the fieldcoils and armature coils.
2. Voltage drop across the pull-in coil limits the current to the motor, keepingits speed low.
3. The magnetic switch plunger pushes the pinion gear to mesh with the ring gear.
4. The screw and low motor speed help the gears mesh smoothly.



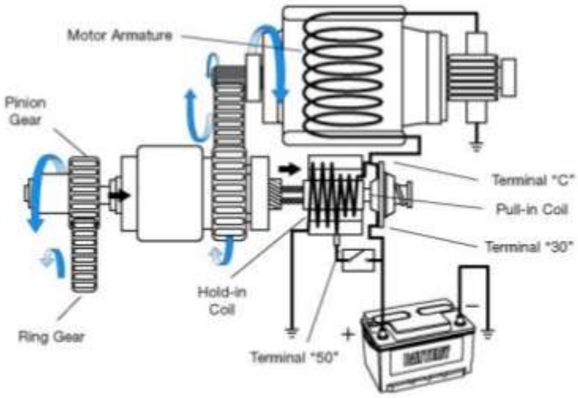
PINION AND RING GEARS ENGAGED

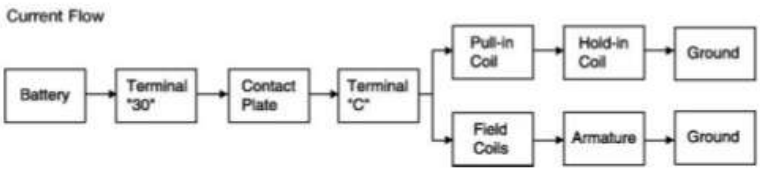
1. When the gears are meshed, the contact plate on the plunger turns on themain switch by closing the connection between terminals “30” and “C.”
2. More current goes to the motor and it rotates with greater torque.
3. Current no longer flows in the puff-in coil. The plunger is held in position bythe hold-in coil's magnetic force.



IGNITION SWITCH IN “ON”

1. Current no longer flows to terminal “50,”but the main switch remains closed to allow current flow from terminal “C” through the pull-in coil to the hold-in coil.
2. The magnetic fields in the two coils cancel each other, and the plunger is pulled back by the return spring.
3. The high current to the motor is cut off and the pinion gear disengages from the ring gear.
4. The armature has less inertia than the one in a conventional starter. Friction stops it, so a brake is not needed.





Starting System Troubleshooting Chart

SYMPTOM	POSSIBLE CAUSE	ACTION NEEDED
Engine will not crank	• Dead battery • Melted fusible link • Loose connections • Faulty ignition switch • Faulty magnetic switch, relay, neutral start switch or clutch switch • Mechanical problem in engine • Problem in theft deterrent system	• Check battery state-of-charge • Replace fusible link • Clean and tighten connections • Check switch operation; replace as needed • Check and replace as needed • Check engine • Check service manual for system tests
Engine cranks too slowly to start	• Weak battery • Loose or corroded connections • Faulty starter motor • Mechanical problems with engine or starter	• Check battery and charge as needed • Clean and tighten connections • Test starter • Check engine and starter; replace worn out parts
Starter keeps running	• Damaged pinion or ring gear • Faulty plunger in magnetic switch • Faulty ignition switch or control circuit • Binding ignition key	• Check gears for wear or damage • Test starter pull-in and hold-in coils • Check switch and circuit components • Check key for damage
Starter spins, but engine will not crank	• Faulty over-running clutch • Damaged or worn pinion gear or ring gear	• Check over-running clutch for proper operation • Check gears for damage and wear; replace as needed
Starter does not engage/disengage properly	• Faulty magnetic switch • Damaged or worn pinion gear or ring gear	• Bench test starter • Check gears for damage and wear; replace as needed

Source: Toyota

STEPPER MOTOR

INTRODUCTION

A stepper motor is basically an electromechanical device which converts electrical pulses into discrete mechanical movements. The shaft or spindle of a stepper motor rotates in discrete step increments when electrical command pulses are applied to it in the proper sequence. The motors rotation has several direct relationships to these applied input pulses. The sequence of the applied pulses is directly related to the direction of motor shafts rotation. The speed of the motor shafts rotation is directly related to the frequency of the input pulses and the length of rotation is directly related to the number of input pulses applied.

WORKING OF THE STEPPER MOTOR

The stepper motor moves indistinct steps during its rotation. Each of these steps is defined by a Step Angle. In the **Figure 1.2-28** you may notice that there are 4 distinct steps for the rotor to make a complete 360 degree rotation. This defines the step angle at 90 degrees. Since this motor does move in a discreet fashion, we can say that a stepper motor is actually a digital motor. This characteristic makes it very suitable for digital interfaces such as with a microcontroller.

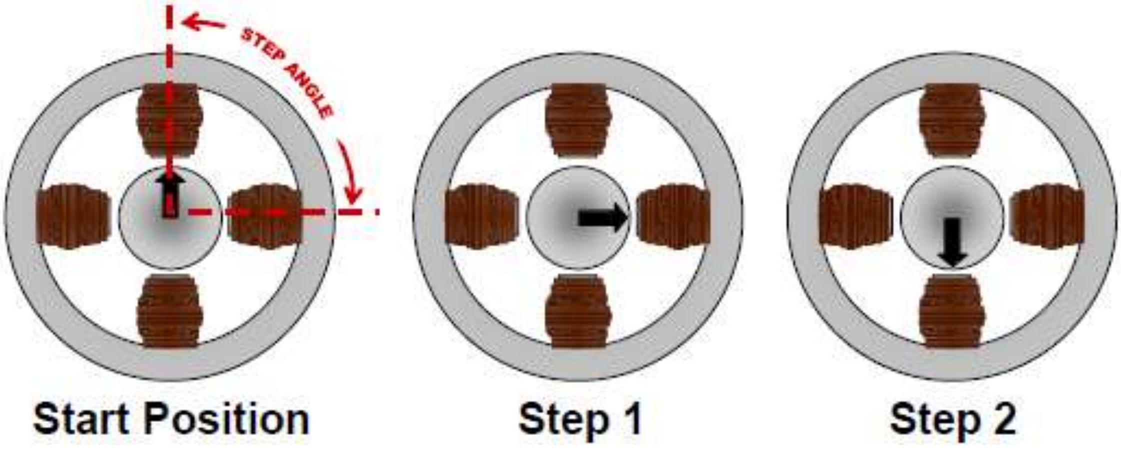


Figure 1.2-28 there are 4 distinct steps for the rotor to make a complete 360 degree rotation. This defines the step angle at 90 degrees

When no power is applied to the motor, the residual magnetism in the rotor magnets will cause the rotor to *detent* or align one set of its magnetic poles with the magnetic poles of one of the stator magnets. This means that the rotor will have 4 possible detent positions. When the rotor is in a detent position, it will have enough magnetic force to keep the shaft from moving to the next position. This is what makes the rotor feel like it is clicking from one position to the next when rotated manually.

When power is applied, it is directed to only one of the stator pairs of windings, which will cause that winding pair to become a magnetized. One of the coils for the pair will become the north pole, and the other will become the south pole. When this occurs, the stator coil that is the north pole will attract the closest rotor tooth that has the opposite polarity, and the stator coil that is the south pole will attract the closest rotor tooth that has the opposite polarity. When current is flowing through these poles, the rotor will now have a much stronger attraction to the stator winding, and the increased torque is called holding torque.

By changing the current flow to the next stator winding, the magnetic field will be changed 90°. The rotor will only move 90° before its magnetic fields will again align with the change in the stator field. The magnetic field in the stator is continually changed as the rotor moves through the 4 steps to move a total of 360°.

MAIN COMPONENTS

- **STATORS -** A stepper motor has some basic components. First, we have a soft iron stator. Asthe name implies this is a stationary component. Each stator will be wrapped with multiple windings or phases that will be energized using a voltage source, initiating current flow through the winding to produce a polarity on each end or pole of the stator.

- **ROTOR -**The rotor is the actual rotating component on the motor. This can either be magnetized, as shown here, or non-magnetized depending on the type of motor you select.

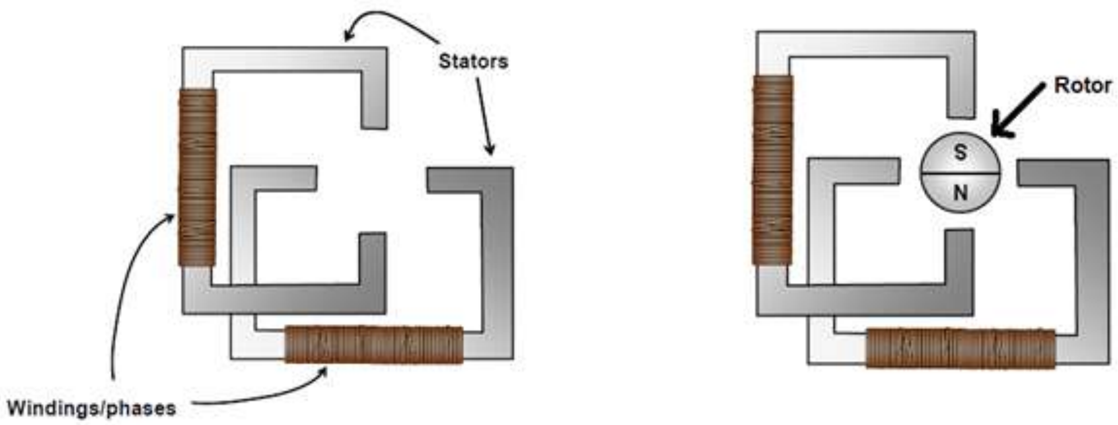


Figure 1.2-29 Statorsand Rotor.

In **Figure 1.2-30a,** if we apply a voltage across the windings around a stator, currentwill flow through the winding. If you take your right hand and position your fingers over a winding in the direction of current flow, you thumb will point in the direction of the magnetic flux**(Right-hand Rule)**. Here we can see that each end of the stator is magnetized to opposite poles. Magnetic flux will flow from North to South thereby continuing through the magnetic rotor to the opposite stator pole. The flux will want to travel the path of least resistance or decrease the reluctance of the path.

Since the rotor does rotate it will position itself to minimize this reluctance **(Figure 1.2-30b)**.By adding more stators and phases, we can charge a winding attracting the rotor poles accordingly then remove the applied voltage allowing other stators to attract the rotor poles.

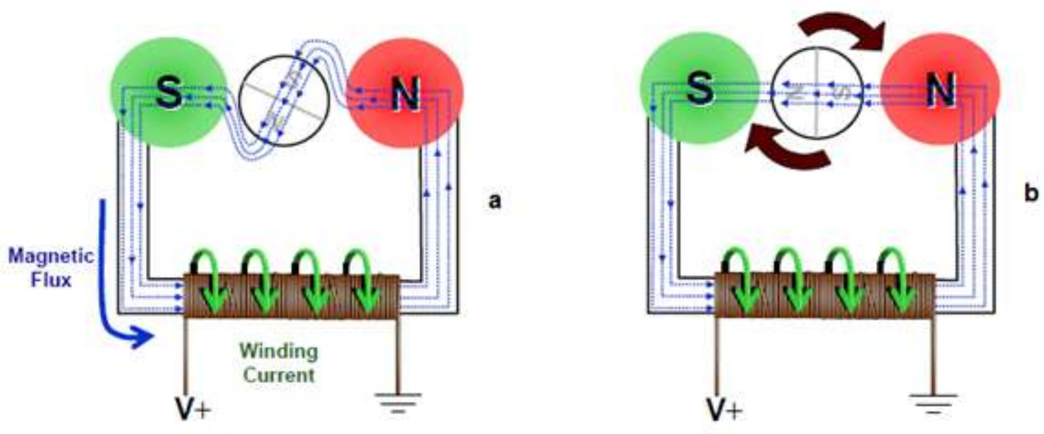


Figure 1.2-30 a) Voltage applied to winding initiates current flow, Magnetic flux begins to flow, b) Rotor rotates to minimize flux path (or reluctance)

TYPES OF STEPPING MOTORS

There are basically three types of stepping motors; permanent magnet, variable reluctance and hybrid. They differ in terms of construction based on the use of permanent magnets and/or iron rotors with laminated steel stators.

1. Permanent Magnet Motor

The permanent magnet motor, as the name implies, has a permanent magnet rotor. It is a relatively low speed, low torque device with large step angles of either 45 or 90 degrees. Its simple construction and lowcost. The permanent magnet motor rotor has no teeth and is designed to be magnetized at a right angle to its axis**(Figure 1.2-31a)**.We can improve the resolution of rotorrotation, or decrease the step angle in a permanent magnet rotor by either increasing the number of pole pairs on the rotor itself**(Figure 1.2-31b)**.We could also increase the resolution by adding more stators and phases**(Figure 1.2-31c)**.

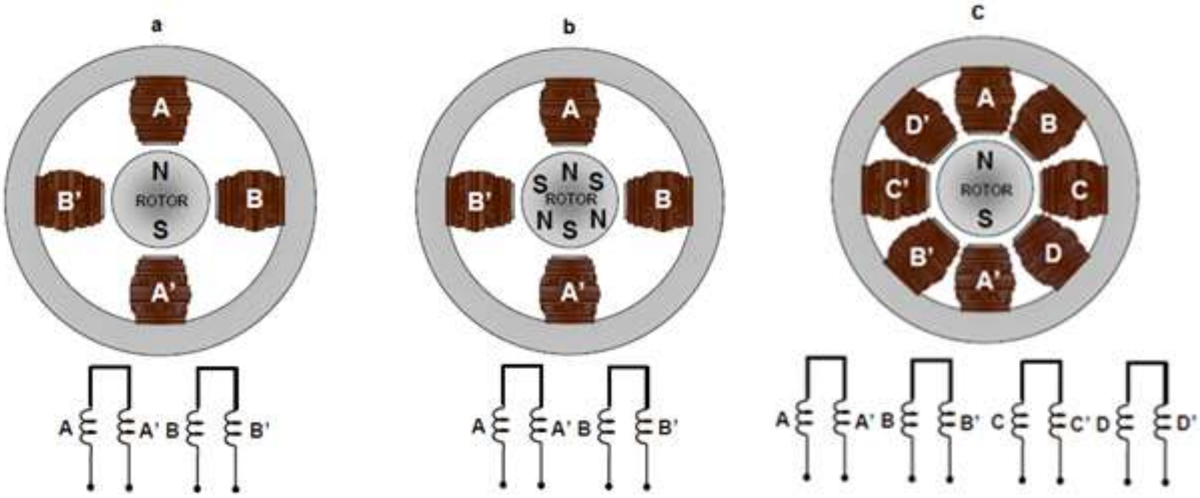


Figure 1.2-31 Permanent Magnet Motor.

Operation

To rotate the rotor, voltage is applied to each phase sequentially; again current begins to flow creating a polarity on each pole of that stator **(Figure 1.2-32)**. Rotation in a particular direction is accomplished by applying voltage to the individual phases in a particular sequence. This means that to rotate the rotor in the opposite direction, simply reverse this voltage sequence. To hold the rotor at a particular position, step it to that angle and then stop the sequence maintaining voltage on the appropriate phase.

