SUBCOURSE
OD0611

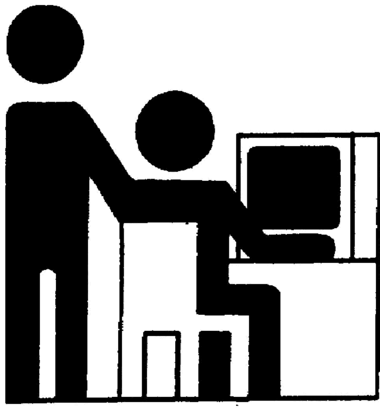
EDITION
B

PRINCIPLES OF AUTOMOTIVE ELECTRICITY

READINESS/
PROFESSIONALISM
THRU
GROWTH

THE ARMY INSTITUTE FOR PROFESSIONAL DEVELOPMENT

ARMY CORRESPONDENCE COURSE PROGRAM



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PRINCIPLES OF AUTOMOTIVE ELECTRICITY

Subcourse Number OD 0611

EDITION B

United States Army Combined Arms Support Command
Fort Lee, VA 23801-1809

4 Credit Hours

EDITION DATE: October 1991

SUBCOURSE OVERVIEW

This subcourse is designed to teach you the relationship of voltage, current, resistance and series and parallel circuits of military vehicle electrical systems. Practice exercises are provided prior to the examination.

There are no prerequisites for this subcourse.

This subcourse reflects the doctrine which was current at the time the subcourse was prepared. In your own work situation, always refer to the latest publications.

The words "he", "him", and "men", when used in this publication, represents both the masculine and feminine genders unless otherwise stated.

TERMINAL LEARNING OBJECTIVE

TASK: Identify electrical flow in circuits and maintenance of vehicle storage batteries.

CONDITIONS: Given this subcourse with illustrated electrical circuits, information on battery maintenance, technical publication extracts, explaining electricity.

STANDARDS: You must identify the electrical flow in circuits and maintenance of vehicle storage batteries in accordance with information provided within this subcourse and applicable publications.

PLEASE NOTE

Proponency for this subcourse has changed
From Armor (AR) to Ordnance (OD).

TABLE OF CONTENTS

TM 9-8000 with Change 1, Principles of Automotive Vehicles, dated 25 Oct 85.

Use the above publication extract to take this subcourse. At the time this subcourse was written, this was the current publication. Always refer to the most current publication in a working environment.

ELECTRICAL CIRCUITS

MQS Manual Tasks: None

OVERVIEW

TASK DESCRIPTION:

In this lesson, you will learn the definition of electrical terms and identify symbols and circuits used in the vehicle's electrical systems.

LEARNING OBJECTIVE:

ACTIONS: Identify electrical flow circuits.

CONDITIONS: Given this subcourse with illustrated electrical circuits, technical publication extract explaining electricity.

STANDARDS: You must specify the amount of voltage, amperage, or resistance in a particular circuit. You must also specify if the circuit is in series or parallel.

REFERENCES: The material contained in this lesson was derived from the following publications:

TM 9-8000
FM 11-60
FM 11-61
TM 9-6140-200-14

INTRODUCTION

Electricity has been used for decades and scientists have been experimenting with it longer. We know that everything that exists consists of particles called molecules. Molecules are further divided into a material called atoms. Atoms consist of some arrangement of protons, electrons, and neutrons. The proton is a positive charged particle; the electron is a negative charged particle; and the neutron is not charged. Molecules are a very basic necessity in the composition of all materials with the exception of hydrogen. Neutrons and protons will always be located in the center of an atom. The electrons will always be located in the outer shells of the atom. There are two types of electrons. They are the bound electron and the free electron. The free electrons are the electrons which will be found in the outermost shell, or orbit of the atom and can be moved readily from their orbit. The innermost shells of the atom contain electrons that are not easily freed and are referred to as bound electrons.

LESSON CONTENT

1. There are many terms and symbols that are particular to the study of electricity. As a maintenance supervisor, an understanding of electrical terns and an ability to interpret schematic wiring diagrams, electrical drawings, and symbols will enable you to properly supervise maintenance personnel in diagnosing and locating electrical problems.

a. <u>Electrical Terms</u>.

(1) AC - Alternating current, or current that reverses its direction at regular intervals.

(2) Ammeter - An electric meter that measures current.

(3) Battery - A device consisting of two or more cells for converting chemical energy into electrical energy.

(4) Circuit - A closed path or combination of paths through which passage of the medium, electric current, air, and liquid, is possible.

(5) Circuit Breaker - In electrical circuits, a mechanism designed to break or open the circuit when certain conditions exist; especially the device in automotive circuits that opens the circuit between the generator and battery to prevent overcharging of the battery. One of the three units comprising a generator regulator.

(6) Conductor - A material through which electricity will flow readily.

(7) Core - An iron mass, generally the central portion of a coil, electromagnet or armature around which wire is coiled.

(8) DC - Direct current or current that flows only in one direction.

(9) Electricity - A form of energy that involves the movement of electrons from one place to another or the gathering of electrons in one area.

(10) Electromagnet - A temporary magnet constructed by winding a number of turns of insulated wire into a coil or around an iron core.

(11) Electron - A negative particle that is a basic constituent of matter and electricity.

(12) Flux - Lines of magnetic force moving through a -magnetic field.

(13) Ground - Connection of an electrical unit to the engine/frame to return the current to its source.

(14) Induction - The action or process of producing voltage by the relative motion of a magnetic field and a conductor.

(15) Insulation - A substance that stops movement of electricity (electrical insulation) or heat (heat insulation).

(16) Magnet - Any body that has the ability to attract iron.

(17) Magnetic Field - The space around a magnet that the magnetic lines of force permeate.

(18) Magnetic Pole - Focus of magnetic lines of force entering or emanating from a magnet.

(19) Magnetism - The property exhibited by certain substances and produced by electron, electric current, and/or motion which results in the attraction of iron.

(20) Negative - A term designating the point of lower potential when the potential difference between two points is considered.

(21) Ohm - A unit of measure of electrical resistance.

(22) Parallel Circuit - The electrical circuit formed when two or more electrical devices have like terminals connected together, positive to positive or negative to negative, so that each may operate independently of the other.

(23) Positive - A term designating the point of higher potential when the potential difference between two points is considered.

(24) Potential - A characteristic of a point in an electric field or circuit indicated by the work necessary to bring a unit positive charge from infinity; the degree of electrification as compared to some standard. For example: the earth.

(25) Relay - In the electrical system, a device that opens or closes a second circuit in response to voltage or amperage changes in a controlling circuit.

(26) Resistance - The opposition offered by a substance or body to the passage through it of an electric current.

(27) Series Circuit - The electrical circuit formed when two or more electrical devices have unlike terminals connected together, positive to negative, so that the same current must flow through all.

(28) Volts - A unit of potential, potential difference, or electrical pressure.

b. Electrical Symbols. As a maintenance supervisor, you must be able to interpret schematic wiring diagram. To read these diagram, you must know the meaning of the symbols used. Examples of same electrical symbols are illustrated in Figure 1-1.

