MODULE CONTENT

| Unit of Competency | **DIAGNOSE AND REPAIR CHARGING SYSTEM** |
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| Module Title | **DIAGNOSING AND REPAIRING CHARGING SYSTEM** |
| Module Descriptor | This unit covers the knowledge, skills and attitudes required to diagnose and repair charging system and its component |
| Nominal Duration | **hours** |
| Summary of the Learning Outcomes: | |
| Upon completion of this module the student must be able to: | |
| LO1. Prepare to diagnose and repair charging system | |
| LO2. Diagnose charging system | |
| LO3. Repair charging system | |
| LO4. Complete work processes | |

**LEARNING EXPERIENCES**

**LEARNING OUTCOMES NO. 1**

**PREPARE TO DIAGNOSE AND REPAIR CHARGING SYSTEM**

| **Learning Activities** | **Special Instructions** |
| --- | --- |
| Read Information Sheet 3.1-1 Prepare to diagnose and repair charging system | If you have some problem with the content of the information sheet don’t hesitate to approach your Trainer.  If you feel that you are now knowledgeable on the content of the information sheet, you can now answer the self-check provided in the module. |
| Answer Self-Check 3.1-1 on Prepare to diagnose and repair charging system | Try to answer the Self-check without looking at the Answer Key  Compare your answer to Answer Key 3.1-1 |
| Observe Trainer’s demonstration on Task Sheet 3.1-1 on Prepare to diagnose and repair charging system | Listen carefully and attentively so that you may be able to perform a task correctly  Ask questions if are in doubt for clarification |
| Perform the Task Sheet 3.1-1 on Prepare to diagnose and repair charging system | Remember the step-by-step procedure of the Prepare to diagnose and repair charging system |
| Evaluate the performance using the Performance Criteria Checklist 3.1-1 | Repeat the task in case fail to meet the criteria |

**INFORMATION SHEET 1.1-1**

**PREPARE TO DIAGNOSE AND REPAIR CHARGING SYSTEM**

**Learning Objectives:**

After reading this **Information Sheet**, you must be able to:

1. Inspection of alternator components operation
2. Repair and replacement of alternator
3. Inspection and repair of charging system circuit

**CHARGING SYSTEM**

The primary purpose of a charging system is to charge the battery. After the battery has supplied the high current needed to start the engine, the battery, even a good battery, has a low charge. The charging system recharges the battery by supplying a constant and relatively low charge to the battery. Charging systems work on the principles of magnetism to change mechanical energy into electrical energy. This is done by inducing voltage.

Voltage is induced in a wire when it moves through a magnetic field. The wire or conductor becomes a source of electricity and has a polarity or distinct positive and negative ends. However, this polarity can be switched depending on the relative direction of movement between the wire and magnetic field. This is why an AC generator produces alternating current **(Figure 19-1)**.

**Figure 19-1** An AC generator.

**ALTERNATING CURRENT CHARGING SYSTEMS**

During cranking, the battery supplies all of vehicle’s electrical power. However, once the engine is running, the charging system is responsible for producing enough energy to meet the demands of all of the loads in the electrical system, while also recharging the battery. With all of the electrical and electronic devices found on today’s vehicles, the charging system has difficult job.

Several decades ago the charging system depended on a DC generator. The DC generator provided direct current (DC) and was similar to an electric motor in construction. The biggest difference between a generator and a motor is the wiring to the armature. In a motor, the armature receives current form the battery. This creates the magnetic field that opposes the magnetic fields in the motor’s coils, which causes the armature to rotate. The armature in a DC generator is driven by the engine. It is not magnetized and the windings simply rotate through the stationary magnetic field of the field windings, inducing a voltage in the conductors inside the armature. A motor can become a generator by allowing current to flow from the armature instead of to it. In a DC generator, the placement of the brushes on the commutator changes the induced AC voltage to a DC voltage output.