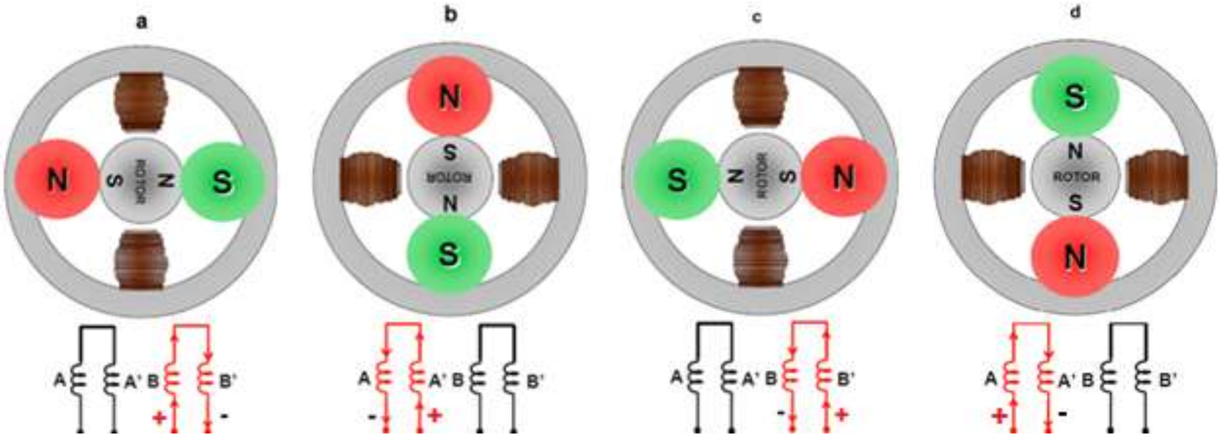


Figure 1.2-32 Operational characteristics of permanent magnet motor.

2. Variable Reluctance Motor

This motor uses a non-magnetized, soft-iron rotor **(Figure 1.2-33)**. The rotor here actually has teeth that are carefully offset from the stator poles to accomplish rotation. Notice also that the individual stator windings are configured differently than what we have discussed so far. All windings have a common terminal that will be connected to a voltage source. The opposite end of each winding is kept separate from the other windings. To increase the resolution on this type of motor, typically more teeth are added to the geared rotor.

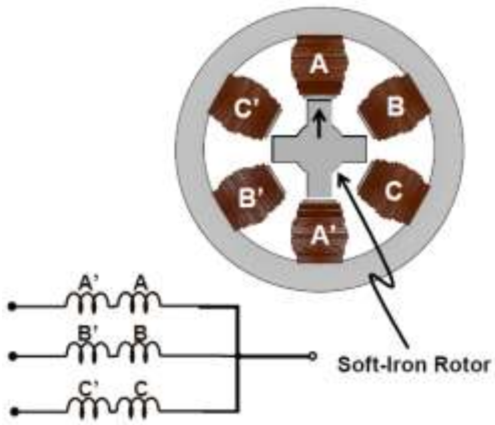


Figure 1.2-33 Variable Reluctance Motor.

Operation

Each winding is again energized one at a time to create a polarity on the appropriate stator poles **(Figure 1.2-34)**. The rotor rotates to minimize the reluctance of the magnetic flux path. What happens next differentiates the variable reluctance motor from most other Stepping Motor types.

Notice that to rotate the motor in a particular direction, the stator pole/winding energizing sequence is actually reversed to that used in a permanent magnet motor.

Also, note that the motors step angle is actually half what it is with a permanent magnet motor with the same number of stator/windings.

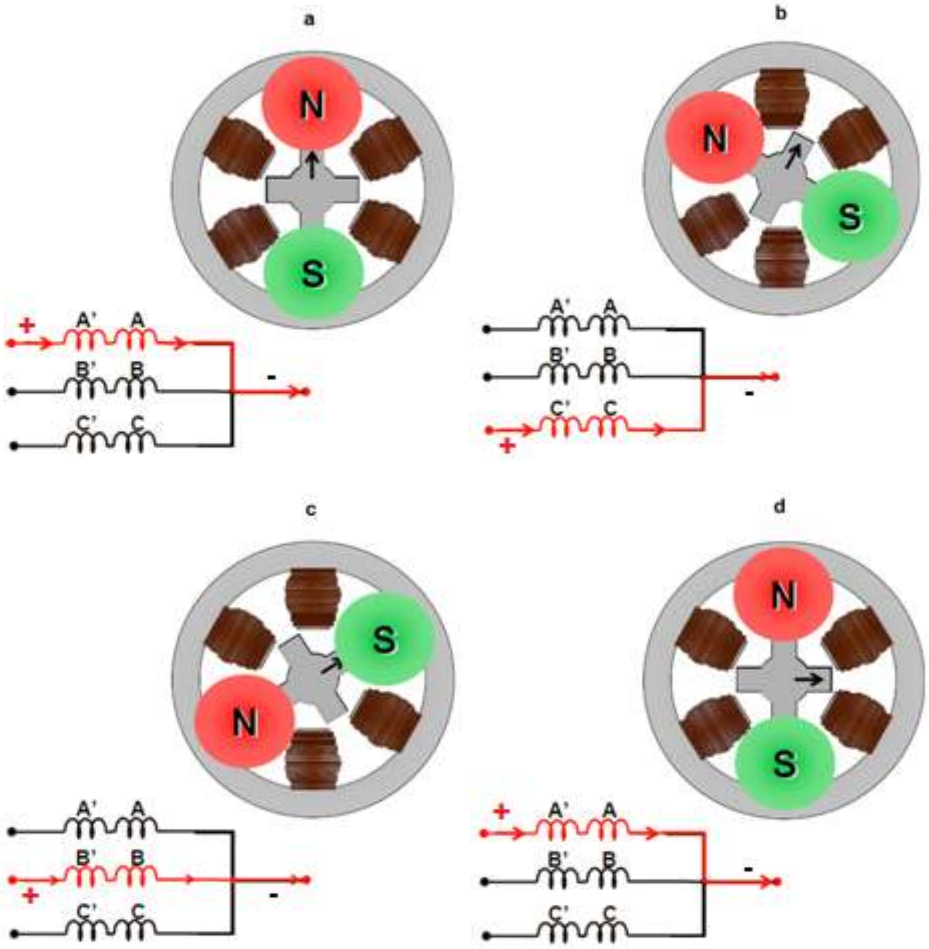


Figure 1.2-34 Operational characteristics of variable Reluctance motor.

3. Hybrid Motor

This type of Stepping motor borrows characteristics from both permanent magnet and variable reluctance motors. **Figure 1.2-35a**shows a side view of Hybrid Stepper Motor with the rotor removed. The rotor is magnetized and also has teeth. Each stator now has a number of teeth or poles. The rotor is actually in two sections or cups, one in the front and one in the back. The two rotor cups are opposite in polarity **Figure 1.2-35b**. On the right side of the slide is a close up view of the individual teeth on the rotor cups. The north rotor cup is represented in red and the south rotor cup in green. The teeth on one cup are offset by a tooth as compared to the other cup.

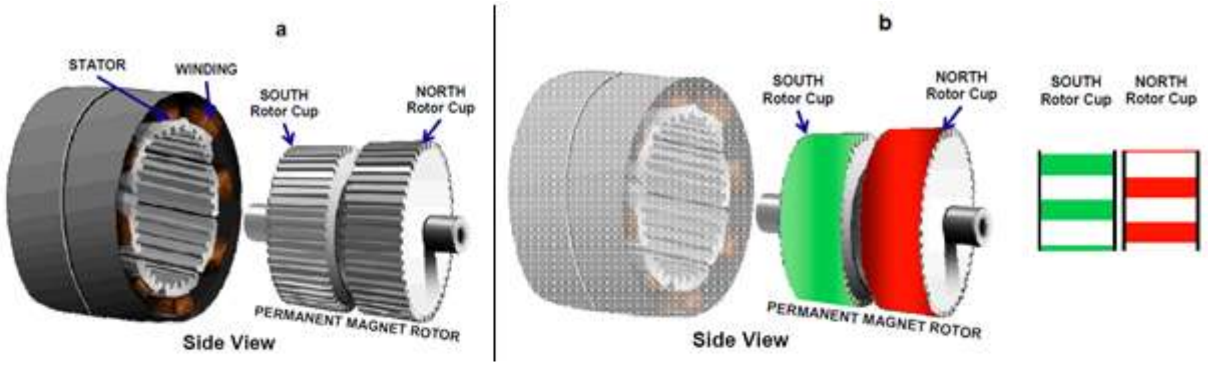


Figure 1.2-35 Hybrid Motor.

Operation

Figure 1.2-36Ishows the Hybrid stepper motor reassembled and turned for a front view. Referring to the winding diagram on the Right and the Stator pole configuration on the Left, we can see that each winding actually energizes four stator poles at once when energized.
Applying a voltage to each of the windings we will control the direction of current flow thereby controlling the polarity of each stator pole. **Figure 1.2-36II** shows that Stator poles A and A’ are aligned perfectly with one of the rotor cup’s teeth. On the other hand B and B’ stator poles are actually half-way with half of the pole attracting one cup’s tooth while repelling the other.

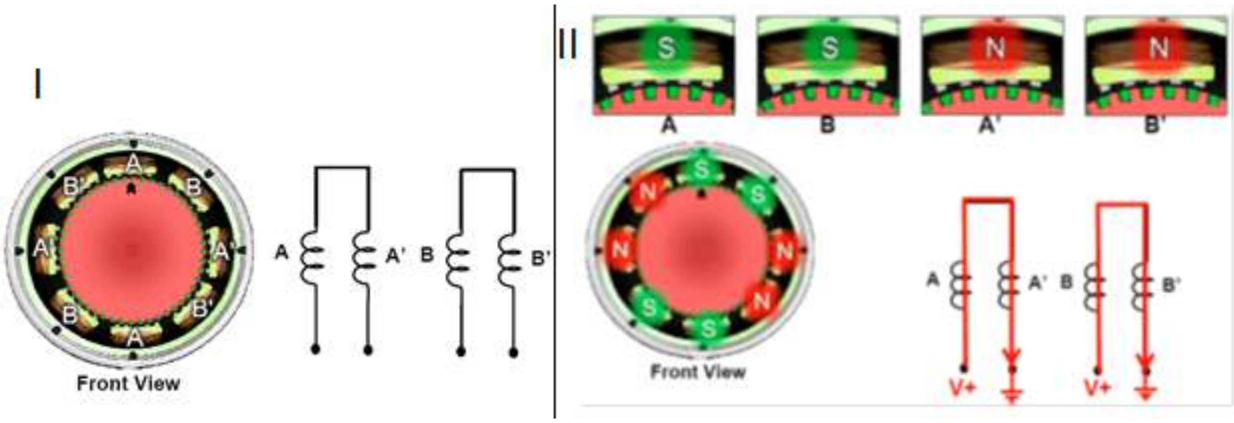


Figure 1.2-36 I) Front view of Hybrid stepper motor, II) Stator poles A and A’ are aligned perfectly with one of the rotor cup’s teeth

The next step in the sequence changes current direction in winding A by reversing the applied voltage **(Figure 1.2-37)**. Winding B maintains current direction from the previous state. Look how this affects the rotor position. Notice now that stator poles A and A’ are now half on each rotor cup while stator poles B and B’ line up perfectly with each cup. The rotor has rotated a very small amount thanks to the construction of the Hybrid motor components. The motor pictured has a step angle of 1.8 degrees per step. This is a significant improvement over the basic permanent magnet motor we looked at before.

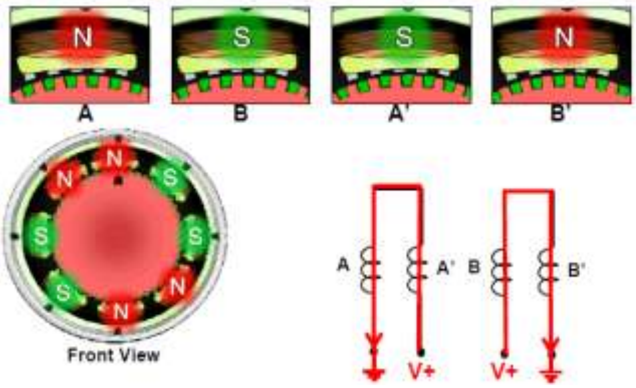


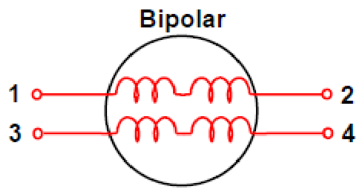
Figure 1.2-37 stator poles B and B' line up perfectly with each cup.

STEPPER MOTOR WINDINGS

There are two types of windings. These two sub-categories are determined by how the lead from each phase winding is brought out of the motor.

1. Bipolar Motor Winding

The bipolar configuration, each winding lead is brought out separately. This type of winding, depending on the voltage applied and to which lead, can produce current flow in two directions. This allows each stator pole to be magnetized to North or South.



Operation

Bipolar motors allow current flow in both directions through each winding. Applying a voltage to lead A' and grounding lead A generates current flow resulting in the stator polarities **(Figure 1.2-38a)**.Removing the voltage from winding A and applying a positive voltage to lead B' on winding B and driving lead B to ground generates current flow and stator polarities **(Figure 1.2-38b)**.This continues to rotate the rotor 360 degrees.

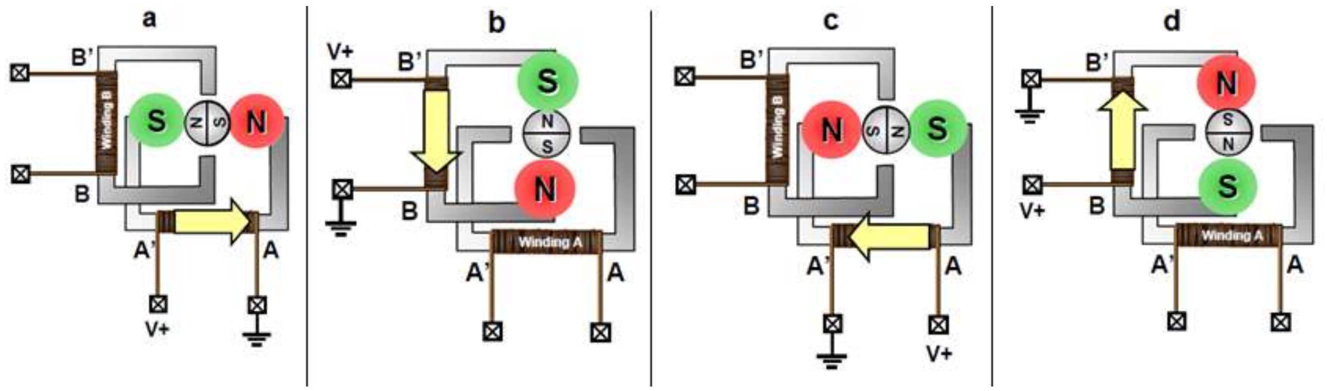
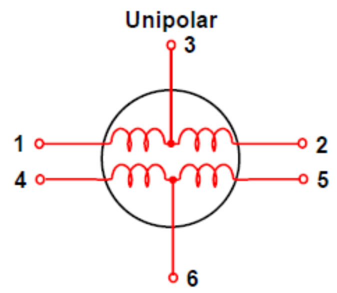


Figure 1.2-38 Bipolar motor (Current flows in entire winding at a time).

2. Unipolar Motor Winding

The Unipolar configuration, on the other hand, only allows current flow in half of thewinding at one time. Notice that each winding has a center tap that is brought outside of the motor along with each winding lead.



Operation

The center-tap lead is connected to a positive voltage source in **Figure 1.2-39a**.Driving one of the leads on winding A to ground allows current to flow in one half of the winding generating a polarity on the stator poles and the rotor rotates accordingly. **Figure 1.2-39b**shows the grounding source is removed from the winding A lead and one of winding B's leads is driven to ground. Again, current flows in half the winding and the appropriate stator poles are energized. This continues to rotate the motor 360 degrees.