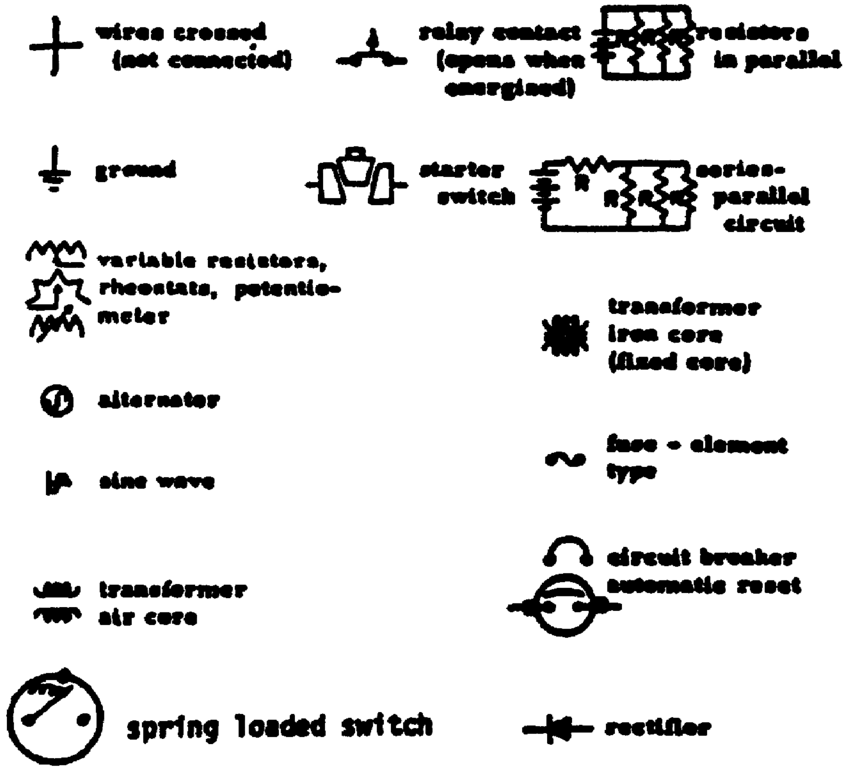


Figure 1-1. Electrical Symbols (page 1 of 2).

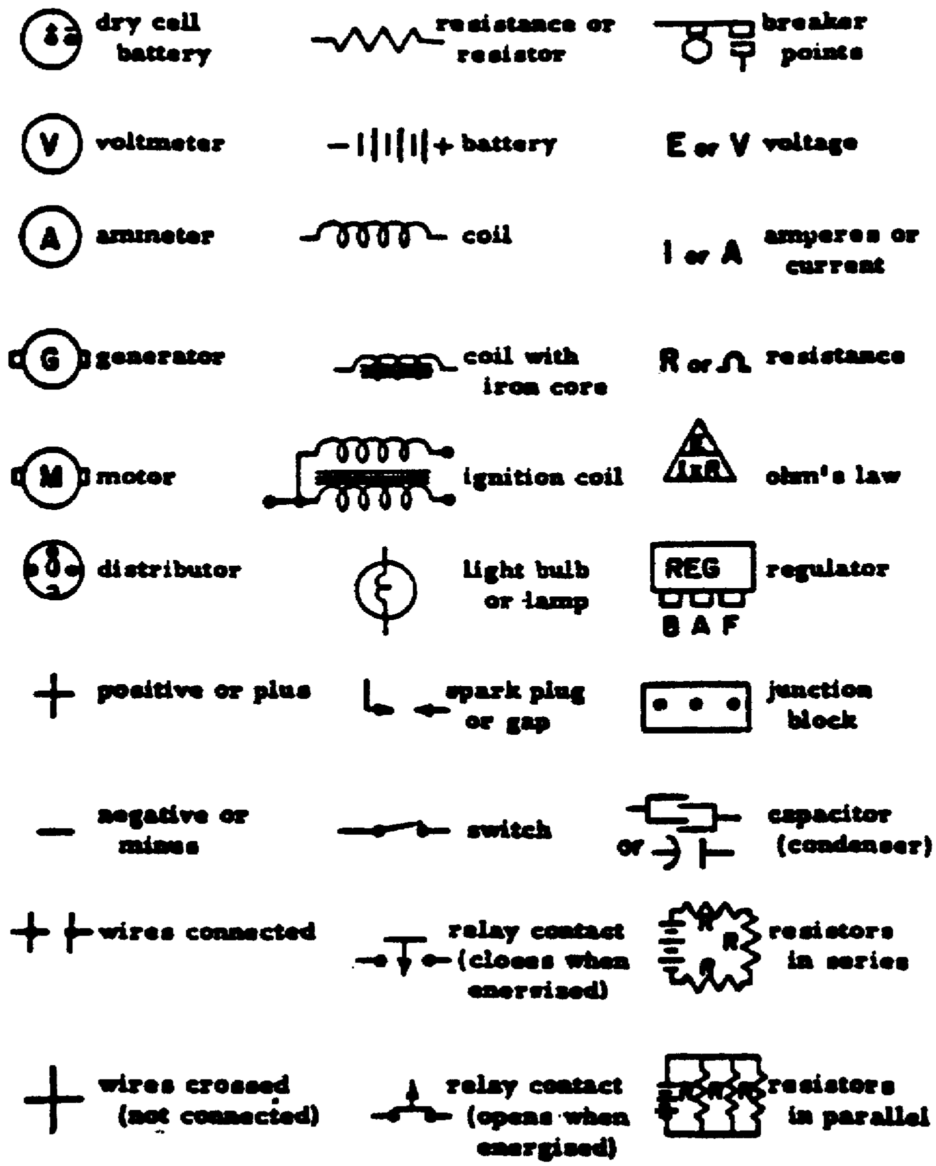


Figure 1-1. Electrical Symbols (page 2 of 2).

2. While the study of electricity may seem complicated, it can be broken down into three elements: voltage, current, and resistance.

a. Voltage. Electrons are caused to flow by a difference in electron balance in a circuit; that is, when there are more electrons in one part of a circuit than in another, the electrons move from the area where they are concentrated to the area where they are lacking. This difference is called potential difference or voltage. Methods of producing voltage include friction (static electricity), chemical reaction (battery), and magnetic induction (generator).

b. Current. Current flow or electron flow is measured in amperes. While it is normally considered that one ampere is a rather small current of electricity, it is actually a tremendous flow of electrons. More than six billion electrons a second are required to make up one ampere. Personnel in the maintenance field are concerned with two types of current, alternating current (AC) and direct current (DC).

(1) Alternating current - While alternating current is acceptable for house or commercial use, it is not acceptable for automotive use. As its name implies, AC alternates back and forth in direction of flow at timed intervals and therefore cannot be stored in a storage battery.

(2) Direct current - DC is used in automotive systems because circuits can be controlled so the current will readily flow to the component where it is needed and return to its source (storage battery) through a frame return circuit.

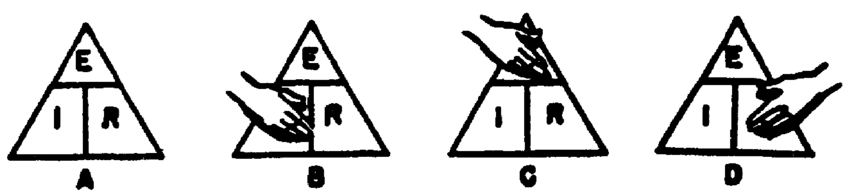
c. Resistance. Resistance is defined as the opposition to current flow. Even though a copper wire will conduct electricity with ease, it still offers resistance to electron flow. This resistance is caused by the energy necessary to break the outer shell electrons free, and the collisions between the atoms of the conductor and the free electrons. It takes force (or voltage) to overcome resistance encountered by the flowing electrons. This resistance is expressed in units called ohms. The resistance of a conductor varies with its length, cross-section area, composition, and temperature.

d. Generators. Generators are a major component of automotive systems as they supply the electrical power to operate all electrical systems of automotive vehicles. Some of the functions of generators are to supply electrical current to the lighting system, the ignition system, heater motor, instruments, and radios. There are two types of generators in use today. They are the alternator or AC generator, and the direct current or DC generator.