DC generators had a very limited current output, especially at low speeds. They could not keep up with demands of the modern automobile and were replaced by AC generators. AC generators are capable of providing high current output even at low engine speeds.

| **S H O P T A L K**  With the implementation of OBD II, new terminology  was given to many parts of an automobile. Prior  to that law, an AC generator was called an alternator.  In fact, in many cases and by many manufacturer  an AC generator is still referred to as an  alternator. To avoid confusion, just remember that  an alternator is na AC generator and vice versa. |
| --- |

AC generators **(Figure 19-2)** use a design that is basically the reverse of a DC generator. In an AC generator **(Figure 19-3)**, a spinning magnetic field (called the rotor) rotates inside as assembly of stationary conductors (called the stator). As the spinning north and south poles of the magnetic field pass the conductors, they induce a voltage that first flows in one direction and then in the opposite direction (AC voltage). Because automobiles use DC voltage, the AC must be changed or rectified into DC. This is done through an arrangement of diodes that are placed between the output of the windings and the output of the AC generator.

**Figure 19-2** An exploded view of an AC generator.

**Figure 19-3** A simplified AC generator.

**AC Generator Construction**

**Rotor** The rotor assembly consists of a drive shaft, coil, and two pole pieces **(Figure 19-4)**. A pulley mounted on one end of the shaft allows the rotor to be spun by a belt driven by the crankshaft pulley.

**Figure 19-4** The rotor is made up of a coil, pole pieces, and a shaft.

The **rotor** is a rotating magnetic field inside the alternator. The coil is simply a long length of insulated wire wrapped around an iron core. The core is located between the two sets of **poles pieces**. A magnetic field is formed by a small amount (4.0 to 6.5 amperes) of current passing through the coil winding. As current flows through the coil, the core is magnetized and the pole pieces assume the magnetic polarity 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 and seven south, with the magnetic field between the pole pieces moving from N poles to the adjacent S poles **(Figure 19-5)**.

**Figure 19-5** The magnetic field moves from the N poles, or fingers, to the S poles.

**Slip Rings and Brushes** Current to create the magnetic field is supplied to the coil from one or two sources, the battery or the AC generators itself. In either case, the current is passed through the AC generator’s voltage regulator before it is applied to the coil. The voltage 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 voltage output. Decreasing the field voltage to the coil has the opposite effect. Output voltage decreases.

**Slip rings** and brushes conduct current to the spinning motor. Most AC generators have two slip rings mounted directly on the rotor shaft. They are insulated from the shaft and each other. Each end of the **field coil** connects to one of the slip rings. A carbon brush located on each slip rings carries the current to and from the field coil. Current is transmitted from the field terminal of the voltage regulator through the first brush and slip ring to the field coil. Current passes through the field coil and the second slip ring and brush before returning to ground **(Figure 19-6)**.

**Figure 19-6** Current is carried by the brushes to the rotor windings via the slip rings.

**Stator** The **stator** is the stationary member of the alternator. It is made up of a number of conductors, or wires, into which the voltage is induced by the rotating magnetic field. Most AC generators use three windings to generate the required amperage output. They can be arranged in either a **delta** configuration or a **wye** configuration **(Figure 19-7)**. The delta winding **(Figure 19-8)** received its name because its shape resembles the Greek letter delta, ∆. The wye winding resembles the letter Y. Alternators use one or the other. Usually, a wye winding is used in applications in which high charging voltage at low engine speeds is required. AC generators with delta windings are capable of putting out higher amperages at high speeds but low engine speed output is poor.

**Figure 19-7** A wye-connected stator winding.

**Figure 19-8** A delta-connected stator winding.

The rotor rotates inside the stator. A small air gap between the two allows the rotor to turn without making contact with the stator. The magnetic field of the rotor is able to energize all three of the stator windings at the same time. Therefore, the generation of AC can be quite high if needed.

Alternating current produces a positive pulse and the na negative pulse. The resultant waveform is known as a sine wave. This **sine wave** can be seen on an oscilloscope. The complete waveform starts at zero, goes positive, then drops back to zero before turning negative. The angle and polarity of the field coil fingers are what cause this sine wave in the stator. When the north pole magnetic field cuts across the stator wire, it generates a positive voltage within the wire. When the south polarity magnetic field cuts across the stator wire, a negative voltage is induced in the wire. A single loop of wire energized by a single north then a south results in a single-phase voltage. Remember that there are three overlapping stator windings. This produces three overlapping sine waves **(Figure 19-9)**. This voltage, since it was produced by three winding, is called **three-phase voltage**.