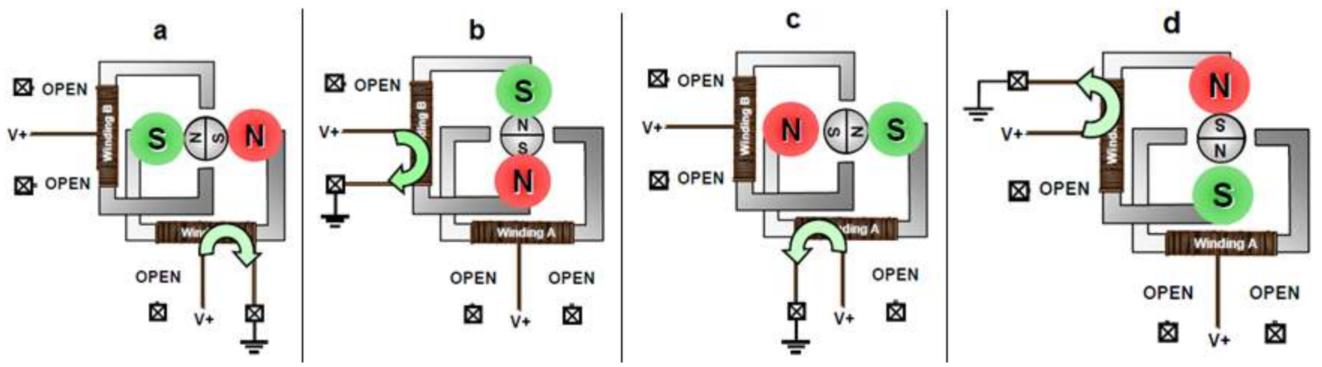


Figure 1.2-39 Unipolar motor (Current flows in ½ winding at a time).

STEPPER MOTOR DRIVE CIRCUITS

The basic function of a motor driver is to provide the rated current to the motor windings in the shortest possible time. Driver voltage plays a large part in a step motor's performance. Higher voltage forces current into the motor windings faster, helping to maintain high speed torque.

Two of the most commonly used drivers for step motors are the following:

1. **Constant current drivers -** Are also known as **PWM** (pulse width modulated) or chopper drives. In this type of driver, the motor current is regulated by switching voltage to the motor on and off to achieve an average level of current. These drivers operate using a high voltage supply, generating a high driver voltage to motor voltage ratio, giving the motor improved high-speed performance.

2. **Constant voltage drivers -** Are also known as, **L/R** or resistance limited (RL) drivers. In this type of driver, the amount of current a step motor receives is limited only by the resistance/impedance of its windings. For this reason, it is important to match the motor's rated voltage to the voltage of the driver. Constant voltage drivers work best in low speed and low current applications. They become inefficient at high speeds and high current levels. In certain situations, resistors may be placed in series with the motor's windings to allow the motor to be operated using a driver voltage larger than the motor's rated voltage to increase performance at higher speeds.

BRUSHLESS DCMOTOR

A brushless DC motor is much like a brushed DC motor, but the purpose of the rotor (armature) and stator (field windings) are reversed. The rotor has a set of permanent magnets and the stator has controllable electromagnets **(Figure 1.2-40)**. Obviously, a brushless motor has no brushes and no commutator. The normal electrical arcing that takes place between the brushes and commutator is eliminated with the brushless design. This arcing not only decreases the usable life of a motor, it also creates electromagnetic interference that is detrimental to advanced electronic systems.

Rather than using brushes, an electronic circuit switches current flow to the different stator's windings to keep the rotor turning. The reversing of current flow through the windings is done by power transistors that switch according to the position of the rotor. Many brushless DC motors use Hall-effect sensors to monitor the position of the rotor. Other brushless motors monitor the CEMF in unexcited field windings to determine the position of the rotor.

The current to the various stator windings is typicallycontrolled by a **pulse width modulation (PWM)**frequency inverter. The voltage to the windings is changed by altering the duty cycle.

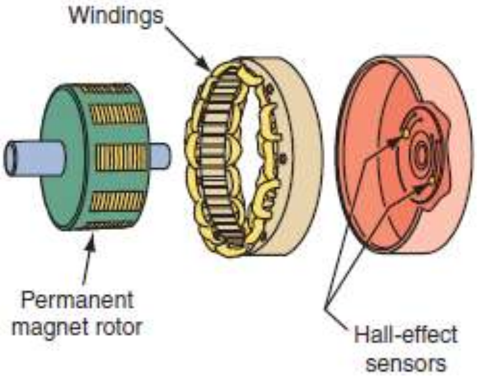


Figure 1.2-40A brushless DC motor.

The **duty cycle** of something is the length of time the device is turned on compared to the time it is off **(Figure 1.2-41)**. Duty cycle can be expressed as a ratio or as a percentage. By quickly opening and closing the power circuit to the motor, the speed of the motor is controlled. This is called pulse width modulation. These power pulses vary in duration to change the speed of the motor. The longer the pulses, the faster the motorturns.

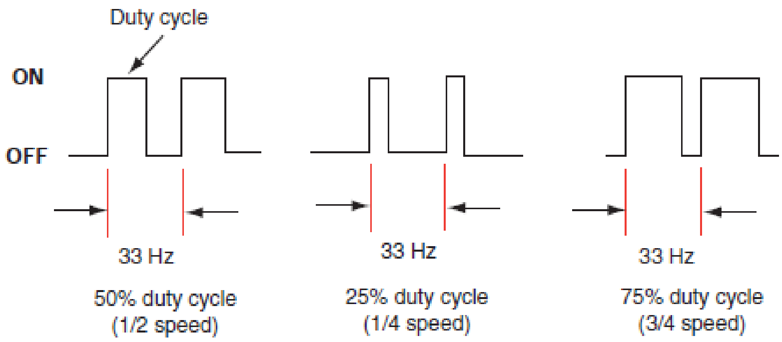


Figure 1.2-41the action of various duty cycles.

1.3 IGNITION SYSTEM

PURPOSE OF IGNITION SYSTEM

The purpose of the ignition system is to ignite the compressed air-fuel mixture in the engine combustion chambers. This should occur at the proper time for combustion to begin. To start combustion, the ignition system delivers an electric spark that jumps a gap at the combustion-chamber ends of the spark plugs. The heat from this arc ignites the compressed air-fuel mixture. The mixture bums, creating pressure that pushes the pistons down the cylinders so the engine runs.

The ignition system may be either a **contact-point** ignition system or an **electronic** ignition system.

CONTACTPOINT IGNITION SYSTEM

COMPONENTS IN CONTACTPOINT IGNITION SYSTEM

The ignition system includes the battery, ignition switch, ignition coil, ignition distributor (with contact points and condenser), secondary wiring, and spark plugs.

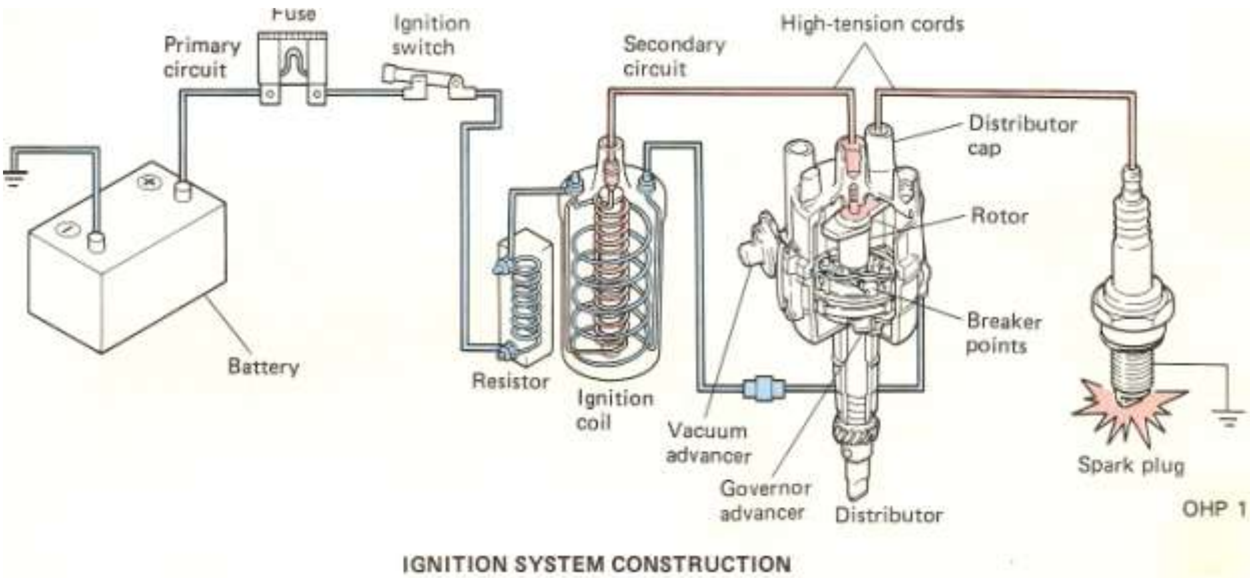


Fig 1.3-1 component Parts of a contact breaker type Ignition System

- **IGNITION SWITCH-** The ignition switch connects the ignition coil to the battery when the ignition key is ON. When the key is turned to START, the starting motor cranks the engine for starting.
- **IGNITION COIL-** The ignition coil is a step-up transformer that raises the battery voltage to a high voltage that may reach 25,000 volts. In some electronic ignition systems, the

voltage may go up to 47,000 volts or higher. The high voltage causes sparks to jump the gap at the spark plugs.

- **IGNITION DISTRIBUTOR -**The ignition distributor does two jobs. First, it has a set of contact points or breaker points that work as a fast-acting switch. When the points close, current flows through the coil. When the points open, current flow stops and the coil produce a high-voltage surge. A condenser connects across the points. It aids in the collapse of the magnetic field and helps reduce arcing that bums away the points.

  Second, the distributor distributes the high-voltage surges to the spark plugs in the correct firing order. A coil wire delivers the high voltage from the coil to the center terminal of the distributor cap. Inside the cap, a rotor is on top of the distributor shaft. In most contact-point distributors, the distributor shaft is driven from the engine camshaft by a pair of spiral gears. The rotor has a metal blade. One end of the blade contacts the center terminal of the distributor cap **(Fig 1.3-2)**.

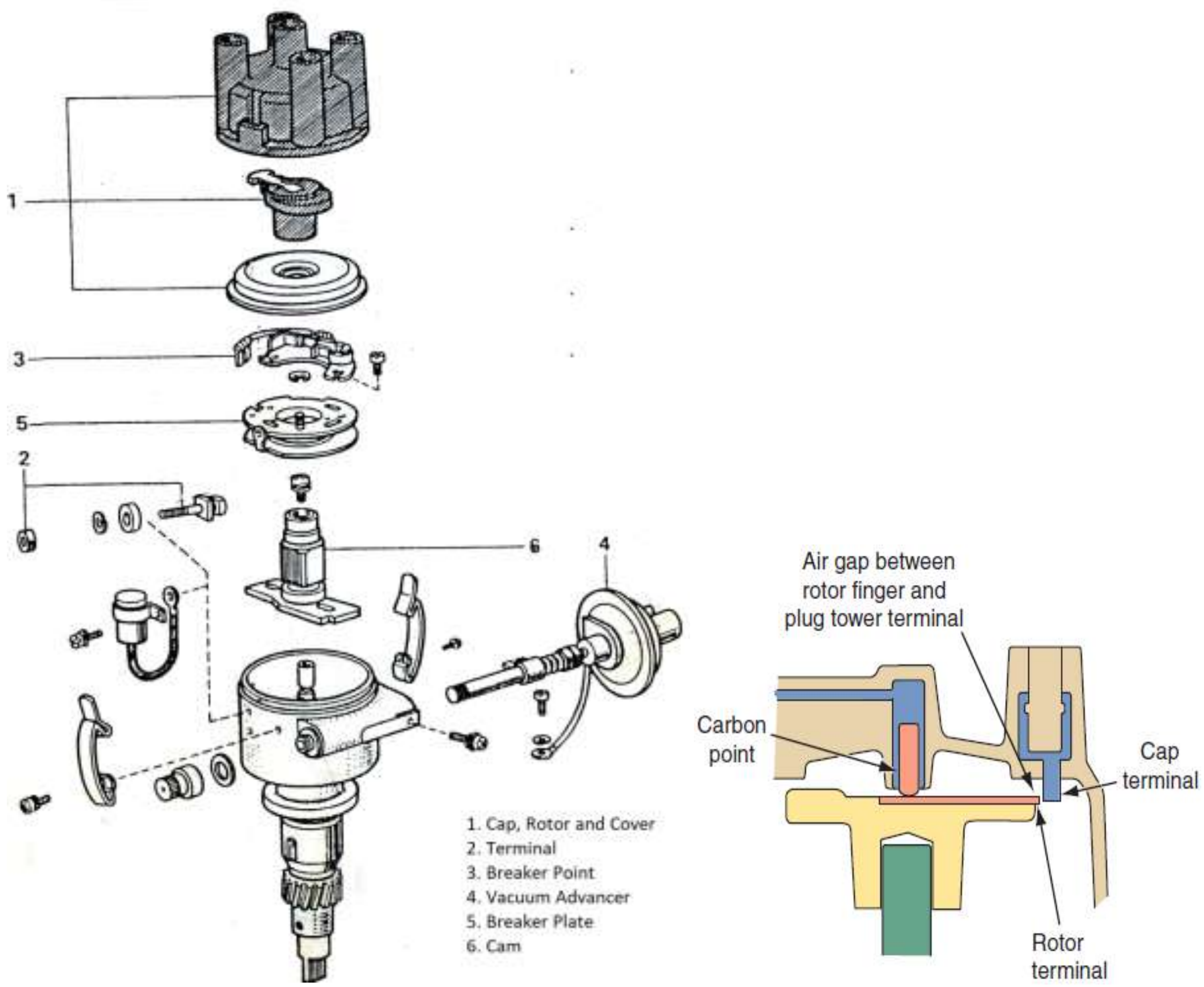


Figure 1.3-2 the relationship of a rotor and distributor cap

When the rotor turns, the other end passes close to the outer terminals in the distributor cap. These are connected by spark-plug wires to the spark plugs. The high-voltage surge jumps the small gap from the rotor blade to the terminal. The spark-plug wires carry the high-voltage surge to the spark plug in the cylinder that is ready to fire.

- **SECONDARY IGNITION CABLES -** The secondary cables or wiring include the coil wire and the spark-plug wires **(Fig 1.3-3)**. These cables connect between the center of the ignition coil and the distributor cap, and between the distributor cap and the spark plugs. Secondary cables for contact-point ignition systems have a 7 mm (0.276 inch) diameter. Many electronic ignition systems require 8 mm (0.315 inch) cables. The use of a silicone insulating jacket makes these cables larger.