(1) Alternating current. The AC generator produces alternating current which is unacceptable for automotive systems. The alternator rust have a rectifier installed to convert AC to DC to satisfy the needs of the storage battery. In the alternator, the magnetic field is rotated and voltage is produced in the stationary coils. One advantage of the AC generator is that it will produce current at low speeds which make it the more acceptable component.

(2) Direct current. The DC generator, as its name implies, produces DC current, but must be run at a much higher speed than the AC generator. The DC generator works much the same way as the AC generator, but the magnetic field is stationary and coils of wire, called an armature, are rotated in the magnetic field. A magnetic switch, brushes, and a commutator are provided.

3. Ohm's Law states that the voltage impressed on a circuit is equal to the sum of the product of current measured in ohms. One ohm is the resistance of a circuit element that permits a steady current of one ampere to flow when a steady force of one volt is applied to the current. An easy way to remember Ohm's Law is to think of a triangle with E at the top and I and R in the lower angles (Figure 1-2).



E = Volts, I = Current in Amperes, R = Resistance in Ohms

Figure 1-2. Ohm's Law Triangle.

The mathematical formula is written in one of the following three ways:

a. E = I x R. The voltage in a circuit equals the current multiplied by the resistance. An example of Ohm's Law in relation to voltage is an electric heater which has a known resistance of 20 ohms. The same heater requires a current flow of 6 amperes for proper operation.

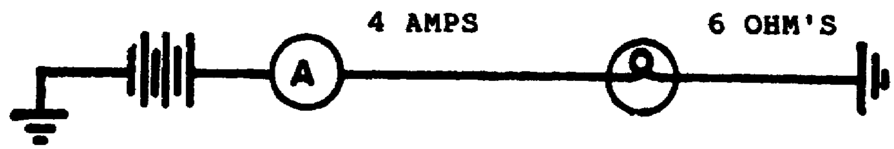


Figure 1-3. Determine Voltage.

b. I = E/R. The current equals the voltage divided by the resistance. An example of Ohm's Law in relation to current is an electric horn that requires a pressure of 12 volts and offers 3 ohms of resistance to the flow of current.

Figure 1-4. Determine Current.

c. R = E/I. The resistance of the circuit equals the voltage divided by the current. An example of Ohm's Law in relation to the resistance is an electric iron that operates from a 120 volt input and requires a current flow of 5 amperes.

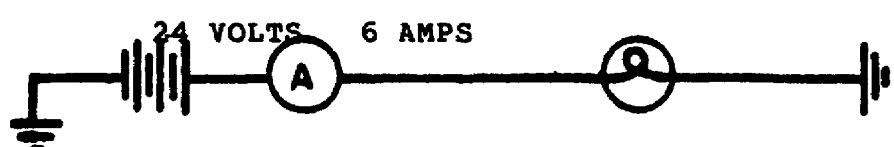


Figure 1-5. Determine Resistance.

4. A very basic circuit consists of a power source, a unit to be operated, and a wire to connect the two together.

a. Series Circuits.

(1) Laws of series circuits.

(a) A series circuit has only one path for current to flow.

(b) Amperage remains the same in all parts of a series circuit.

(c) When resistance is added in series, the total resistance increases and current decreases.

(d) The sum of all different voltage drops is equal to the applied voltage.

(2) Figure 1-6 shows a series circuit consisting of one or more units connected in series (negative to positive) to form a single path for current to flow. Most every one is familiar with the old type of Christmas tree lights where all of the bulbs go out when any one of the bulbs burn out. These lights are connected in series (negative to positive). A break anywhere in the circuit will cause all of the lights to go out.

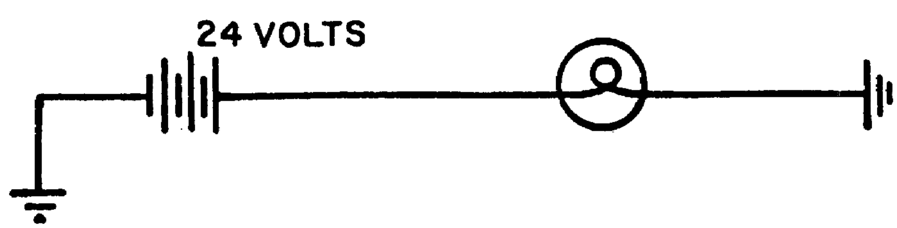


Figure 1-6. Series Circuits.

b. <u>Parallel Circuits</u>.

(1) Laws of parallel circuits.

(a) A parallel circuit has two or more paths for current to flow.

(b) Applied voltage is the same to each branch of the circuit.

(c) When resistance is added in parallel, the total or effective resistance decreases.

(d) The sum of the amperage in each branch is equal to the total amperage.

(e) The total or effective resistance will always be less than the lowest resistance.

(2) Figure 1-7 demonstrates how the voltage source is applied equally to each of the electrical components in a parallel circuit and how the parallel circuit has two or more paths for current to flow. Opening or closing the circuit of any branch does not affect the other circuits.

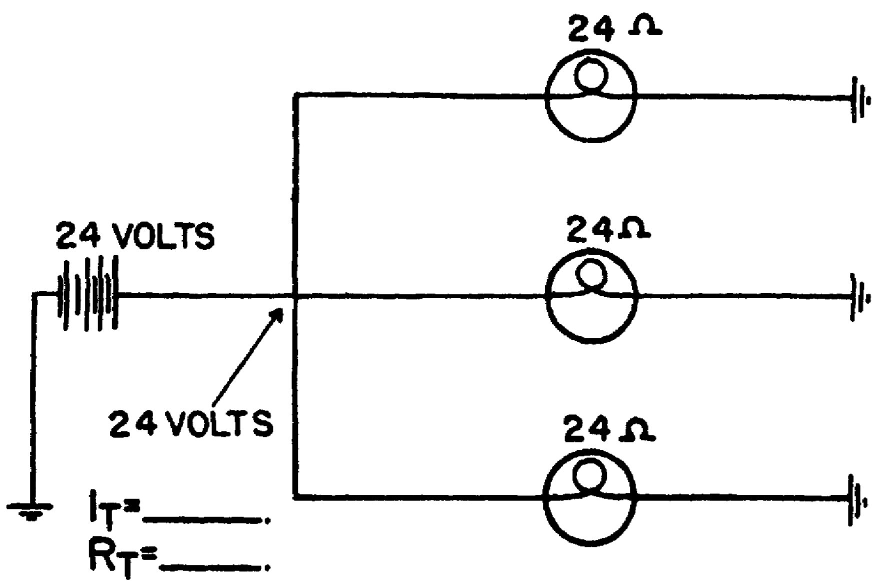


Figure 1-7. Parallel Circuits.

LESSON ONE

Practice Exercise

The following items will test your grasp of the materials covered in this lesson. There is only one correct answer for each item. When you have completed the exercise, check your answers with the answer key that follows. If you answer any item incorrectly, study that part of the lesson which contains the portion involved.