**Figure 19-9** The voltage produced in each stator winding is added together to create a three-phase voltage.

**End Frame Assembly** The end frame assembly, or housing, is made of two pieces of cast aluminum. It contains the bearings for the end of the rotor shaft where the drive pulley is mounted. Each end frame also has built-in ducts so the air from the rotor shaft fan can pass through the AC generator. Normally, a heat sink containing three positive rectifier diodes is attached to the rear end frame. Heat can pass easily from these diodes to the moving air **(Figure 19-10)**. Three negative rectifier diodes are contained in the end frame itself. Because the end frames are bolted together and then bolted directly to the engine, the end frame assembly is part of the electrical ground path. This means that anything connected to the housing that is not insulated from the housing is grounded.

**Figure 19-10** A bridge rectifier.

**Cooling Fans** Behind the drive pulley on most AC generators is a cooling fan that rotates with the rotor. This cooling fan draws air into the housing through the openings at the rear of the housing. The air leaves through openings behind the cooling fan **(Figure 19-11)**. The moving air pulls heat from the diodes and their heat decreases.

Cooling the diodes is important for the efficiency and durability of an AC generator. Several different generator designs have been introduced recently that increase the cooling efficiency of a generator. One of these is the AD-series generator from General Motors. The “A” stands for air-cooled and the “D” means dual fans. This series is lighter than most other generators but capable of very high outputs. This type generator does not have an external fan; instead, it has two internal fans.

**Figure 19-11** The cooling fan draws air in from the rear of the generator to keep the diode cool.

**Liquid Cooled Generators** Another recent design uses liquid cooling **(Figure 19-12)**. Using water or coolant to cool a generator is a very efficient way to keep diodes temperatures down. But the real reason for eliminating the fan and using liquid to cool the generator is to reduce noise. The rotating fan is a source of underhood noise that some automobile manufacturers want to eliminate. These new generators have water jackets cast into the housing . Hoses connect the housing to the engine’s cooling system. Not only do these generators make less noise, they have higher power output and should last longer in the high temperature environment of the engine compartment.

**Figure 19-12** A water-cooled AC generator.

**AC GENERATOR OPERATION**

As mentioned earlier, AC generators produce alternating current that must be converted, or rectified, to DC. This is accomplished by passing the AC through diodes.

**DC Rectification**

**Figure 19-13** shows that when AC passes through a diode, the negative pulses are blocked off to produces the scope pattern shown. If the diode is reversed, it blocks off current during the positive pulse and allows the negative pulse to flow **(Figure 19-14)**. Because only have of the AC current pulse (either the positive of the negative) is able to pass, this is called **half-wave rectification**.

**Figure 19-13** Half-wave rectification, diode positively biased.

**Figure 19-14** Half-wave rectification, diode negatively biased.

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

Full-wave rectification for stator winding requires another circuit with similar characteristics. **Figure 19-15** shows a wye stator with two diodes attached to each winding. One diodes is insulated, or positive, and the other is grounded, or negative. The center of the Y contains a common point for all windings. It can have a connection attached to it. It is called the stator neutral junctions. At any time during the rotor movement, two windings are in series and the third coil is neutral and inactive. As the rotor revolves, it energizes the different sets of windings in different directions. However, the uniform result is that current in any direction through two windings in series produces the required DC for the battery.

**Figure 19-15** A wye stator wired to six diodes.

The diode action does not change when the stator and diodes are wired into a delta pattern. **Figure 19-16** shows the major difference. Instead of having two windings in series, the windings are in parallel. Thus, more currents is available from the delta-wound AC generator because the parallel paths allow more current to flow through the diodes. Nevertheless, the action of the diodes remains the same.

**Figure 19-16** A delta stator wired to six diodes.

Many Ac generators have an additional set of three diodes called the **diode trio**. The diode trio is used to rectify current from the stator so that it can be used to create the magnetic field coil of the rotor. Using the diode trio eliminates extra wiring. To control generator output, a voltage regulator regulated the current from the diode trio and to the rotor **(Figure 19-17)**.