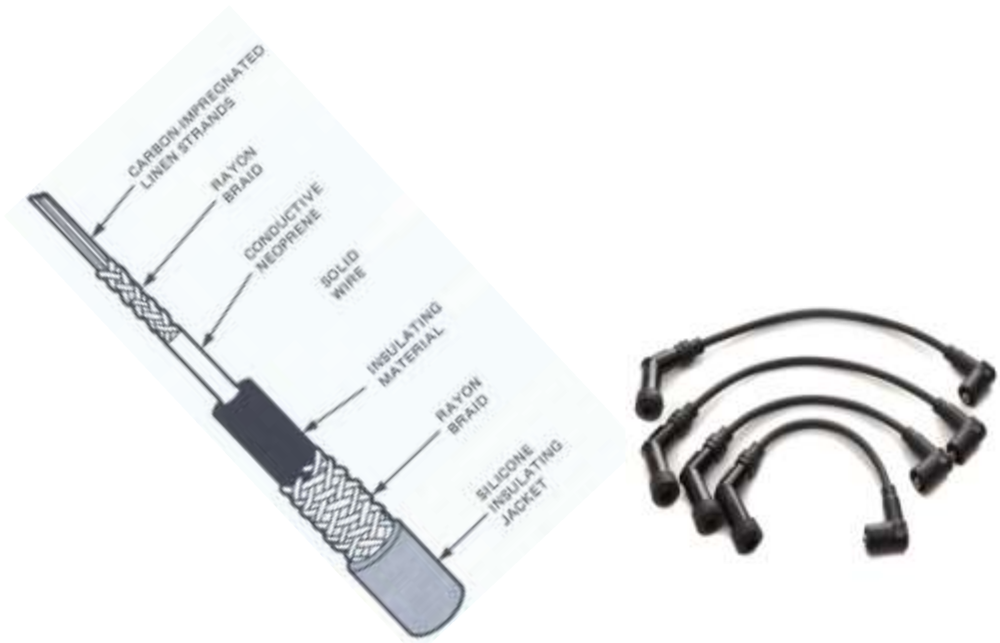


Figure 1.3-3 Spark plug cable construction

- **SPARK PLUGS-** The spark plug has two solid-metal conductors called electrodes positioned to form a gap. The gap is between the insulated center electrode and the ground electrode. The spark jumps the gap to ignite the compressed air-fuel mixture in the engine cylinders.

IGNITION COILS (producing the spark)

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 supply30,000 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** that transforms battery voltage into short bursts of high voltage. As explained previously, 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. 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**(Fig 1.3-4)**. 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 often 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 achieved. 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.

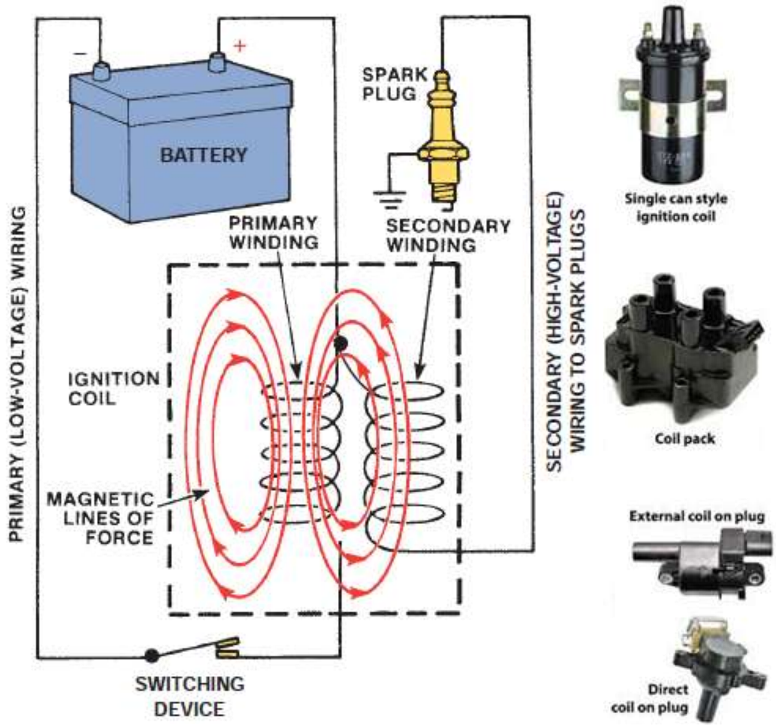


Figure 1.3-4 Current passing through the coil's primary winding creates magnetic lines of force that cut across and induce voltage in the secondary windings

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 may not fire at all. If the current is applied longer than needed to fully saturate the winding, the coil will overheat.

A typical coil requires 2 to 6 milliseconds to become saturated. The actual required time depends on the resistance of the coil's primary winding and the voltage applied to it. Some early systems electronically limit the primary current flow at low speeds to prevent the coil from overheating. When the engine reaches higher speeds, the current limitation feature is disabled. 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.

CONTACT POINTS

The contact-point set mounts on a breaker plate in the distributor (**Fig 1.3-5**). The points are operated by a breaker cam on top of the distributor shaft. The cam has the same number of lobes as there are cylinders in the engine. As the cam revolves, the points close and open, they act as a mechanical switch to make and break the primary circuit.

One contact point mounts on the grounded breaker plate and is stationary. The other point mounts on the end of an insulated movable arm. The arm swings back and forth on a pivot as the cam lobes push on the rubbing block to open the points. A spring attached to the movable point arm closes the points.

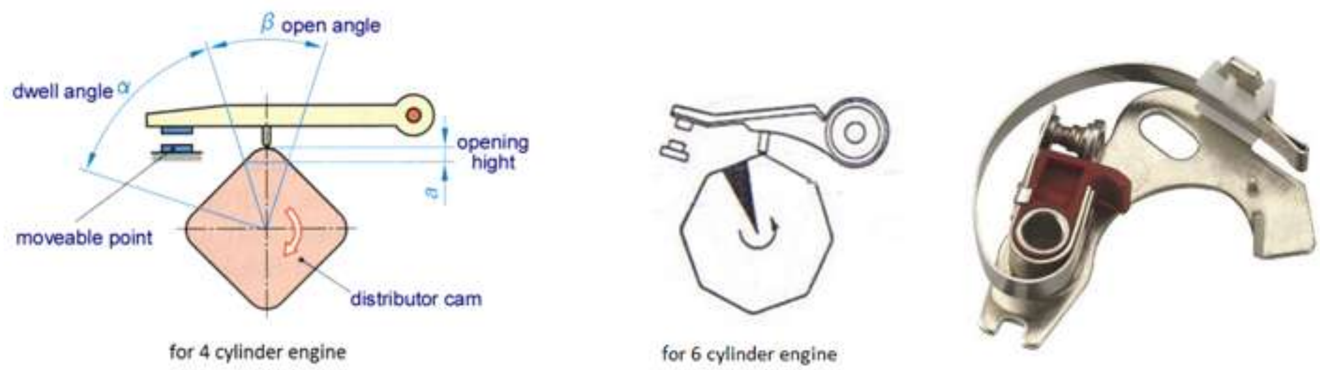


Fig 1.3-5 the contact-point set

When the points close, this connects the coil primary winding to the battery. A magnetic field builds up in the coil. As the breaker cam rotates, the next lobe pushes the movable arm away from the stationary contact point. This opens the points and stops the current flow. The magnetic field collapses and a high-voltage surge results. The length of time in degrees of distributor-shaft rotation that the contact points remained closed is the dwell. The distance that separates the points when they are fully open is the gap. Points are normally adjusted by dwell or gap measurements.

The distributor shaft and cam are driven by the engine camshaft which turns at one-half crankshaft speed. It takes two complete revolutions of the crankshaft to rotate the distributor shaft one complete revolution. The relationship between piston position and spark-plug firing is ignition timing.

- **Dwell -** is the length of time the points are closed and current flows through the primary winding of the coil. The points open and the cycle begin again at as the spark occurs at the spark plug. The whole procedure repeats continuously as long as the engine runs.

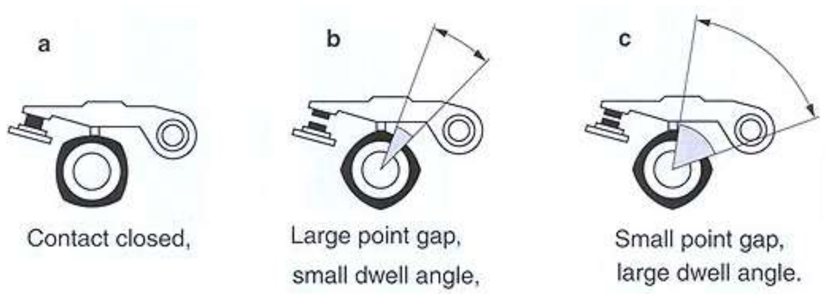


Fig 1.3-6 contact breaker (schematic diagram)

CAPACITOR (CONDENSER)

Capacitor is to hold tiny charge and to prevent pitting of the switch points, as the current is broken, in the dc coil. When the dc current is broken, this creates a collapsing magnetic field, and the collapsing magnetic field creates a counter Electro motive force, in the primary of the ignition coil. To prevent the primary from having too big a spark, the energy is dissipated into the plates of the capacitor, so that the closed current, can happen again, and when this happens, the capacitor is shorted out, and the voltage (12v) is dissipated back into the coil again.

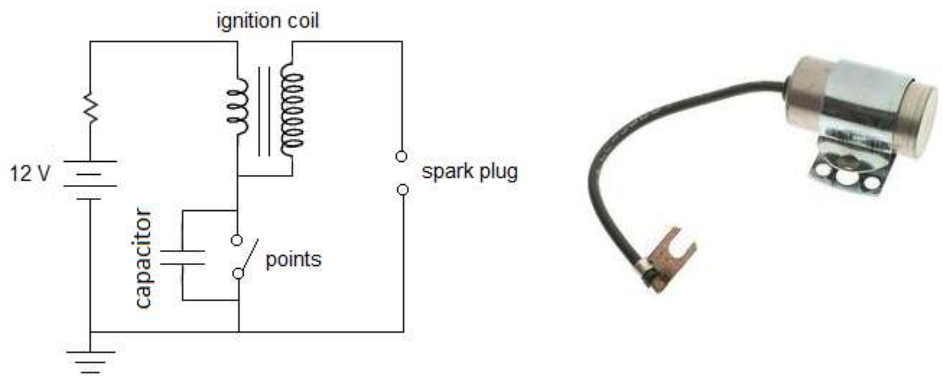


Figure 1.3-7 capacitor

PRIMARY RESISTANCE (BALLAST RESISTOR)

Excessive current flows in the primary circuit, causes arcing and burning of the contact points. To prevent this, a resistance is placed between the ignition switch and the coil primary winding. The resistance may be a separate resistor or a special resistance wire. For easier starting, the resistance is bypassed and full battery voltage reaches the coil during cranking. After the engine starts, the resistance reduces coil voltage to 5 to 8 volts.

ADVANCING THE SPARK

When the engine is idling, the spark is timed to reach the spark plug just before the piston reaches TDC on the compression stroke. At higher speeds, the spark must occur earlier. If it does not, the piston will be past TDC and moving down on the power stroke before combustion pressure reaches its maximum. The piston is ahead of the pressure rise which results in a weak power stroke. This wastes much of the energy in the fuel.

To better use the energy in the fuel, the spark takes place earlier as engine speed increases. This spark advance causes the mixture to bum producing maximum pressure just as the piston moves through TDC. Most contact-point distributors have two mechanisms to control spark advance. A **centrifugal-advance mechanism** adjusts the spark based on the engine speed. A **vacuum advance mechanism** adjusts the spark based on engine load. On the engine, both work together to provide the proper spark advance for the engine operating conditions.

1. **CENTRIFUGAL ADVANCE -** The centrifugal-advance mechanism **(Fig 1.3-8)**advances the spark by pushing the breaker cam ahead as engine speed increases. Two advance weights, two weight springs, and a cam assembly provide this action. The cam assembly includes the breaker cam and an oval-shaped advance cam. At low speed, the springs hold the weights in. As engine speed increases, centrifugal force causes the weights to overcome the spring force and pivot outward. This pushes the cam assembly ahead. The contact points open and close earlier and advancing the spark.

Fig 1.3-8 Centrifugal-advance mechanism

2. **VACUUM ADVANCE**

When the throttle valve is only partly open, a partial vacuum develops in the intake manifold. Less air-fuel mixture gets into the engine cylinders. Then the fuel bums slower after it is ignited. The spark must be advanced at part throttle to give the mixture more time to burn. The vacuum-advance mechanism **(Fig 1.3-9)** advances spark timing by shifting the position of the breaker plate. The vacuum-advance unit has a diaphragm linked to the breaker plate. A vacuum passage connects the diaphragm to a port just above the closed throttle valve. When the throttle valve moves past the vacuum port, the intake-manifold vacuum pulls on the diaphragm. This rotates the breaker plate so the contact points open and close earlier. Any vacuum port above the throttle valve provides ported vacuum.

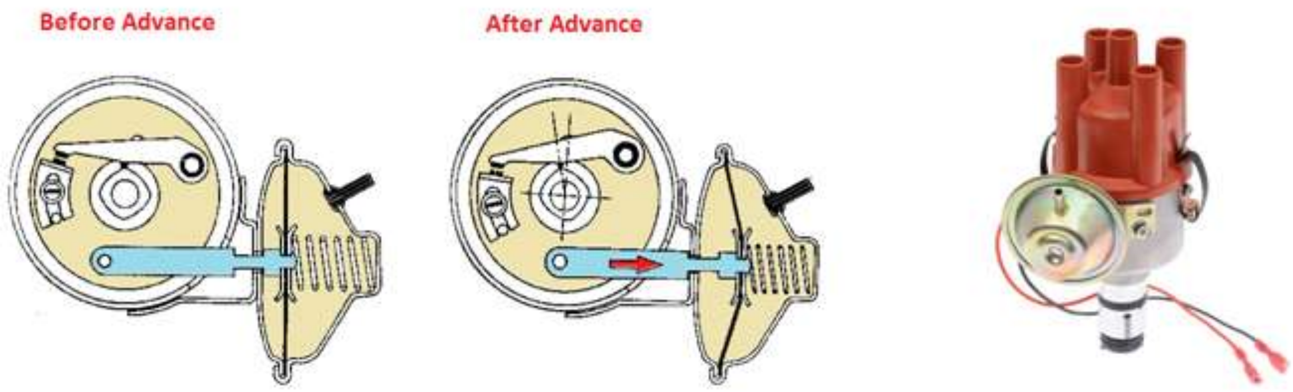


Fig 1.3-9 Operation of the vacuum advance unit

COMBINED CENTRIFUGAL AND VACUUM ADVANCE

At any speed above idle, there is some centrifugal advance. Depending on intake-manifold vacuum, there may also be some vacuum advance. **For example;** at 40 miles per hour (64 km/h), there are 15 degrees of centrifugal advance and the vacuum advance can produce up to 15 degrees of additional advance at part throttle. The advances combine to produce a maximum advance of 30 (15 + 15) degrees. When the engine runs at wide-open throttle, intake manifold vacuum drops to zero. There is no vacuum advance.

SPARK PLUGS

The spark plug **(Fig 1.3-10)** has a metal outer shell enclosing a ceramic insulator. Centered in the insulator is the center electrode which carries the high-voltage current from the ignition coil. A ground electrode attaches to the metal shell and is bent inward to produce the proper spark gap. The gap varies from 0.035 inch [0.9 mm] for contact point ignition systems to 0.080 inch (2.03 mm) for some electronic ignition systems. The spark jumps from the center electrode to the ground electrode. The wider the gap, the higher the voltage required to jump it.

Spark plugs may have a suppressor or resistance(normally about 5 K ohms)built into the center electrode. It reduces television and radio interference (static) caused by the ignition system. Spark plugs may require gaskets when installed to assure a leak-proof seal. Many engines use spark plugs with tapered seats which seal without a gasket.

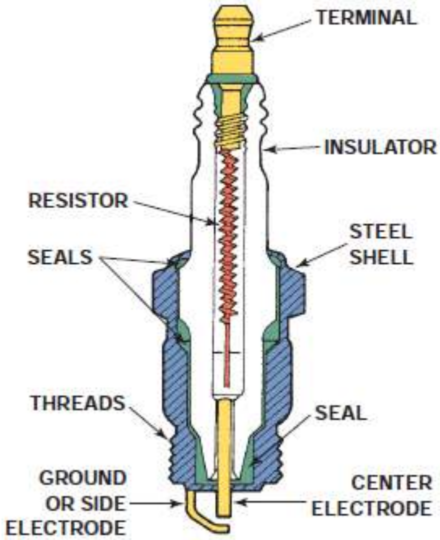


Figure 1.3-10 Components of a typical spark plug

Some engines have two spark plugs in each combustion chamber. Both plugs may fire together or one slightly ahead of the other. The additional plugs help reduce exhaust emissions and increase engine power.