<u>Situation</u>. You have been tasked to supervise maintenance personnel in the testing, repair, and replacement of electrical systems/components. To become proficient in that area, you have decided to increase your knowledge in the area of automotive electricity.

1. What are the three elements of electricity?

    A. Short, Voltage, and watt.
    B. Current, voltage, and open circuit.
    C. Resistance, amperage, and electron.
    D. Voltage, current, and resistance.

2. An ohm is

    A. a unit of measure of electrical resistance.
    B. a unit of measure of electrical potential.
    C. a material which electricity will flow through.
    D. the force that causes current to flow.

3. What is a circuit breaker?

    A. A device for turning lights on or off.
    B. One of the three units comprising a generator regulator.
    C. A warning device for instrument control.
    D. A turn signal control device.

4. What is measured with an ammeter?

    A. Pressure.
    B. Resistance.
    C. Current.
    D. Potential.

5. What is one advantage of an alternator?

A. It does not need a rectifier.
B. It produces direct current.
C. It delivers more current at lower speeds.
D. It is gear-driven.

6. If one component burns out in a series circuit,

A. the rest of the circuit will continue to operate.
B. the entire circuit is inoperative.
C. one third of the circuit is inoperative.
D. two thirds of the circuit is inoperative.

7. What is alternating current?

A. Current that restricts voltage.
B. Current that flows in only direction.
c. current that flows back and forth in direction.
D. Current with high amperage.

8. What is the current in a flashlight that requires 3 volts of pressure and has 1 ohm of resistance?

A. 1 ampere.
B. 3 amperes.
C. 2 amperes.
D. 6 amperes.

9. What is the resistance of a blower motor in a heater that operates on a 24 volt circuit and requires 3 amperes of current?

A. 12 ohms.
B. 10 ohms.
C. 8 ohms.
D. 6 ohms.

10. What is the voltage in a car headlight that has a known resistance of 3 ohms and requires 4 amperes of current?

A. 6 volts.
B. 9 volts.
C. 12 volts.
D. 15 volts.

11. What is the current in a stereo speaker that requires 120 volts of pressure and has 8 ohms of resistance?

A. 10 amperes.
B. 15 amperes.
C. 20 amperes.
D. 25 amperes.

12. What is the resistance of a vehicle headlight that operates on a 24 volt circuit and requires 1.8 amperes of current?

A. 2.5 ohms.
B. 5.3 ohms.
C. 9.6 ohms.
D. 13.3 ohms.

13. What is the voltage of an electric windshield wiper motor with a known resistance of 6 ohms and requirement of 4 amperes of current for proper operation?

A. 6 volts.
B. 12 volts.
C. 18 volts.
D. 24 volts.

14. What constitutes a parallel circuit?

A. Two or more components connected together positive to positive.
B. Two or more components that depend upon each other for proper operation.
C. Two or more paths for current to flow.
D. Two or more resisters to control current flow.

LESSON ONE

PRACTICE EXERCISE

ANSWER KEY AND FEEDBACK

Item	Correct Answer and Feedback.
1.	D. Voltage, current, and resistance. Voltage is the forage or pressure that causes current to flow in a wire, and resistance is the opposition to current movement. (Page 7, para 2).
2.	A. Unit of measure of electrical resistance. An ohm is the amount of resistance that must be overcome for current to move in an electrical circuit. (Page 4, para 1.a.(21)).
3.	B. One of three units comprising a generator regulator. In electrical circuits, a mechanism designed to break or open the circuit when certain conditions exist. (Page 3, para 1.a.(5)).
4.	C. Current. The ammeter is designed specifically for measuring current flow in an electrical circuit. (Page 3, para 1.a.(2)).
5.	C. It delivers more current at lower speeds. When current is induced into the alternator, it will start charging. The DC generator does not produce current until it reaches high speed. Therefore, the alternator is the preferred component. (Page 7, paras d. and d.(1)).
6.	B. The entire circuit is inoperative. A series circuit only has one path for current to flow. Any component in that circuit that burns out causes the entire circuit to be inoperative because it now has an open circuit. (Page 10, para 4.a.(2)).

7. C. Current that flows back and forth in direction.

As its name implies, alternating current will flow back and forth in direction of flow at timed intervals. (Page 7, para 2.b.(1)).

8. B. 3 amperes.

Ohm's Law allows you to determine the amount of amperage or current in a circuit by equation I = E/R or 3 ohms. (Page 9, para b.).

9. C. 8 ohms.

Ohm's Law allows you to determine the amount of resistance in a circuit by equation R = E/I or 8 ohms. (Page 9, para c.).

10. C. 12 volts.

Ohm's Law allows you to determine the amount of voltage in a circuit by equation E = I x R or 12 volts. (Page 9, para a.).

11. B. 15 amperes.

Ohm's Law allows you to determine the amount of amperage in a circuit by equation I = E/R = 15 amperes. (Page 9, para b.).

12. D. 13.3 ohms.

Ohm's Law allows you to determine the amount of resistance in a circuit by equation R = E/I. (Page 9, para c.).

13. D. 24 volts.

Ohm's law allows you to determine the amount of voltage in a circuit by equation E = I x R or 24 volts. (Page 9, para a.).

14. C. Two or more paths for current to flow.

A parallel circuit consists of two or more resister units (electrically operated components in separate branches). [Page 11, para b.(2)].

LESSON TWO

BATTERY MAINTENANCE

MQS Manual Tasks: none

OVERVIEW

<u>TASK DESCRIPTION</u>.

In this lesson you will learn the procedures for inspection and maintenance of Lead Acid Storage Batteries.

<u>LEARNING OBJECTIVE</u>:

ACTIONS: Inspect storage batteries.

CONDITIONS: Given situations describing storage battery conditions.

STANDARDS: You must identify all faults and determine battery serviceability. Describe the inspection procedures for each situation.

REFERENCES: TM 9-6140-200-14.

INTRODUCTION

Lead acid storage batteries are used in automotive application to supply electricity to vehicle components as required and act as a voltage stabilizer in vehicle electrical systems.

LESSON CONTENT

1. Inspection and maintenance of lead acid storage batteries is an important part of ensuring that your vehicles will be able to perform their mission. Without proper maintenance, lead acid batteries can fail and then you are without equipment at a critical time.

a. Description of Vehicle Storage Batteries. The lead acid storage battery is an electro-chemical device for storing energy in the chemical form. When this energy is needed to operate an electrical component in the system, it is released as electricity. Storage batteries perform four functions in automotive application.

(1) They supply electrical energy for vehicle engine starts.

(2) They supply short term overload demands in excess of generator electrical output.

(3) They supply limited or emergency power when the generator is not operating.

(4) They act as a voltage stabilizer in the vehicle electrical system.

b. Safety Precautions. Certain safety precautions must be observed when you are working around storage batteries.

(1) While removing or installing vehicle batteries, remove the ground cable (negative side of the battery) first and connect it last to eliminate arcing.

(2) Avoid open flames and arcing of cables near the battery. One small spark can cause the battery to explode.

(3) Avoid contact with sulfuric acid; it can cause severe burns. Keep a strong solution of soda and water available, as a precaution if contact occurs. If soda solution is not available, flush the area of contact with clear water.

(4) Ventilate the battery room well at all times to avoid explosions due to the presence of hydrogen gas which is produced by storage batteries.