**Figure 19-17** A wiring diagram of a charging circuit with a diode trio.

**Voltage Regulation**

Voltage output of an AC generator can reach as high as 250 volts if it is not controlled. The battery and the rest of the electrical system must be protected from this excessive voltage. Therefore, the voltage output from a charging system must be controlled. Current output does not need to be controlled because an AC generator naturally limits the current output. The **voltage regulator** controls the voltage output of an AC generator.

Regulation of voltage is accomplished by varying the amount of field current flowing 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. To ensure that the battery stays fully charged, most regulators are set for a system voltage between 14.5 and 15.5 volts.

The regulator must receive system voltage as an input in order to regulate the voltage output. This input voltage to an AC generator is called the **sensing voltage**. If the sensing voltage is below the regulator setting, an increases in field current is allowed which causes an increase in charging voltage output. Higher sensing voltage will result in decrease in 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 (trickle charge) on the battery. If a heavy load is turned on, such as the headlights, the additional draw causes a decrease in battery voltage. The regulator senses the low system voltage and increases current to the rotor. This increases the strength of the magnetic field around the rotor and increases the generator’s output voltage. When the load is turned off, the regulator sense the rise in system voltage and reduces the field current.

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 system voltage until it is at higher level so the battery will accept it and can become fully charged.

**Field Circuits**

To properly test and service a charging system, it is important to identify the type of field circuit in that system’s generator. There are basically three types of field circuits. The first type is called the A-circuit. It has the regulator on the ground side of the field coil. The battery feed (B+) for the field coil is picked up inside the AC generator **(Figure 19-18)**. By placing the regulator on the ground side of the field coil, the regulator allows the control of field current by varying the current flow to ground.

**Figure 19-18** An A-circuit.

The second type of field circuit is the B-circuit. In this case the voltage regulator controls the power side of the field circuit. The field coil is grounded inside the AC generator **(Figure 19-19)**. Normally the B-circuit regulator is mounted outside of the generator.

The third type of field circuit is called the isolated field. The AC generator has two field wires attached to the outside of the case. One is the ground, the other is the B+. The voltage can be located on either the ground or the B+ side of the circuit **(Figure 19-20)**.

There are two basic types of regulators: electronic and electromechanical. Older vehicles were equipped with electromechanical regulators, while newer vehicles have electronic regulators. Also, many newer vehicles do not have separate voltage regulators; instead, they control the output of the charging system through the PCM.

**Figure 19-19** A B-circuit.

**Figure 19-20** In the isolated field circuit AC generator, the regulator can be installed on either side of the field.

**Electronic Regulators**

Electronic regulators can be mounted externally or internally in relation to the AC generator. The use of electronics allows for quick and accurate control of the field current. Electronic regulation is through the ground side of the field current (A-current control).

Pulse width modulation controls the generator’s output by varying the amount of time the field coil is energized. For example, assume that a vehicle is equipped with a 100-ampere generator. If the electrical demand placed on the charging system requires 50 amps, the regulator would energize the field coil for 50% of the time **(Figure 19-21)**. If the electrical system’s demands were increased to 75 amps, the regulator would energize the field coil 75% of the cycle time.

The electronic regulator uses a zener diode that blocks current flow until a specific voltage is obtained, at which point it allows the current to flow. The schematic for an electronic voltage regulator with a zener diode is shown in **Figure 19-22**.

**Integrated circuit voltage regulators** are used on most late-model vehicles. This is the most compact regulator design. All of the control circuitry and components are located on a single silicone chip. The chip is sealed in a plastic module and mounted either inside or on the back of the AC generator. Integrated circuit regulators are non-serviceable and must be replaced if defective.

**Figure 19-23** illustrates a solid-state integrated regulator. It mounts inside the AC generator slip ring end frame along with the brush holder assembly. All voltage regulator parts are enclosed in a solid mold. The rectifier bridge contains the six diodes needed to change AC to DC, which is then available at the output battery terminal. Field current is supplied through a diode trio, which is connected to the stator windings.