SPARK·PLUG HEAT RANGE AND REACH

One important design characteristic of sparkplugs is the **reach (Fig 1.3-11)**. This refers to the length of the shell from the contact surface at the seat to the bottom of the shell, including both threaded and non-threaded sections. Reach is crucial because the plug's air gap must be properly placed in the combustion chamber to produce the correct amount of heat.

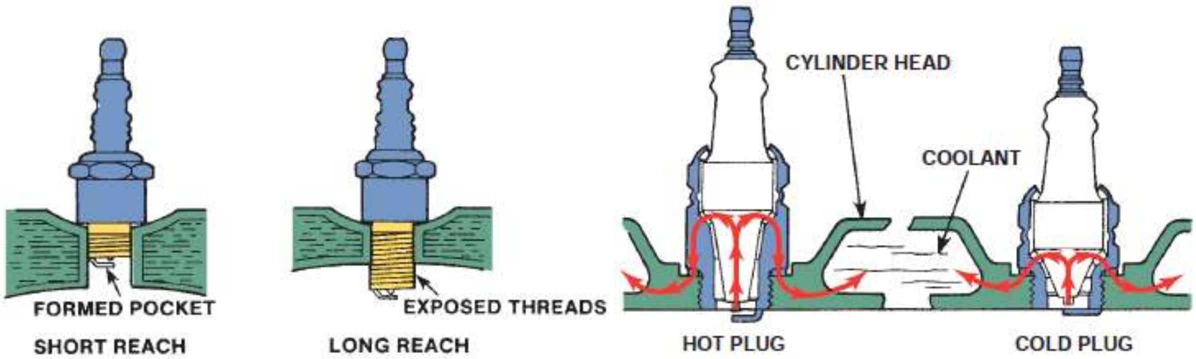


Figure 1.3-11 Spark plug reach: long versus short and heat range: hot versus cold

When a plug's reach is too short, its electrodes are in a pocket and the arc is not able to adequately ignite the 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 and cause pre-ignition. **Pre-ignition** is a term used to describe abnormal combustion, which is caused by something other than the heat of the spark.

Automotive spark plugs are available with a thread diameter of 12 mm, 14 mm, and 18 mm. The 18-mm spark plugs are mostly found on older engines and have a tapered seat that seals, when tightened properly, into a tapered seat in the cylinder head. The 12-mm and 14-mm plugs can have a tapered seat or a flat seat that relies on a thin steel gasket to seal in its bore in the cylinder head. All spark plugs have a hex-shaped outer shell that accommodates a socket wrench for installation and removal.

Electrode Designs - Spark plugs are available with many different shapes and numbers of electrodes. When trying to ascertain the advantages of each design, remember the spark is caused by electrons moving across an air gap. The electrons will always jump in the direction of the least electrical resistance. Therefore, if there are four ground electrodes to choose from, the electrons will jump to the closest. Also, keep in mind that the quality and pressure of the air in the air gap influences the resistance of the air gap. Again, the electrons will jump across the path of least resistance. Therefore, spark plugs with four ground electrodes do not typically supply a spark to all four electrodes **(Fig 1.3-12a)**.

The shape of the ground electrode may also be altered. A flat, conventional electrode tends to crush the spark, and the overall volume of the flame front is smaller. A tapered ground electrode increases flame front expansion and reduces the heat lost to the electrode.

One brand of spark plug has a V-shaped ground electrode **(Fig 1.3-12b)**. This style of electrode does not block the flame front and allows it to travel upward through the V notch into the combustion chamber. These spark plugs may be equipped with three separate points of platinum, one a teach end of the V and the other at the center electrode.

a

b

Figure 1.3-12 a) spark plug with four ground electrodes, **b)**spark plug has a small diameter Iridium center electrode and a grooved ground electrode

There are also different center electrode designs. These variations are based on the diameter and shape of the electrode. A small diameter center electrode **(Fig 1.3-12b)** requires less firing voltage and tends to have a longer service life. Some center electrodes are tapered.

Spark Plug Gaps

The correct spark plug air gap is essential for achieving 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 maintain the spark. A gap that is too narrow requires lower voltages and can lead to rough idle and prematurely burned electrodes, due to higher current flow.

ELECTRONIC IGNITION SYSTEMS

The ignition system in today's vehicles is an integral part of the electronic engine control system. The engine control module (ECM) controls all functions of the ignition system and constantly corrects the spark timing. The desired ignition timing is calculated by the PCM according to inputs from a variety of sensors. These inputs allow the PCM to know the current operating conditions. The PCM matches those conditions to its programming and controls ignition timing accordingly. It is important to remember that there has always been a need for engine speed- and load-based timing adjustments. Electronic systems are very efficient at making these adjustments. Many of the inputs used for ignition system control are also used to control other systems, such as fuel injection. These inputs are available on the CAN buses **(Fig 1.3-13)**.

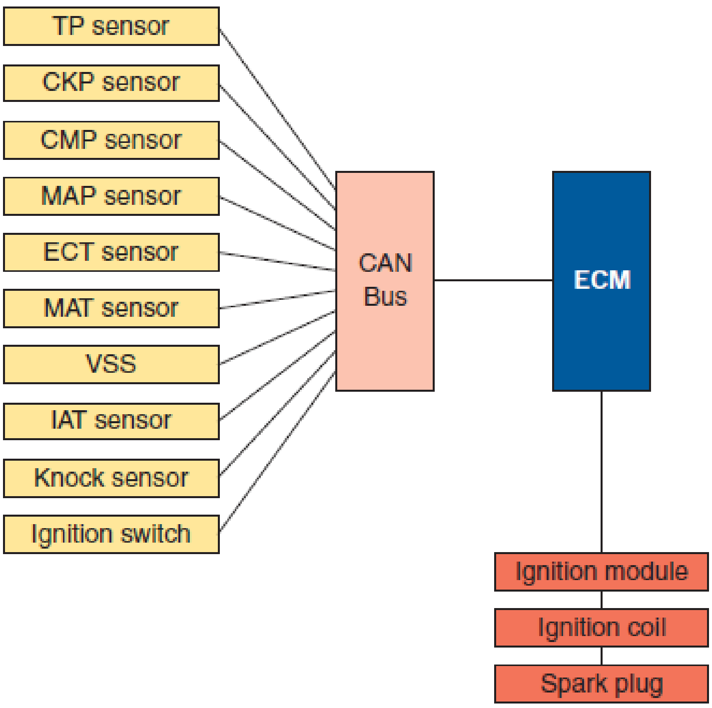


Figure 1.3-13 many of the inputs used for ignitionsystem control are also used to control other systems and are available on the CAN buses.

There are three basic ignition system designs:

1. Distributor-Based **(DI)** systems
2. Distributor-less Ignition Systems **(DLI)**
3. Direct Ignition Systems **(DIS)**

- The latter two designs are designated as electronic ignition (EI) systems by the SAE. DIS is the commonly used design on today's engines.

BASIC CIRCUITRY

All ignition systems consist of two interconnected electrical circuits: a **primary** (low-voltage) **circuit** and a **secondary** (high-voltage) **circuit (Fig 1.3-14)**.

Depending on the exact type of ignition system, componentsin the primary circuit include the following:

- Battery
- Ignition switch
- Ballast resistor or resistance wire (some systems)
- Starting bypass (some systems)
- Ignition coil primary winding
- Triggering device
- Switching device or control module (igniter)the secondary circuit includes these components.
- Ignition coil secondary winding
- Distributor cap and rotor (some systems)
- High-voltage cables (some systems)
- Spark plugs

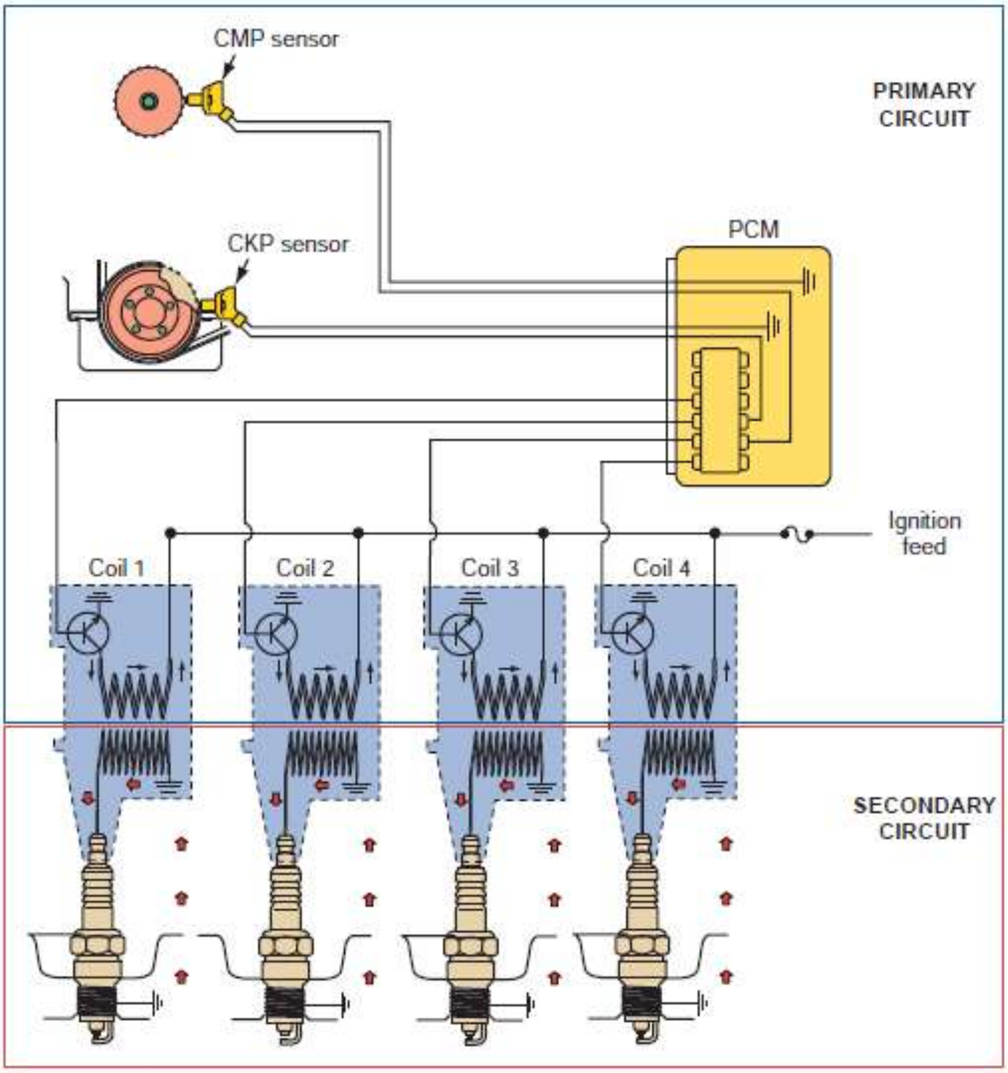


Figure 1.3-14 Ignition systems have a primary (low-voltage) and a secondary (high-voltage) circuit.

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 there it passes through some type of switching device and back to ground. The current flow through the ignition coil's primary winding creates a magnetic field. As the current continues to flow, the magnetic field gets stronger. When the triggering device signals to the switching unit that the piston is approaching TDC on the compression stroke, current flow is stopped. This causes the magnetic field around the primary winding to collapse across the secondary winding. The movement of the magnetic field across the winding induces a high voltage in the secondary winding. The action of the secondary circuit begins at this point.

Some older ignition systems had a **ballast resistor** or resistance wire connected between the ignition switch and the positive terminal of the coil. This resistor limited the voltage and current to the coil. Today, ignition systems do not use a resistor, and voltage to the coil is controlled by the PCM.

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. 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 distributor-less or electronic ignition (EI) systems.

EI SYSTEMS

EI systems have no distributor; spark distribution is controlled by an electronic control unit and/or the vehicle's computer. 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.

The energy produced by the secondary winding is voltage. This voltage is used to establish a complete circuit so current can flow. The excess energy is used to maintain the current flow across the spark plug's gap. Distributor-less ignition systems are capable of producing much higher energy than conventional ignition 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.

TRIGGERING AND SWITCHINGDEVICES

Triggering and switching devices are used to ensure the spark occurs at the correct time. A triggering device is simply a device that monitors the movement of the engine's pistons. A switching device is what controls current flow through the primary winding. When the triggering device sends a signal to the switching device that the piston of a particular cylinder is on the compression stroke, the switching device stops current flow to the primary winding. This interruption of current flow happens when the PCM decides it is best to fire the spark plug.

Electronic switching components are normally located in an ignition control module, which may be part of the vehicle's PCM. On older vehicles, the ignition module may be built into the distributor or mounted in the engine compartment.

The ignition module advances or retards the ignition timing in response to engine conditions. Early systems had little control of timing and used mechanical or vacuum devices to alter timing. Today's computer-controlled systems have full control and can adjust ignition timing in response to the input signals from a variety of sensors and the programs in the computer.

Most electronically controlled systems use an NPN transistor to control the primary ignition circuit, which ultimately controls the firing of the spark plugs. 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 current to the base of the transistor, current flows through the primary winding of the coil. When the current to the base is interrupted, the current to the coil is also interrupted. An example of how this works is shown in **Fig 1.3-15**, which is a simplified diagram of an electronic ignition system.

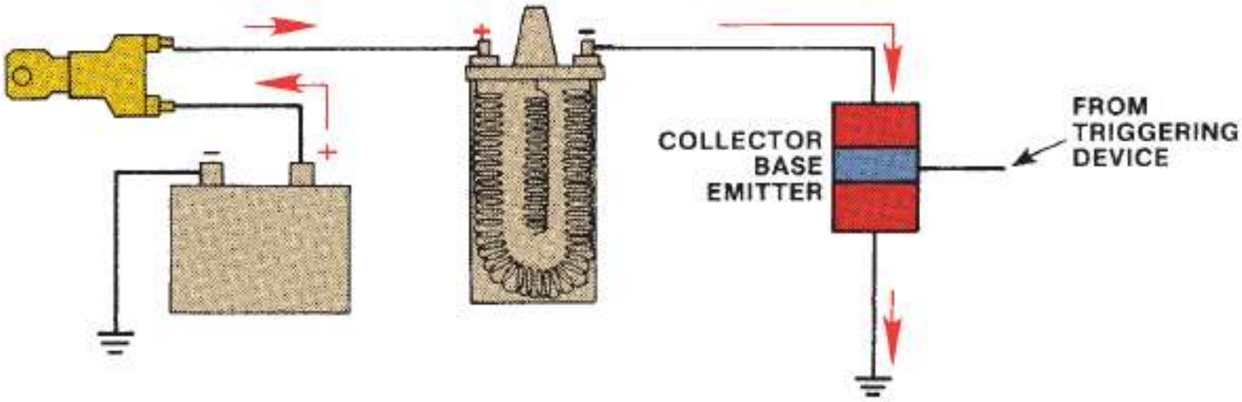


Figure 1.3-15 when the triggering device supplies a small amount of current to thetransistor's base, the primary coil circuit is closed and current flows.

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.

These sensors can be located inside the distributor or mounted on the outside of the engine to monitor crankshaft position (CKP). In many cases, the input from a CKP is supplemented by inputs from a CMP. On nearly all late-model engines, the CKP and CMP are magnetic pulse generators or Hall-effect switches. When the triggering devices are in the distributor, they can be any of the following types of sensors.