(5) While working with batteries, wear chemical protective splash goggles (goggles with no vent holes which prevent splashed acid or chemicals from entering the eyes), rubber gloves, and a rubber gown while filling batteries with electrolyte.

c. Battery Construction. The lead acid battery consists of a number of cells connected together. Each cell will produce approximately two volts; the number of cells needed will depend upon the voltage desired. For example, one 12-volt battery will have six cells.

(1) A cell consists of a compartment made of hard rubber, plastic, or other bituminous material into which the cell element is placed. The cell element consists of two types of lead plates, known as positive and negative plates. These plates (Figure 2-1) are insulated from each other by suitable separators (usually made of plastic, rubber, or glass) and submerged in a sulfuric acid solution (electrolyte).

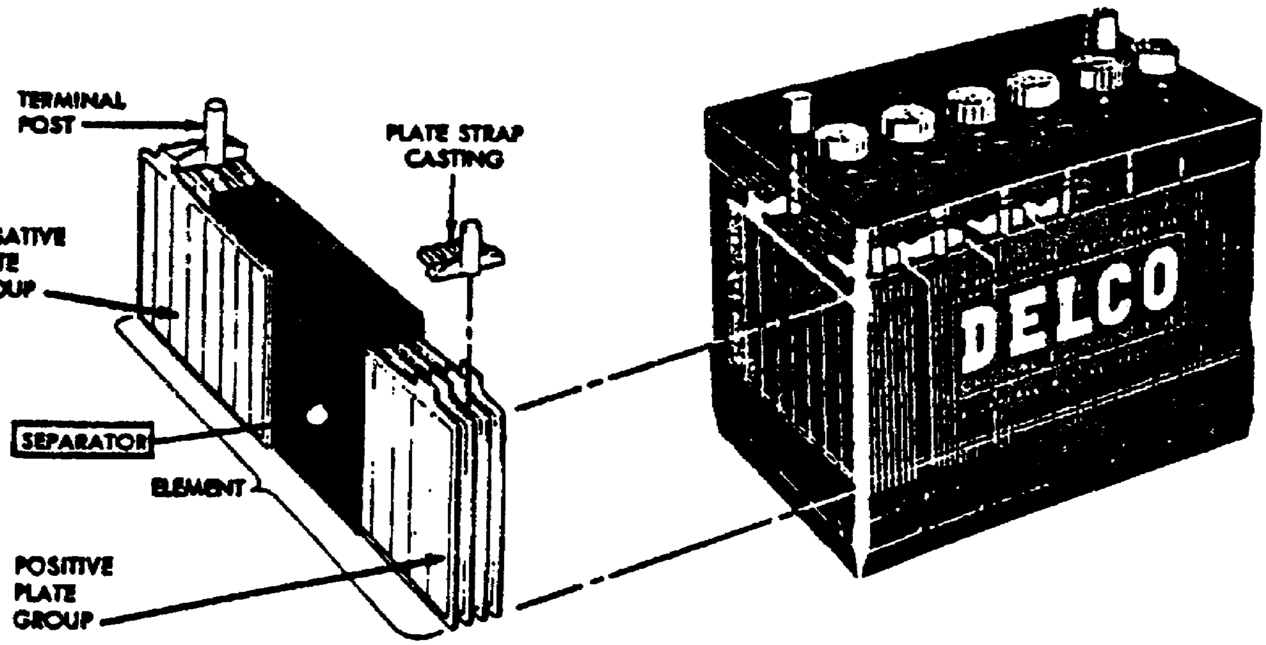


Figure 2-1. Negative and Positive Plate Group With Separators.

(2) Battery cells are filled with a solution of sulfuric acid and water, known as electrolyte. This solution contains approximately one-part of acid, by volume, three-parts water. The strength of the electrolyte is measured in terms of specific gravity. Specific gravity is the ratio of weight of a given volume of electrolyte to an equal volume of pure water. The specific gravity of pure water is 1.000. Sulfuric acid has a specific gravity of 1.830. A mixture of sulfuric acid and water will vary in strength from 1.000 to 1.830. Normally, electrolyte (water and acid mixture) will have a strength of 1.280 when the battery is fully charged. As a storage battery discharges, the sulfuric acid is depleted and the electrolyte is converted into water. This action provides a guide in determining the state of discharge of the lead acid cell. If the specific gravity reading is below 1.225, the battery is in a low state of charge. Testing and recharging of a lead-acid battery will be covered later in the subcourse.

CAUTION

Sometimes, pure sulfuric acid will be issued. This acid must be mixed with water to produce the desired specific gravity. When mixing electrolyte, always pour the acid into the water. NEVER pour water into the acid.

d. Battery Classification. Storage batteries are classified according to their rate of discharge and ampere-hour capacity. Most batteries are rated according to a 20-hour rate of discharge. If a fully charged battery is completely discharged during a 20-hour period, it is discharged at the 20-hour rate. At the end of the discharge time, the average voltage must be 1.75 volts or higher. If a battery can deliver 20 amperes continuously for 20 hours, the battery has a rating 20 X 20, or 400 ampere-hours. The batteries used in military vehicles are the 6TN battery with a capacity of 45 ampere-hours. When more capacity is required than can be supplied by one battery, additional batteries can be connected in parallel to increase total capacity. If two 100-amp, 12 volt batteries were connected in parallel, they would have a combined capacity of 200-amps. The total voltage would remain the same (12 volts).

e. Maintenance of Storage Batteries.

(1) Visually inspect the battery to determine if maintenance or repairs are required.

(a) Inspect the battery case for holes or cracks. If a hole or large crack is evident, turn in the battery to intermediate support maintenance.

(b) Inspect the battery for loose posts. If slight pressure causes the post to move, turn the battery in to intermediate support maintenance.

(c) Inspect posts, clamps, and battery holddowns for corrosion. The posts and terminals should be cleaned and coated lightly with grease. Turn in to maintenance if:

- o A post is out-of-round to the extent that it prevents full contact between the post and a new clamp.

NOTE. Post and clamps are tapered for a tighter fit. Also, the positive post is larger in diameter than the negative post.

- o The post is less than 5/8 inch high. This condition would prevent full contact between the post and a good clamp.

(2) Inspect filler caps. Check to see that the caps are not damaged or broken and that the gasket is present. Some filler caps have a built-in gasket made of the same material as the cap. The gasket is tapered from the outside edge toward the center of the cap to provide a tight seal with the case. Make sure the vent holes in the caps (Figure 2-2) are open to permit escape of gases. Replace all caps that are defective.

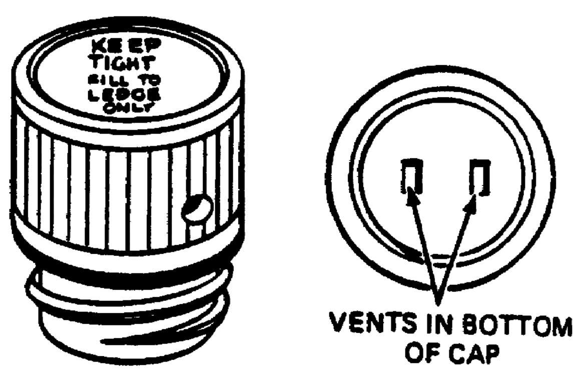


Figure 2-2. Vent Cap (Plug).

(3) Check the electrolyte level of each cell. At a minimum, the electrolyte level should cover the cell plates (Figure 2-3). When adding water to batteries, the electrolyte level should be brought up to the bottom of the split ring.