**Figure 19-21** Pulse width modulation with 50% on-time.

**Figure 19-22** A simplified circuit of an electronic regulator with a zener diode.

**Figure 19-23** component locations of an AC generator with an internally mounted voltage regulator.

**Fail-Safe Circuits** To prevent simple electrical problems from causing high-voltage outputs that can damage delicate electronic components, many voltage regulators contains **fail-safe circuits**.

A detailed explanation of how these circuits operate can be quite confusing. All you need to know is what a fail-safe circuit does, not how it does it. If wire connections to the AC generator become corroded or are accidently disconnected, the regulator’s fail-safe circuits may limit voltage output that might otherwise rise to dangerous levels. Under certain conditions, the fail-safe circuits may prevent the AC generator from charging at all. A fusible line in the fail-safe circuitry confines damage to the AC generator. Delicate electronic components in other vehicle systems are not damaged.

**Computer Regulation**

On a growing number of late-model vehicles, separate voltage regulators are no longer used. Instead, the voltage regulation circuitry is located in the vehicle’s powertrain control module or another control module **(Figure 19-24)**. Regardless of where the circuitry is located, it I s still used to control current to the field windings in the rotor.

This type of system does not control rotor field current by acting like a variable resistor. Instead, the computer switches or pulses field current on and off at a fixed frequently of about 400 cycles per second. By varying on-off times, a correct average field current is produced to provide correct AC generator output. At high engine speeds with little electrical system load, field circuit on time may be as low as 10%. At low engine speeds with high loads, the computer may energize the field circuit 75% or more of the time to generate the higher average field current needed to meet output demands.

**Figure 19-24** The basic circuit for a generator with its regulator as part of the PCM.

A significant feature of this system is its ability to vary the amount of voltage according to vehicle requirements and ambient temperatures. This precise control allows the use of smaller, lighter, storage batteries. It also reduces the magnetic drag of the AC generator, increasing engine output by several horsepower. Precise management of the charging rate can result in increased gas mileage and eliminate potential rough idle problems caused by parasitic voltage loss at low idling speeds. Most importantly, it allows the computer’s diagnostic capabilities to be used in troubleshooting charging system problems, such as low-or high-voltage outputs.

**Indicators**

It is very important to monitor charging system performance during the course of vehicle operation. Vehicles are equipped with an ammeter, voltmeter, or indicator light. These allow the driver to monitor the charging system

**Indicator light** The indicator light is the simplest and most common method of monitoring AC generator performance. When the charging system fails to supply sufficient current, the light turns on. However, when the ignition switch is first activated, the light also comes on because the AC generator is not providing power to the battery and other electrical circuits. Thus, the only current path is through the ignition switch, indicator light, voltage regulator, part of the AC generator, and ground, then back through the battery **(Figure 19-25)**. Only the battery, regulator, and alternator are in the circuit. With no current flowing through the indicator light, it goes out.

With the engine running, the indicator light comes on again if the electrical load is more than the AC generator can supply, which occasionally happens when the engine is idling. If there are no problems, the light should go out as the engine speed is increased. If it does not, either the AC generator or regulator is not working properly.

**Figure 19-25**An electronic regulator with an indicator light on due to no AC generator output.

| **S H O P T A L K**  On late-model cars, the indicator light can be combined  with the oil pressure warning light; it usually is  labeled “engine.” If this light turns on while the  engine is running, either the AC generator is not charging  or the oil pressure is low—or both**.** |
| --- |

**Meter** Some vehicles have an ammeter or voltmeter in their instrument cluster. The voltmeter displays the voltage at the battery. If the charging system is working fine, the voltmeter will read more than 12 volts.

The ammeter monitors current flow in and out of the battery. When the AC generator is delivering current to the battery, the ammeter shows a positive (+) indication. When not enough current (or none at all) is being supplied, the result is a negative (-) indication.

**NEW DEVELOPMENTS**

In the quest to improve fuel economy, decrease emission levels, and make vehicles more reliable, engineers have applied advanced electronics to starter and generators.