1. Magnetic Pulse Generator

Basically, a magnetic pulse generator or inductance sensor consists of two parts: a trigger wheel and a pickup coil. The trigger wheel may also be called a reluctor, pulse ring, armature, or timing core. The pickup coil, which consists of a length of wire wound around 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, or behind the crankshaft vibration damper **(Fig 1.3-16)**.

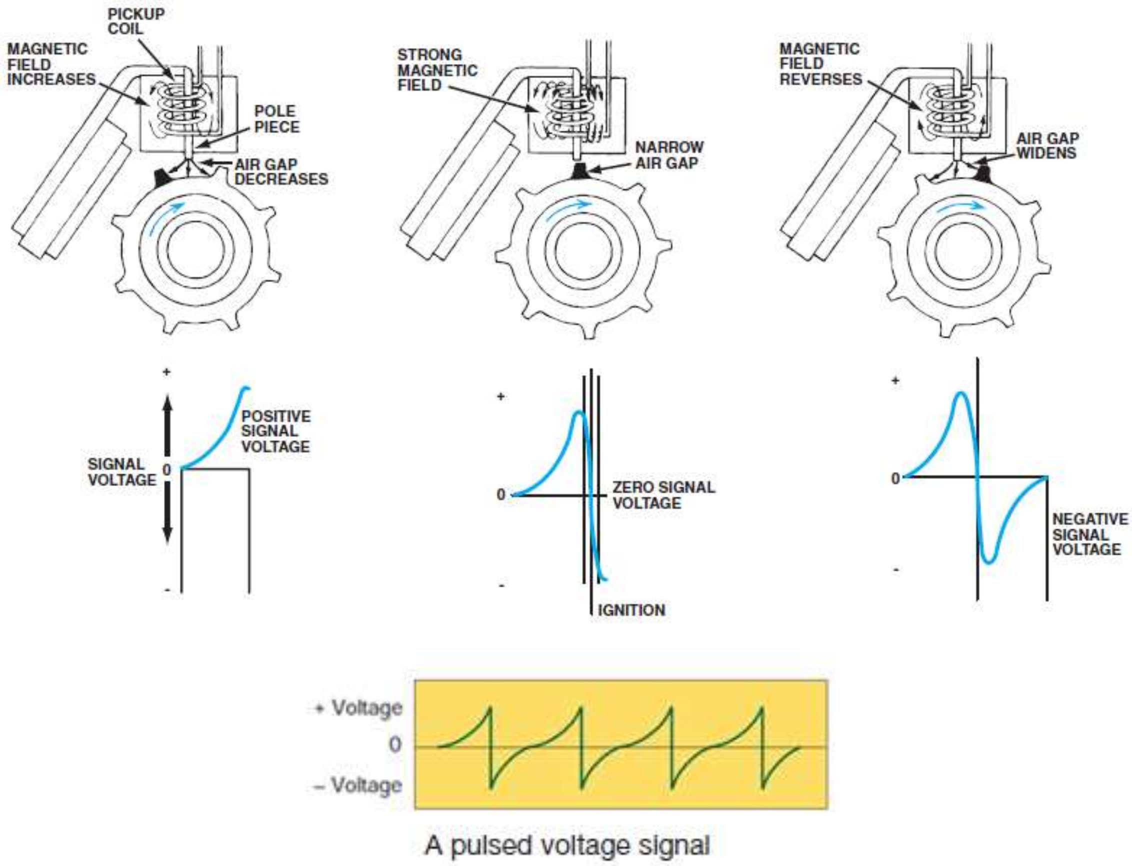


Figure 1.3-16 A strong magnetic field is produced in the pickup coil as the teeth aligns with the core and the magnetic field expands and weakens as the teeth pass the core.

The magnetic pulse or PM generator operates on the principles of electromagnetism. A voltage is induced in a conductor when a magnetic field passes over the conductor or when the conductor moves over a magnetic field. The magnetic field is provided by a magnet in the pickup unit, and the rotating trigger wheel provides the required movement through the magnetic field to induce voltage.

As the trigger wheel rotates past the pickup coil, weak AC signal is induced in the pickup coil. This signal is sent to the ignition module. In early ignition systems, the change in polarity was used as a signal to prepare the ignition coil for another spark plug firing.

When a tooth is aligned to the pickup coil, the magnetic field is not expanding or contracting. There is no change in the magnetic field and at that point zero voltage is induced in the pickup coil. The zero voltage signals from the coil is called the timing or “sync” pulse and is used by the PCM as the basis for timing the events in the ignition system. The timing pulses correspond with the position of each piston within their cylinder.

2. Hall-Effect Sensor

The Hall-effect sensor or switch is the most commonly used engine position (CKP) sensor. A Hall-effect sensor produces an accurate voltage signal throughout the entire speed range of an engine. It also produces a square wave signal that is more compatible with computers. In an ignition system, the shutter blades are mounted on the distributor shaft**(Figure 1.3-17)**, flywheel, crankshaft pulley, or cam gear so the sensor can generate a position signal as the crankshaft rotates. A Hall-effect sensor may be normally on or off depending on the system and its circuitry. When a normally off sensor is used, there is maximum voltage output from the sensor when the magnetic field is blocked by the shutter. The opposite is true for normally on sensors. They have a voltage output when the magnetic field is not blocked.

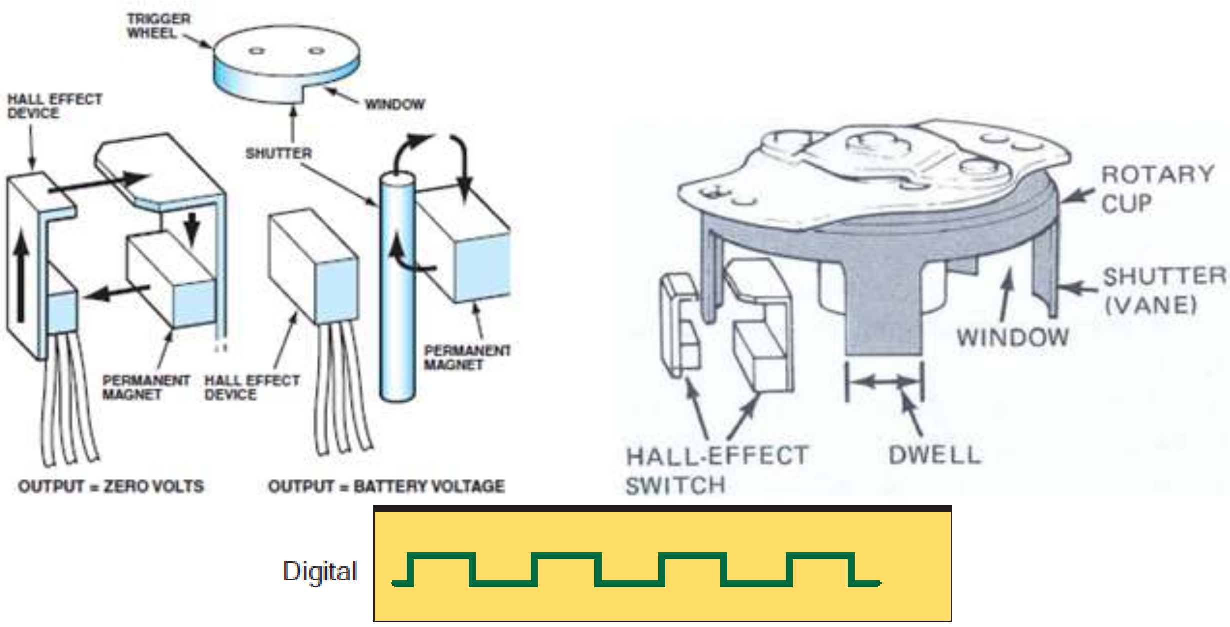


Figure 1.3-17 Operation of a Hall-effect switch

A typical Hall-effect sensor has three wires connected to it. One wire is the reference voltage wire. The PCM supplies a reference voltage of 5 to 12 volts, depending on the system. The second wire delivers the output signal from the sensor to the PCM, and the third wire provides a ground for the sensor.

The signal from a Hall-effect CKP is also used to match fuel injector timing with the engine's firing order on engines equipped with sequential fuel injection. Hall-effect switches are also used as camshaft position (CMP) sensors. When the engine is being started, the PCM receives a signal from the CKP, but the spark plugs will not fire until the PCM receives a reference pulse from the CMP. After the engine starts, the PCM no longer relies on the CMP for ignition sequencing. However, if the CMP is bad, the engine will not restart. If the CKP goes bad, the engine will typically not start or run.

Photoelectric Sensor

Some early distributor ignition systems relied on photoelectric sensors **(Figure 1.3-18)** to monitor engine position. They consisted of an LED, a light-sensitive phototransistor (photo cell), and a slotted disc called an interrupter. As the interrupter rotated between the LED and the photo cell, pulsating voltage was generated in the photo cell. This voltage was passed onto the ignition module and was used as the basis for all ignition timing.

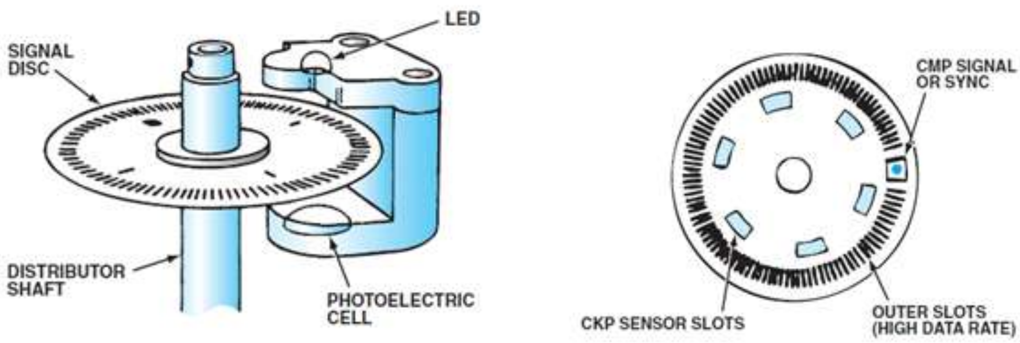


Figure 1.3-19 Optical signal generator works by interrupting a beam of light passing from the LEDs to photodiodes

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 pickup coil detects the passing of the trigger teeth as the distributor shaft rotates. However, unlike a magnetic pulse generator, the pickup coil of a metal detection sensor does not have a permanent magnet. Instead, the pickup 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 1.3-20)**. 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.

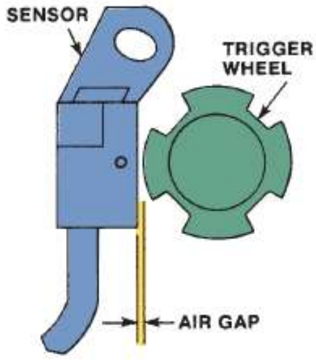


Figure 1.3-20in a metal detecting sensor, the revolving trigger wheel teeth alter the magnetic field produced by the electromagnet in the pickup coil.

Timing Retard and Advance

One of the most important duties of an ignition system is to provide the spark at the correct time. On late-model engines, this is the job of the ignition module.

On earlier ignition systems, this was accomplished at the distributor through mechanical and vacuum-responsive devices.

Mechanical devices used weights and springs attached to the distributor shaft that moved with engine speed to advance timing. When engine speed increased, the weights moved out and moved the mounting plate for the triggering unit. The shifting of the triggering unit caused it to send a signal to the switching unit earlier, causing an advance in timing. When engine speed decreased, the weights were pulled by the springs and the timing retards. These units responded solely to engine speed.

Vacuum Advance Units that changed ignition timing in response to engine load were also fitted to distributors **(Figure 1.3-21)**. A vacuum advance unit, com comprised of a spring-loaded diaphragm, was attached to the triggering device plate. Vacuum was applied to one side of the diaphragm and atmospheric pressure was applied to the other side. Any increase in vacuum allowed atmospheric pressure to move the diaphragm, which caused a movement of the triggering device's mounting plate. The more vacuum that was present on one side, the more the atmospheric pressure could move the diaphragm and advance the timing. A spring was used to return the plate toward its rest position when vacuum decreased. At full throttle, there is no vacuum advance. Maximum vacuum advance is only at cruising speeds with no load.

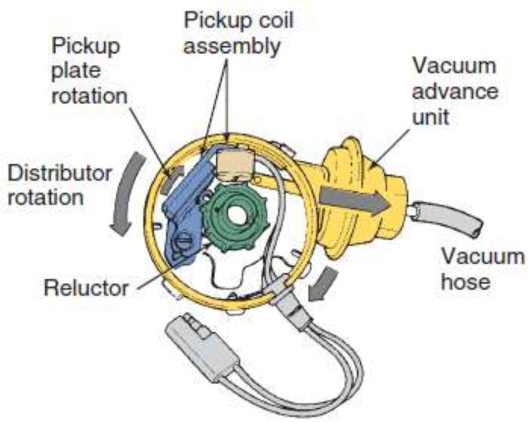


Figure 1.3-21typical vacuum advance unit operation

DISTRIBUTOR IGNITIONSYSTEM OPERATION

The primary circuit of a DI system is controlled by a triggering device and a switching device located inside the distributor or external to it. Although these systems are no longer used by auto makers, there are many of them still on the road and they need service.

Distributor

The reluctor, or trigger wheel, and distributor shaft assembly rotate on bushings in the aluminum distributor housing. A roll pin extends through a retainer and the distributor shaft to hold the shaft in place in the distributor. Another roll pin is used to fasten the drive gear to the lower end of the shaft. This drive gear typically meshes with a drive gear on the engine's camshaft. The gear size is designed to drive the distributor shaft at the same speed as the camshaft, which rotates at one-half the speed of the crankshaft.

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 internal ignition module
- DI systems with external and remote ignition module
- DI systems with the ignition modules mounted on the distributor

Computer-Controlled DI Systems -After the manufacturerseliminated the mechanical and vacuum advance mechanisms on their distributors, the ECM or PCM controlled ignition timing. This allowed for more precise control of ignition timing and provided improved combustion. The PCM adjusted the ignition timing according to engine speed, engine load, coolant temperature, throttle position, and intake manifold pressure. These systems varied with application and used a variety of triggering devices.

ELECTRONIC IGNITIONSYSTEMS

Very few newer engines are equipped with a distributor; rather they have electronic ignitions. In the past, the term *electronic ignition* was designated to those ignition systems that used electronic controls. Today, electronic ignitions are those that do not use a distributor. There are **two types of EI systems** used on today's engines: waste spark **(Figure 27–23)** and coil-over- cylinder **(Figure 27–24)** systems. In both cases, an ignition module, controlled by the PCM, controls the firing order and ignition timing. A crank sensor is used to trigger the ignition system.

Figure 1.3-22A coil pack for a double-ended or waste spark ignition system

Figure 27–24 A coil per cylinder ignition system

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

- Elimination of a rotor and its subsequent resistance.
- No moving parts and therefore requires little maintenance.
- It is possible to control the ignition of individual cylinders to meet specific needs.
- Flexibility in mounting location. This is important because of today's smaller engine compartments.
- 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.

Double-Ended Coil or Waste Spark Systems

Double-ended or waste spark ignition systems use one ignition coil for two spark plugs **(Figure 27–25)**. Both ends of the coil's secondary side are directly connected to a spark plug, which means that two plugs are ignited at the same time; one is fired on the compression stroke of one cylinder and the other is fired on the exhaust stroke of another.