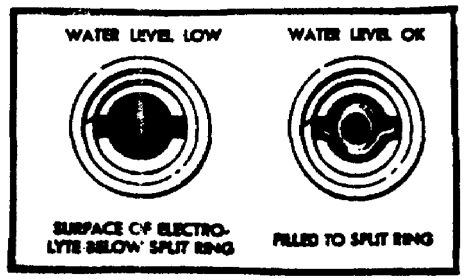


Figure 2-3. Visual Level Fill.

(4) Charge the batteries. Connect the battery to the charger, following the equipment manufacturer's recommendations. Observe the polarity of the battery (connections are made positive to positive and negative to negative). Specific charging rates will vary, depending on the battery (eight to ten amperes for 6TN and four to five amperes for 2HN batteries). Leave the battery caps on and at one hour intervals, check the specific gravity of each cell. The temperature should not exceed 130 degrees during the charging. If the temperature is too high, reduce the charging rate. Do not overcharge the batteries. Overcharged batteries will be damaged internally, shortening their life. Overcharging is indicated by excessive use of water. Overcharging can be avoided by removing the battery from the charger when specific gravity reading remains the same for three successive hourly tests. Add water to the battery during charging, if it is needed.

CAUTION

During charging, batteries give off highly explosive hydrogen gas. The charging area must be well ventilated and every precaution must be taken to prevent sparks that could cause an explosion.

(5) Measure specific gravity. Use the optical battery/antifreeze tester "duo-check" (Figure 2-4), when measuring the specific gravity of a battery. This tester is quick, accurate, and reliable. There is no guesswork or arithmetic involved and the tester will automatically adjust for temperature.

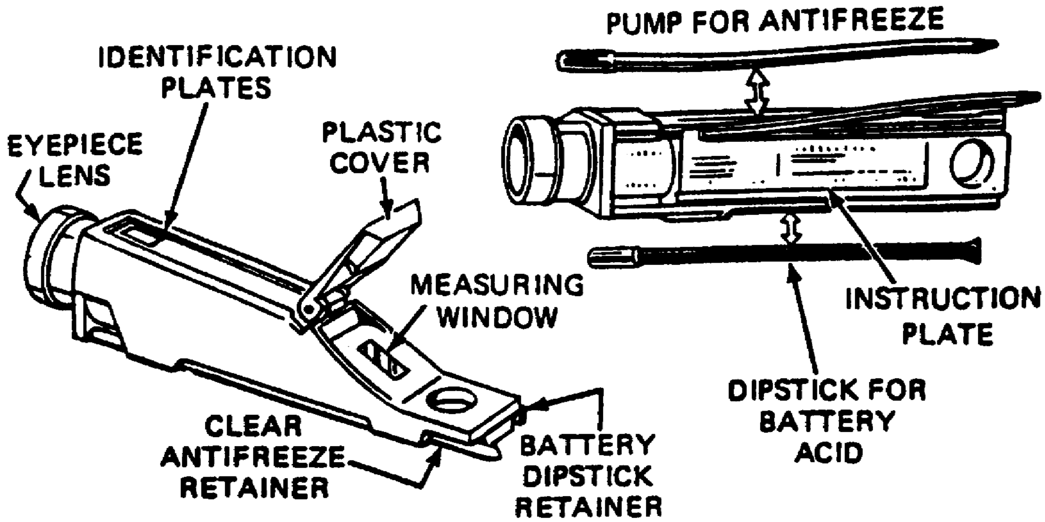


Figure 2-4. Optical/Antifreeze Tester (Duo-deck).

(a) Before using the duo-check tester, clean and dry the plastic cover and measuring window. Wipe each piece clean with a soft cloth (Figure 2-5). Clean the eyepiece lens. Clean water can be used to clean any dirty areas if it is needed.

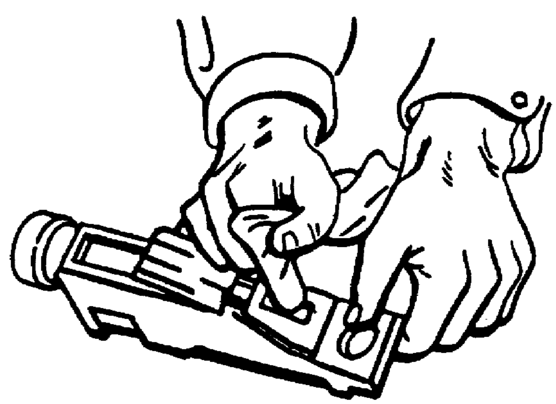


Figure 2-5. Cleaning the Tester.

(b) Swing the plastic cover down until it rests against the measuring window. Using the black dipstick, place a few drops of electrolyte onto the exposed portion of the measuring window (Figure 2-6).

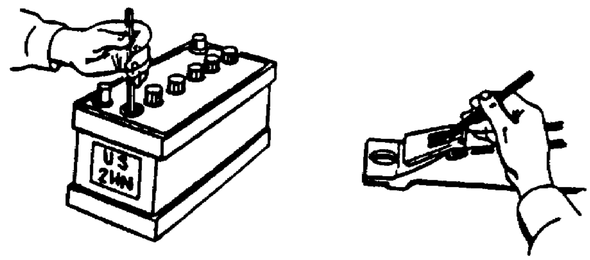


Figure 2-6. Electrolyte Sample.

(c) Point the tester toward a bright light source. When looking through the eyepiece lens, you will see a rectangle with two calibrated scales. The battery charge readings will appear on the left scale; antifreeze readings on the right scale. The electrolyte sample will divide the rectangle with an area of light and an area of shadow. Read the scale where they meet (Figure 2-7).

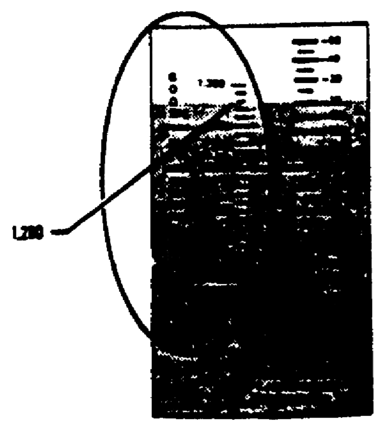


Figure 2-7. Battery State of Charge.

(d) Always perform a separate test for each battery cell. Test the battery before adding water to the cells.

f. Control and Protective Devices. Electricity, when properly controlled, is of vital importance to the operation of equipment. When it is not properly controlled, it can become very dangerous and destructive. Such devices as fuses, circuit breakers, and switches are connected into circuits to control electrical force.

(1) The simplest protective device is a fuse. All fuses are rated according to the amount of current that is safely carried by the fuse element at a rated voltage. The most important fuse characteristic is its current-versus-time or "blowing" ability. Current-versus-time indicates how quickly an overloaded fuse will blow: fast, medium, and delayed. Fast may range from five microseconds through 1/2 second; medium, 1/2 to five seconds; and delayed, five to 25 seconds. When a fuse blows, it should be replaced with another of the same rated voltage and current capacity, including the same current-versus-time characteristic. Normally, when the circuit is overloaded, or a fault develops, the fuse element melts and opens the circuit it is protecting.

(2) A circuit breaker is designed to break the circuit and stop the current flow when the current exceeds a predetermined value. It is commonly used in place of a fuse and may sometimes eliminate the need for a switch. A circuit breaker differs from a fuse in that it "trips" to break the circuit, and it may be reset, while the fuse melts and must be replaced. Some circuit breakers must be reset by hand, while others reset themselves automatically. When the circuit breaker is reset, if the overload condition still exists, the circuit breaker will trip again to prevent damage to the circuit.