**42-Volt Generators**

Vehicles with a 42-volts electrical system will have an air or liquid-cooled generator capable of production 42 volts and 5 to 10 kilowatts. Currently, a conventional 12-volts generator puts out about 1.5 kilowatts. Depending on the design of the system **(Figure 19-26)**, the vehicle may be fitted with a DC to DC converter that changes some of the generator’s output to charge a 12-volts battery or power the 12-volt loads of the vehicle. Switched reluctance techniques are used to generates the power needed for these high-voltage systems. Plus, switched reluctance system are very efficient generators at low speeds. This design has a toothed stator and rotor and does not use windings or magnets in its rotor.

**Figure 19-26** The different system layouts for 42 volts electrical systems: (A) a system with two batteries and a converter, (B) a system with one battery and a converter, (C) a two-battery system, and (D) a one –battery system

**Starter/Generators**

The main difference between a generator and a motor is that a motor has two magnetic fields that oppose each other, whereas a generator has one magnetic field and wires are moved through the field. Using electronic to control the current to and from the battery, engineers have developed a generator that can also work as a starter motor. These units are commonly called starter/generators.

A starter/generators may be based on two sets of windings and brushes, a brushless design with a permanent magnet, or switched reluctance **(Figure 19-27)**.

A starter/generator can be mounted externally to the engine and connected to the crankshaft with a drive belt. Starter/generators can also be mounted directly on the crankshaft between the engine and the transmission or integrated into the flywheel **(Figure 19-28)**. This unit serves as a generator, charging both directly from the engine during braking (regenerative braking).

**Figure 19-27** A switched reluctance starter/generator. Note the design of the rotor.

**Figure 19-28** An integrated starter/generator assembly built into the flywheel.

Starter/generators are capable of high charging outputs and can crank the engine at high speeds. They also allow for other features that make the vehicle more efficient:

v Stop-start. When the engine is not needed, such as at a stoplight, it is automatically turned off. It restarts smoothly and instantly when any demand for power is detected by the control mode.

v Regenerative braking. This feature collects energy created from braking and uses it to recharge the vehicle’s batteries. As the vehicle decelerates and the brakes are applied, the power flow reverses; then the wheels drive the engine. As the flywheel turns, it produces a charge that develops driveline drag and contributes to stopping. Regenerative braking allows items such as the headlights, stereo, and climate control system to continue to operate when the engine shuts off.

v Electrical assist. The starter/generator help the engine at startup and during hard acceleration, providing short bursts of added power.

Some starter/generator are belt driven **(Figure 19-29)** and use all of the techniques designed regenerative braking, torque assistance, and high efficiency. The belt tensioner is mechanically or electrically controlled to allow the starter/generator to driver or to be driven by the belt. A system used by Toyota has an electromagnetic clutch fitted to the crankshaft pulley. During normal operation, the clutch is engaged and the belt is driven by the crankshaft. When the engine is stooped, the crank pulley clutch disengages and the motor/generator works as a motor to keep the accessories going. It also restarts the engine when needed.

**Figure 19-29** A belt-drive starter/generator.

**Hybrid Vehicles**

A vehicle equipped with a starter/generator can be considered a mild hybrid because it is capable of most of the functions of a hybrid vehicle. Functions such as stop-start, regenerative braking, and electrical assist are common to both a full hybrid vehicle and a mild hybrid.

Only full hybrids have the ability to drive in an electric only mode. A hybrid vehicle has a much higher voltage system; therefore, the motor is capable of providing much more power, more frequently, and for longer periods of time. The motor is located between the transmission and the engine **(Figure 19-30)**.

Honda’s integrated motor assist (IMA) is a thin brushless electric motor **(Figure 19-31)** that assists the gasoline engine during acceleration, functions as a generator to recharge the battery pack during deceleration, and serves as the gasoline engine’s starter motor. Power for the motor comes mainly from regenerative braking, rather than from the gasoline engine. If the charge of the IMA battery is low, the motor/generator will also recharge while the vehicle is cruising. If the IMA system battery is low, a separate 12-volt battery and starter motor will start the engine.

**Figure 19-30** Honda’s integrated motor assist unit for hybrid vehicles fits between the engine and the transmission.

**Figure 19-31** Honda’s integrated motor assist unit a brushes motor.