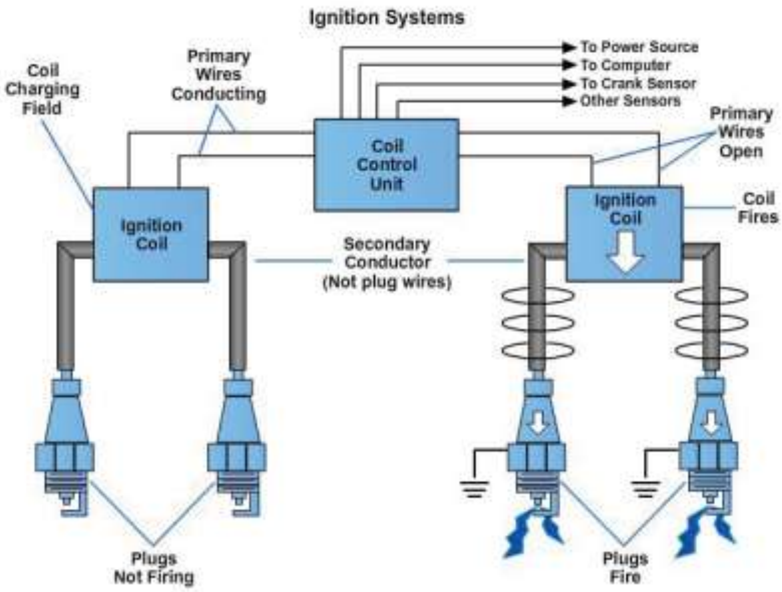


Figure 27–25 An EI system with a double-ended coil.

A four-cylinder engine has two ignition coils, a six cylinder has three, and an eight-cylinder has four.

The computer, ignition module, and various sensors combine to control spark timing. 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 27–26)**. Remember that there is more than one coil in a distributor-less 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.

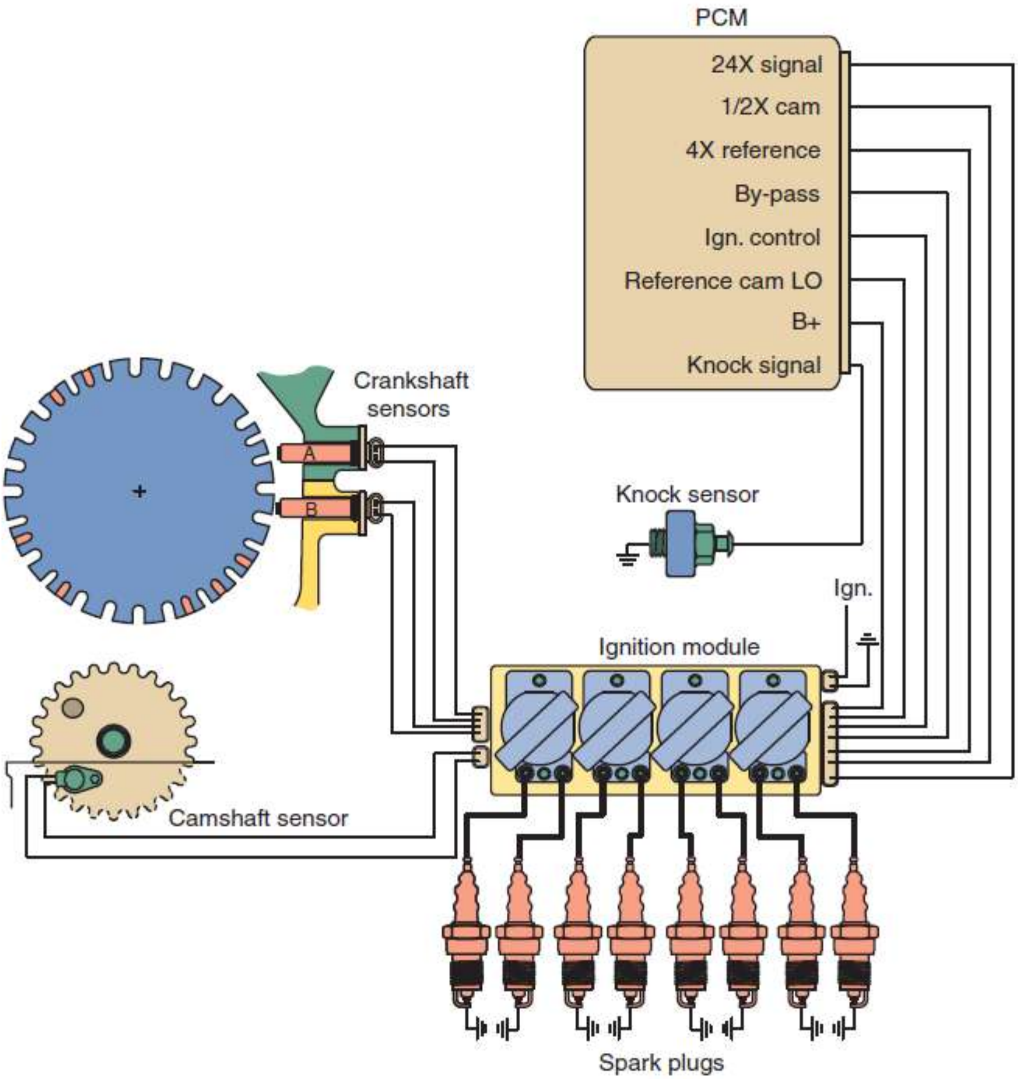


Figure 27–26 An EI system with two crankshaft position sensors and one camshaft position sensor.

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 program med 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 EI system, the ignition coils can be serviced as a complete unit or separately. The coil assembly is typically called a **coil pack** and is comprised of two or more individual coils.

Waste Spark -Double-ended coil systems are based on the **waste spark** method of spark distribution. Both ends of the ignition coil's secondary winding are connected to a spark plug. Therefore, one coil is connected in series with two spark plugs. The two spark plugs belong to cylinders whose pistons rise and fall together. With this arrangement, one cylinder of each pair is on its compression stroke and the other is on its exhaust stroke when the spark plugs are fired. Typically, cylinder pairings are:

- Four-cylinder engines: 1 & 2 and 3 & 4
- V6 engines: 1 & 4, 2 & 5, and 3 & 6
- Inline six cylinders: 1 & 6, 2 & 5, and 4 & 3
- V8 engines: 1 & 4, 3 & 8, 6 & 7, and 2 & 5 or 1 & 6,8 & 5, 4 & 7, and 2 & 3
  - (The pairings on V8s will vary as manufacturers vary how they number the cylinders.)

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 electrode—and the other plug fires just the reverse side to center electrode **(Figure 27–27)**. Both plugs fire simultaneously, completing the series circuit. Each plug always fires the same way on both the exhaust and compression strokes.

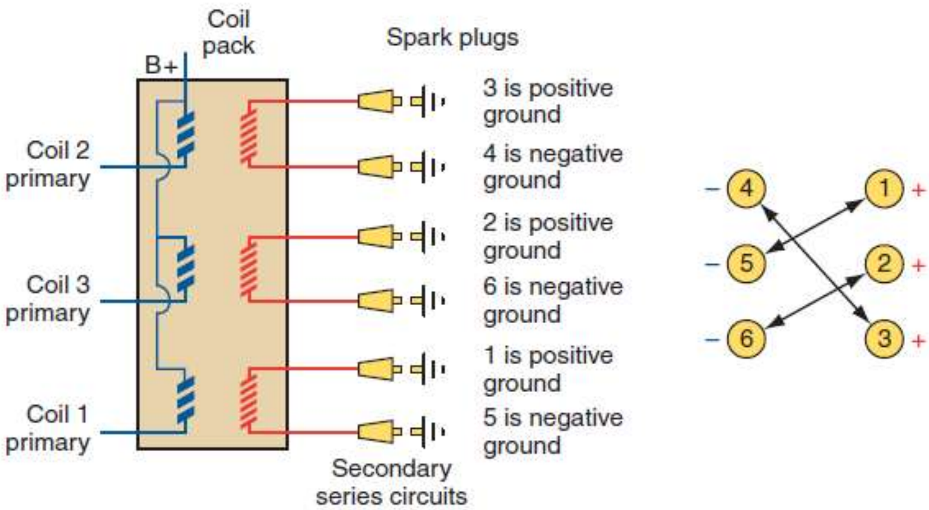


Figure 27–27 Polarity of spark plugs in an EI system

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.

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 27–28)**, one spark plug is connected directly to the ignition coil and the companion spark plug is connected to the coil by a high-tension cable.

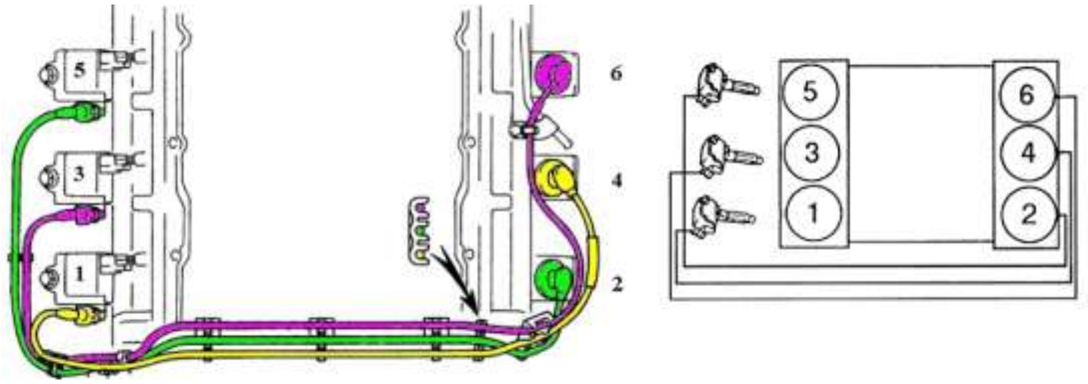


Figure 27–28 A six-cylinder engines with three coils and three spark plug wires

Coil-per-Cylinder Ignition

The operation of a coil-per-cylinder ignition system is basically the same as any other ignition system. By definition, these systems have an individual coil for each spark plug. There are two different designs of coil-per-cylinder systems used today: the **coil-over-plug(COP)** and the separate coil. COP systems rely on a single assembly of an ignition coil and spark plug **(Figure 27–29)**. In these systems, the spark plug is directly attached to the coil and there is no spark plug wire.

Figure 27–29 A coil-on-plug assembly

The separate coil system is often called a **coil-by-plug** or **coil-near-plug** ignition system **(Figure 27–30)**. These systems have individual coils mounted near the plugs and use a short secondary plug wire to connect the coil to the plug. These systems are used when the location of the spark plug does not allow enough room to mount individual coils over the plugs, or when the plugs are too close to the exhaust manifold.

Having one coil for each spark plug allows for more time between each firing, which increases the life of the coil by allowing it to cool. In addition, it also allows for more saturation time, which increases the coil's voltage output at high engine speeds. The increased output makes the coils more effective with lean fuel mixtures, which require higher firing voltages.

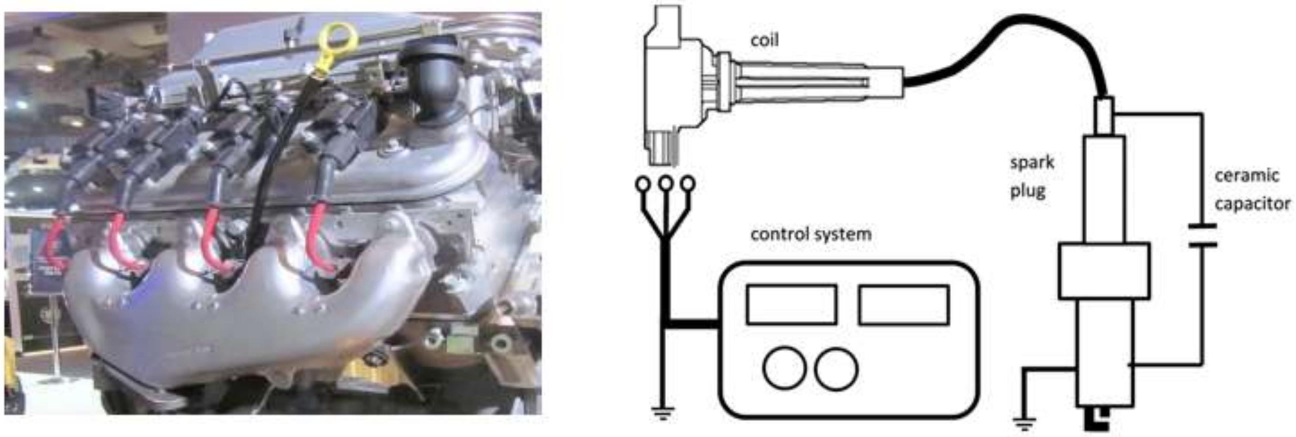


Figure 27–30 A coil-near-plug system

Another advantage of using the coil-per-cylinder system is that the ignition timing at each cylinder canbe individually changed for maximum performance and to respond to knock sensor signals. Other advantages of a coil-per-cylinder system are that all of the engine's spark plugs fire in the same direction and coil failure will affect only one cylinder.

In a typical coil-per-cylinder system, a crankshaft position sensor provides a basic timing signal. This signal is sent to the PCM. The PCM is programmed with the firing order for the engine and determines which ignition coil should be turned on or off. Some engines require an additional timing signal from the camshaft position sensor. On some systems, there is also a coil capacitor for each bank of coils for radio noise suppression.

Coil-over-Plug (COP) Ignition The true difference between COP and other ignition systems is that each coil is mounted directly atop the spark plug **(Figure27–31)**, so the voltage from the coil goes directly to the plug's electrodes without passing through a plug wire. This means there are no secondary wires to come loose, burn, leak current, break down, or replace. Eliminating plug wires also reduces radio frequency interference (RFI) and electromagnetic interference (EMI) that can interfere with computer systems. However, the absence of plug wires also means that the coils need to be removed and reconnected with adapters or plug wires to test for spark, connect a pickup for an ignition scope, or perform a manual cylinder power balance test.

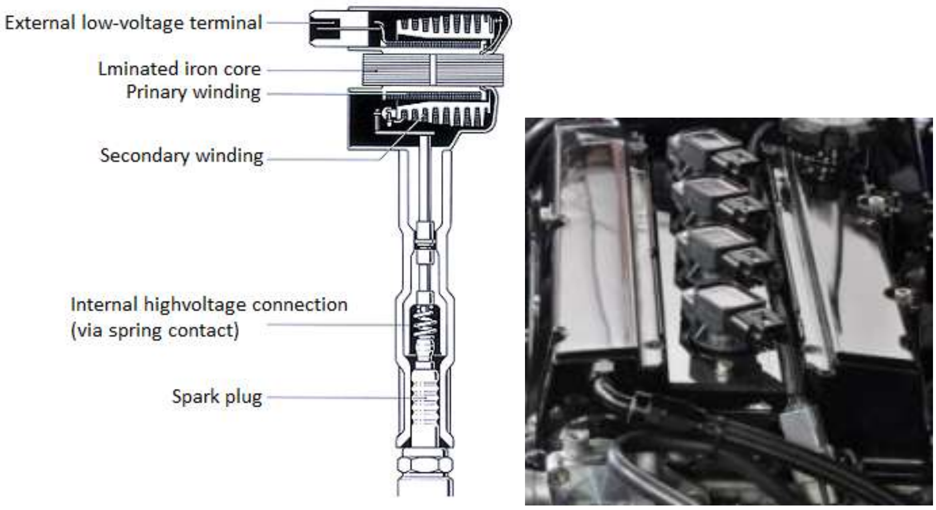


Figure 27–31 In a COP system, the coil is mounted directly above the spark plug

Twin Spark Plug Systems

Most engines have one spark plug per cylinder, but some have two. One spark plug is normally located on the intake side of the combustion chamber and the other is at the exhaust side. When ignition takes place in two locations within the combustion chamber, more efficient combustion and cleaner emissions are possible. Two coil packs are used, one for the intake side and the other for the exhaust side. These systems are called **dual** or **twin plug** systems **(Figure 27–32)**.