(3) A switch may be described as a device used in an electrical circuit for making, breaking, or changing connections under conditions for which the switch is rated. Switches are rated in amperes and volts; the rating refers to the maximum voltage and current of the circuit in which the switch is to be used. Because it is placed in series, all the circuit current will pass through the switch. Switch contacts should be opened and closed quickly to minimize arcing; therefore, switches normally utilize a snap action.

LESSON TWO

Practice Exercise

The following items will test your grasp of the materials covered in this lesson. There is only one correct answer for each its. When you have completed the exercise, check your answers with the answer key that follows. If you answer any item incorrectly, study that part of the lesson which contains the portion involved.

1. When removing the battery cables, the ______________ cable should be removed first.

   A. positive.
   B. ground.
   C. center.
   D. outside.

2. Battery cells are filled with a solution of _____________________________ and ________________________ which is known as electrolyte.

   A. water and sulfuric acid.
   B. electrolyte and water.
   C. distilled water and soda.
   D. nitric acid and sulfur.

3. The ______________ is used to test the specific gravity of a battery state of charge.

   A. voltmeter.
   B. hydrometer.
   C. ammeter.
   D. duo-check.

4. A ________________ is defined as a device used in an electrical circuit for making, breaking, or changing connections.

   A. circuit breaker.
   B. switch.
   C. fuse.
   D. rheostat.

5. When adding water to batteries, the electrolyte level in the cells of a battery should be ______________________________ .

A. to the top of the filler hole.
B. just covering the top of the plates.
C. up to the bottom of the split ring.
D. halfway between the plates and the vent.

6. Battery vent caps should be _________________________ .

A. inspected for damaged or missing gaskets.
B. painted red for identification.
C. checked for cleanliness and serviceability.
D. installed snugly to prevent spillage of electrolyte.

7. When testing battery state of charge, you test _________ .

A. the center cells.
B. before adding water.
C. after adding water.
D. any one cell.

8. When mixing electrolyte, you should ____________________ .

A. pour water into the acid.
B. pour water and acid together.
C. pour acid into the water.
D. pour acid and water alternately.

9. The number of cells in a battery is determined by the _____________________________ .

A. voltage that is desired.
B. amperage that is required.
C. space designated for the battery.
D. components the battery supports.

10. The simplest protective device in an electrical system is the _________________________ .

A. switch.
B. circuit breaker.
C. fuse.
D. relay.

LESSON TWO

PRACTICE EXERCISE

ANSWER KEY AND FEEDBACK

Item		Correct Answer and Feedback
1.	B.	When removing the battery cables, the ground cable (negative side) should be removed first. (Page 20, para b. (1)).
2.	A.	Battery cells are filled with a solution of water and sulfuric acid which is known as electrolytes. (Page 22, para (2)).
3.	D.	The duo-check is used to test the battery state of charge. (Page 25, para (5).
4.	B.	A switch is defined as a device used in an electrical circuit for making, breaking, or changing connections. [Page 27, para (3)].
5.	C.	Electrolyte level in the cells of a battery should be up to the bottom of the split ring. [Page 24, para (3)].
6.	A.	Battery vent caps should be inspected for damage or missing gaskets. [Page 23, para (2)].
7.	B.	Test the battery before adding water to the cells. [Page 26, para (d)].
8.	C.	When mixing electrolyte, you should pour acid into the water. (Page 22, CAUTION).
9.	A.	The number of cells in a battery is determined by the voltage that is desired. (Page 21, para c.).
10.	C.	The simplest protective device in an electrical system is a fuse. [Page 27, para (1)].

APPENDIX

PUBLICATION EXTRACTS

TM 9-8000, 25 October 1985

Use the above publication extracts to take this subcourse. At the time this subcourse was written, these were the most current publications. In your work situation, always refer to the latest publications.

REMOVED PAGES
31-36

PART THREE

ELECTRICAL SYSTEMS AND RELATED UNITS

CHAPTER 11

BASIC PRINCIPLES OF ELECTRICITY

Section I. ELECTRICITY

11-1. Composition of Matter.

a. To understand electricity, first study matter, the name for all material substances. Everything (solids, liquids, and gases) is made up of tiny particles known as atoms. These atoms combine in small groups of two or more to form molecules. Air is made up of molecules. These molecules are made up of atoms, and these toms can be further subdivided. When atoms are divided, smaller particles are created, some of which have positive and others, negative electrical charges. Atoms of different materials are discussed below.

b. There are over 100 different basic materials in the universe. These basic materials are called elements. Iron is one element; copper, aluminum, oxygen, hydrogen, and mercury are other elements. An element gets its name from the fact that it cannot be broken down easily into simpler (or more elemental) substances. In other words, more than 100 basic elements are the building materials from which the universe is made. If any one of these elements is studied closely, it is obvious that it is made up of those same basic particles having positive and negative electrical charges as discussed above.

c. The basic particles that make up all the elements, and thus all the universe, are called protons, electrons, and neutrons. A proton is a basic particle having a single positive charge; a group of protons produces a positive electrical charge. An electron is a basic particle having a single negative charge; therefore, a group of electrons produces a negative electrical charge. A neutron is a basic particle having no charge; a group of neutrons, therefore, would have no charge.

d. Examine the construction of atoms of the various elements, starting with the simplest of all, hydrogen. The atom of hydrogen consists of one proton, around which is circling one electron (fig. 11-1). There is an attraction between the two particles, because negative and positive electrical charges always attract each other.

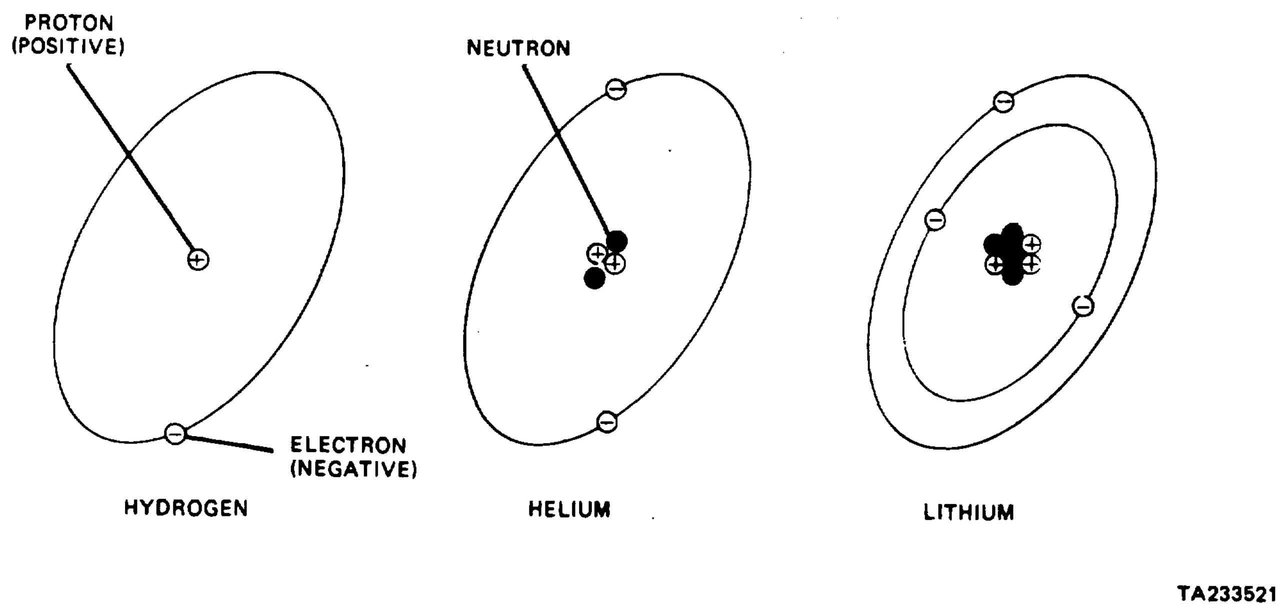


Figure 11-1. Composition of Matter.