Some engines fire only one plug per cylinder during starting. The additional plug fires once the engine is running. During dual plug operation, the two coil packs are synchronized so the two plugs of each cylinder fire at the same time. Therefore, in a waste spark system, four spark plugs are fired at a time: two during the compression stroke of a cylinder and two during the exhaust stroke of another cylinder.

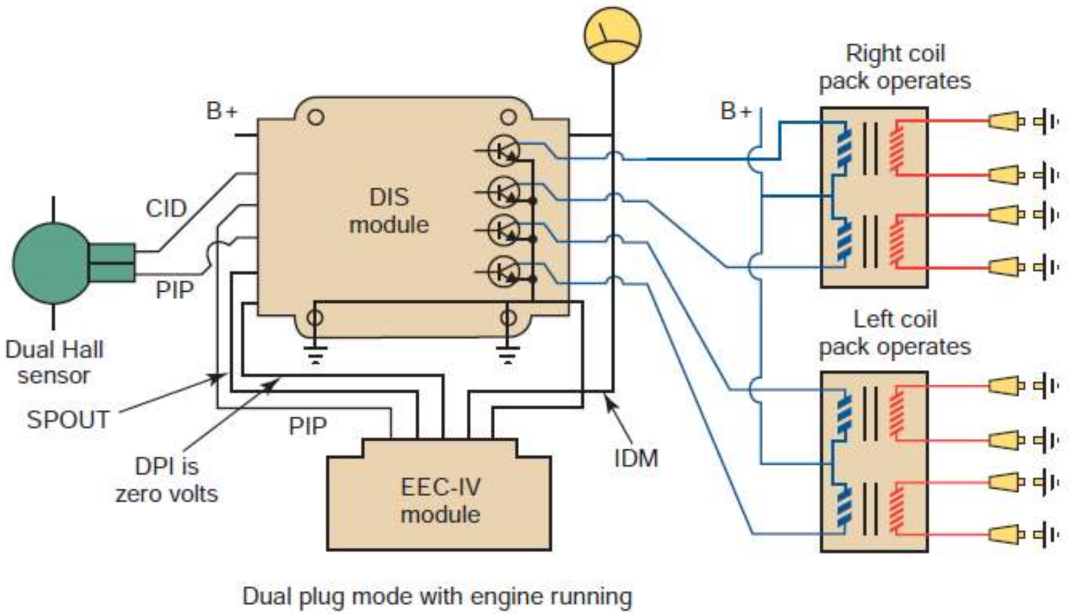


Figure 27–32 A dual plug system for a four-cylinder engine

EI SYSTEM OPERATION

From a general operating standpoint, most electronic ignition systems are similar. One difference in designs the number of ignition coils. **COP** systems have the same number of coils as the engine has cylinders. **Waste spark** systems have half the numbers of coils as there are cylinders. Perhaps the biggest difference in system operation is based on the use of **CKP** and **CMP** sensors.

All systems have a CKP to monitor crankshaft position and engine speed. Some also monitor the relative position of each cylinder. Not all systems have a CMP; some have more than one. The signals from a CMP sensor are used for cylinder identification and for verifying the correlation between the position of the crankshaft and the camshafts. The design of the trigger wheels or rotors for these two sensors also varies. The design is primarily based on whether the sensor is a magnetic pulse (variable reluctance) or Hall-effect sensor. Both can be used for either sensor. Inputs from these sensors are critical to the operation of the fuel injection and ignition systems.

The layout and operation of these sensors are designed to provide fast engine starts and synchronization of the fuel injection and ignition systems with the position of the engine's individual pistons.

Misfire Detection

A high data rate CKP sensor is used to detect engine misfires, and the CMP is used to identify which cylinders misfiring. Misfires are detected by variations in crankshaft rotational speed for each cylinder. An interesting feature of most misfire monitors is the ability of the PCM to distinguish an actual misfire from other things that may cause the engine's speed to fluctuate. Driving on a rough road can cause the vehicle's wheels to change rotational speed; this in turn will affect the rotational speed of the crankshaft. To determine whether the engine has misfired or the vehicle is merely driving on a poor surface, the PCM receives wheel speed data from the antilock brake system. A rough road will cause variances in wheel speed and the PCM looks at that data before concluding a misfire occurred.

Basic Timing

The PCM totally controls ignition timing and ignition timing is not adjustable. When the engine is cranked for starting, the PCM sets the timing at a fixed value. This value is used until the engine is running at a predetermined speed. Once that speed is met, the PCM looks at several inputs, including engine speed, load, throttle position, and engine coolant temperature, and makes adjustments accordingly. The PCM continues to rely on those inputs and its programmed strategy throughout operation. All PCMs have limits as to how far the timing can be retarded and advanced.

Timing Corrections -The PCM adjusts ignition timing according to its programming and sensor inputs. There are times when the timing is adjusted or corrected to compensate for slight changes in the operating conditions or abnormal occurrences.

- **Temperature:** Ignition timing is advanced when the coolant temperature is low. When the temperature is very high, the timing is retarded.
- **Engine Knock:** When a knock is detected, the PCM retards the timing in fixed steps until the knock disappears. When the knocking stops, the PCM stops retarding the timing and begins to advance the timing in fixed steps unless the knocking reoccurs.
- **Stabilizing Idle:** When the engine idle speed moves away from the desired idle speed, the PCM will adjust the timing to stabilize the engine speed. It is important to know that ignition timing changes are made only to correct minor idle problems. Ifthe engine's speed is above the desired speed, the timing is retarded and when it is too low, the timing is advanced.
- **EGR Operation:** When the EGR valve opens, the timing is advanced. The amount of advance depends on intake air volume and engine speed.
- **Transition Correction:** When the vehicle is accelerated immediately after deceleration, the timing is temporarily advanced or retarded to smooth the transition.
- **Torque Control:** To provide smooth shifting of an automatic transmission, the PCM will temporarily retard the ignition timing to reduce the engine's torque when the transmission is beginning to change gears.
- **Traction Control Correction:** When excessive wheel slippage occurs, the PCM will retard the timing to reduce the torque output from the engine. Once the slippage has been corrected, timing returns to normal.

Ignition System Troubleshooting Chart

Condition	Possible Cause	Check or Correction
1. Engine cranks normally but fails to start	a. No voltage to ignition system	Check battery, ignition switch, wiring
	b. Ignition-module lead open, grounded, Repair as needed loose, or corroded	Repair as needed
	c. Primary connections not tight	Clean, seat connectors
	d. Ignition coil open or shorted	Test coil, replace if defective
	e. Defective reluctor or pickup coil	Replace
	f. Ignition-module defective	Replace
	g. Defective cap or rotor	Replace
	h. Fuel system faulty	Check system
	i. Engine faulty	Check system
2. Engine backfires but fails to start	a. Incorrect timing	Set timing
	b. Moisture in cap	Dry cap
	c. Voltage leak across cap	Replace cap
	d. Secondary cables not connected in firing order	Reconnect correctly
	e. Cross-firing between secondary cables	Replace defective cables
3. Engine runs but misses	a. Spark plugs fouled or faulty	Clean, re-gap, or replace
	b. Cap or rotor faulty	Replace
	c. Secondary cables defective	Replace
	d. Defective coil	Replace
	e. Bad connections	Clean, tighten
	f. High-voltage leak	Check cap, rotor, secondary cables
	g. Advance mechanisms defective	Check, repair or replace
	h. Defective fuel system	Check system
	i. Mechanical problems in engine	Repair
4. Engine runs but backfires.	a. Incorrect timing	Set timing
	b. Ignition cross-firing	Check cables, cap, rotor for leakage paths
	c. Faulty anti-backfire valve	Replace
	d. Spark plugs of wrong heat range	Install correct plugs
	e. Defective air-injection system	Check system
	f. Engine overheating	Check system
	g. Fuel system not supplying proper air-fuel ratio	Check system
	h. Engine defects such as carbon deposits on valves	Check system
5. Engine overheats	a. Late timing	Set timing
	b. Lack of coolant or other trouble in cooling system	Check system
	c. Late valve timing or other engine conditions	Check system

6. Engine lacks power	a. Incorrect timing b. Troubles listed in Item 3 c. Exhaust system restricted d. Thick engine oil e. Wrong fuel f. Excessive rolling resistance g. Engine overheats	Set timing Clear Change, using correct viscosity oil Use correct fuel Check tires, brakes, alignment See item 5
7. Engine pings (spark knock)	a. Incorrect timing b. Wrong fuel c. Spark plugs of wrong heat range d. Advance mechanism defective e. Carbon buildup in cylinders	Set timing Use correct fuel Install correct plugs Repair or replace Service engine
8. Spark-plugs defective	a. Idle solenoid out of adjustment or fuel *shut-off* faulty b. Hot spots in combustion chambers c. Engine overheating d. Advanced timing	Adjust or replace Service engine See item 5 Set timing

Self-Check -1	Written Test

Directions: Answer all the questions listed below. Use the Answer sheet provided in the next page:

1. True or False? A faulty voltage regulator can cause a no-charge or overcharge condition.
2. What is the purpose of a rectifier assembly?
3. A rotating magnetic field inside a set of conducting wires is a simple description of a ______.
   a) DC generator
   b) AC generator
   c) voltage regulator
   d) none of the above
4. What part of the AC generator is the rotating magnetic field?
   a) stator
   b) rotor
   c) brushes
   d) poles
5. Slip rings and brushes.
   a) mount on the rotor shaft
   b) conduct current to the rotor field coils
   c) are insulated from each other and the rotor shaft
   d) all of the above
6. The alternating current produced by the AC generator is rectified into DC, or direct current, through the use of.
   a) transistors
   b) electromagnetic relays
   c) diodes
   d) capacitors
7. The purpose of the regulator in the charging system of a vehicle is to control:
   a) engine speed
   b) fuel consumption
   c) generator input
   d) generator output
8. ‘Star (wye)’ and ‘Delta’ are types of:
   a) rotor winding
   b) stator winding
   c) field winding
   d) regulatorwinding
9. *True or False?* The strength of the magnetic polesin an electromagnet decreases with an increase in the number of turns of wire and the current flowing through them.
10. The device that prevents the engine from turningthe armature of the starter motor is the;
    a) overrunning clutch
    b) pinion gear
    c) flywheel
    d) pole shoe

11. The part of the armature that the brushes ride onis called the ____________.
12. To start the engine, the starting motor rotates thecrankshaft about;
    a) 3000rpm
    b) 45,000 rpm
    c) 50 rpm
    d) 200rpm
13. All of these are part of a starter motor*except*:
    a) An armature
    b) A commutator
    c) Field coils
    d) A regulator
14. The ignition switch will *not* remain in whichof the following positions?
    a) ACCESSORIES
    b) OFF
    c) ON (RUN)
    d) START
15. A solenoid uses two coils. Their windingsare called:
    a) Push-in and pull-out
    b) Pull-in and push-out
    c) Push-in and hold-out
    d) Pull-in and hold-in
16. Name the engine operating conditions that most affect ignition timing requirements.
17. The purpose of the pull-in winding in the operatingsolenoid of a pre-engaged starter motor is to:
    a) hold the pinion in mesh
    b) pull the pinion out of mesh
    c) hold the pinion out of mesh
    d) pull the pinion into mesh
18. What happens when the low-voltage currentflow in the coil primary winding is interrupted bythe switching device?
    a) The magnetic field collapses.
    b) A high-voltage is induced in the coil secondarywinding.
    c) Both a and b.
    d) Neither a nor b.
19. *True or False?* A spark plug with four ground electrodeswill provide four separate sparks when fired.
20. Which of the following is a function of all ignitionsystems?
    a) to generate sufficient voltage to force a sparkacross the spark plug gap
    b) to time the arrival of the spark to coincide withthe movement of the engine's pistons
    c) to vary the spark arrival time based on varyingoperating conditions
    d) all of the above
21. Reach, heat range, and air gap are all characteristicsthat affect the performance of which ignitionsystem component?
    a) ignition coils
    b) ignition cables
    c) spark plugs
    d) breaker points
22. The voltage required to ignite the air-fuelmixture 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

23. 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 secondarycircuit
    d) The insulated circuit and the ground circuit
24. Which of the following components is part ofboth the primary and the secondarycircuits?
    a) Ignition switch
    b) Distributor rotor
    c) Switching device
    d) Coil
25. The contact-point distributor has two major jobs;
    a) to advance and retard the spark
    b) to distribute the high-voltage surges and switch thecurrent to the coil on and off
    c) to distribute the battery voltage and switch the currentto the spark plugs on and off
    d) to provide centrifugal advance and vacuumadvance
26. Technician A says the spark occurs when the contactpoints open. Technician B says the spark occurs when thecoil magnetic field collapses. Who is right?
    a) A only
    b) B only
    c) both A and B
    d) neither A nor B
27. The device that provides spark advance by pushing thebreaker cam ahead as engine speed increases is the;
    a) vacuum-advance mechanism
    b) throttle body
    c) primaryresistance
    d) centrifugal-advancemechanism
28. In the electronic ignition system, the primary circuit isopened and closed by;
    a) a solenoid
    b) contact points
    c) a mechanical switch
    d) an electronic switch
29. Technician A says a Hall-effect switch uses thepresence or absence of a magnetic field to switch asupplied voltage on and off. Technician B says theHall voltage switches on when a steel blade enters theair gap of a Hall-effect switch. Who is right?
    a) A only
    b) B only
    c) both A and B
    d) neither A nor B
30. The ignition component that steps up voltage is the:
    a) capacitor
    b) condenser
    c) coil
    d) king lead

Note: **Satisfactory rating - 7 points** **Unsatisfactory - below 7 points**

Answer Sheet

Score = ____________
Rating: _____________

Name: ___________________________ Date: ________________

Short Answer Questions

Answer

1. true
2. to convert ac to dc
3. b
4. b
5. d
6. c
7. c
8. b
9. false
10. a
11. Commutator
12. d
13. d
14. d
15. d
16. Idle and high speed
17. d
18. c
19. false
20. d
21. c
22. d
23. c
24. d
25. b
26. c
27. d
28. d
29. b
30. c

Information Sheet-2	Select and prepare appropriate tools

Self-Check -2	Written Test

Directions: Answer all the questions listed below. Use the Answer sheet provided in the next page:

Note: **Satisfactory rating - 3 points** **Unsatisfactory - below 3 points**

Answer Sheet

Score = ____________

Rating: _____________

Name: _________________________ Date: _______________

Short Answer Questions

Information Sheet-N	CONTENT-N

Self-Check -N	Written Test

Directions: Answer all the questions listed below. Use the Answer sheet provided in the next page:

Note: **Satisfactory rating - 5 points** **Unsatisfactory - below 5 points**

Answer Sheet

Score = ___________

Rating: ____________

Name: _________________________ Date: _______________

Short Answer Questions

Operation Sheet 1	CONTENT-

Methodof---------------:

Step 1-

Step 2-

Step 3-

Step N

.

Operation Sheet 2	CONTENT-

Procedures for-----------------

Step 1-

Step 2-

Step 3-

Step N

Operation Sheet-N	CONTENT-N

Techniques for---------------------:

Step 1-

Step 2-

Step 3-

Step N

.

LAP Test	Practical Demonstration

Name: ______________________________ Date: ________________

Time started: ________________________ Time finished: ________________

Instructions: Given necessary templates, tools and materials you are required to perform the following tasks within --- hour.

Task 1.

Task 2.

Task N.

List of Reference Materials

1- BOOKS

2- WEB ADDRESSES (PUTTING LINKS)