Opposing the attraction between the two particles, and thus preventing the electron from moving into the proton, is the centrifugal force on the electron caused by its circular path around the proton. This is the same sort of balance achieved if a ball tied to a string was whirled in a circle in the air. The centrifugal force exerted tries to move the ball out of its circular path, and is balanced by the string (the attractive force). If the string should break, the centrifugal force would cause the ball to fly away. Actually, this is what happens at times with atoms. The attractive force between the electron and proton sometimes is not great enough to hold the electron in its circular path, and the electron gets away.

e. A slightly more complex atom is shown in figure 11-1. This is an atom of helium. Notice that there are now two protons in the center and that two electrons are circling around the center. Because there is an additional proton in the center, or nucleus, of the atom, an electron must be added so as to keep the atom in electrical balance. Notice also that there are two additional particles in the nucleus; these are called neutrons. Neutrons are necessary in order to overcome the tendency of the two protons to move apart from each other. For, just as unlike electrical charges attract, so do like electrical charges repel. Electrons repel electrons. Protons repel protons, except when neutrons are present. Though neutrons have no electrical charge, they do have the ability to cancel out the repelling forces between protons in an atomic nucleus and thus hold the nucleus together.

f. A still more complex atom is shown in figure 1-1. This is an atom of lithium, a light, soft metal. Note that a third proton has been added to the nucleus and that a third electron is now circling around the nucleus. There also are two additional neutrons in the nucleus; these are needed to hold the three protons together. The atoms of other elements can be seen in a similar manner. As the atomic scale Increases in complexity, protons and neutrons are added one by one to the nucleus, and electrons to the outer circles. After lithium comes beryllium with four protons and five neutrons, boron with five protons and five neutrons, carbon with six and six, nitrogen with seven and seven, oxygen with eight and eight, and so on. In each of these, there are normally the same number of electrons circling the nucleus as there are protons in the nucleus.

11-2. Composition of Electricity (Fig. 11.2).

a. When there are more than two electrons in an atom, they will move about the nucleus in different size orbits. These orbits are referred to as shells. The innermost shells of the atom contain electrons that are not easily freed and are referred to as bound electrons. The outermost shell will contain what is referred to as free electrons. These free electrons differ from bound electrons in that they can be moved readily from their orbit.

b. If a point that has an excess of electrons (negative) is connected to a point that has a shortage of electrons (positive), a flow of electrons (electrical current) will flow through the connector (conductor) until an equal electric charge exists between the two points.

11-3. Electron Theory of Electricity (Fig. 11-2). A charge of electricity is formed when numerous electrons break free of their atoms and gather in one area. When the electrons begin to move in one direction (as along a wire, for example), the effect is a flow of electricity or an electric current. Actually, electric generators and batteries could be called electron pumps, because they remove electrons from one part of an electric circuit and concentrate them in another part of the circuit. For example, a generator takes electrons away from the positive terminal and concentrates them at the negative terminal. Because the electrons repel each other (like electrical charges repel), the electrons push out through the circuit and flow to the positive terminal (unlike electrical charges attract). Thus, we can see that an electric current is actually a flow of electrons from negative to positive.

This is just the reverse of the old idea of current flow. Before scientists understood what electric current was, they assumed that the current flowed from positive to negative. However, their studies showed that this was wrong, because they learned that the current is electron movement from negative (concentration of electrons) to positive (lack of electrons).

11-4. Conductors and insulators (Fig. 11-3).

a. *General.* Any material that will allow electric current to flow through it is an electrical

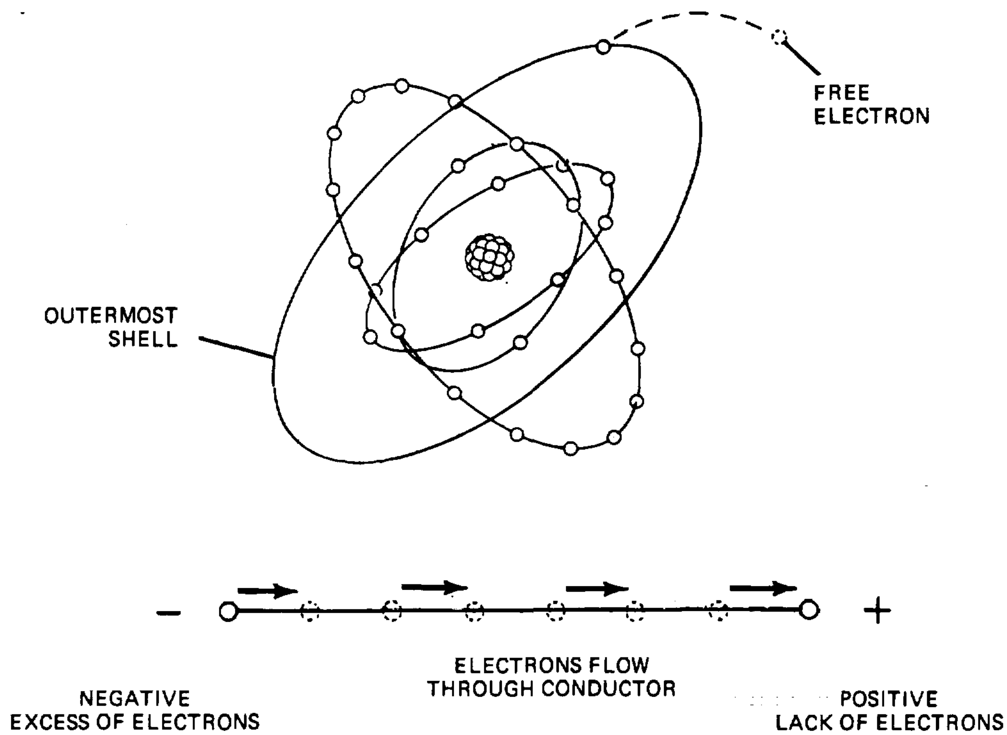


Figure 11-2. Composition of Electricity.

conductor. Any material that blocks electric current flow is an electrical insulator. Conductors are used in automotive equipment to carry electric current to all of the electrical equipment. Insulators also are necessary to keep the electric current from taking a shorter route instead of going to the intended component. The electrical properties of a substance depends mainly on the number of electrons in the outermost orbits of its atoms that cannot, at any time, contain more than eight electrons.

b. Conductors (A, Fig. 11-3). Whenever there are less than four electrons in the outer orbits of the atoms of a substance, these electrons will tend to be free. This will cause the substance to permit free motion of electrons, making it a conductor. Electrical energy is transferred through conductors by means of the movement of free electrons that migrate from atom to atom within the conductor. Each electron moves a short distance to the neighboring atom, where it replaces one or more electrons by forcing

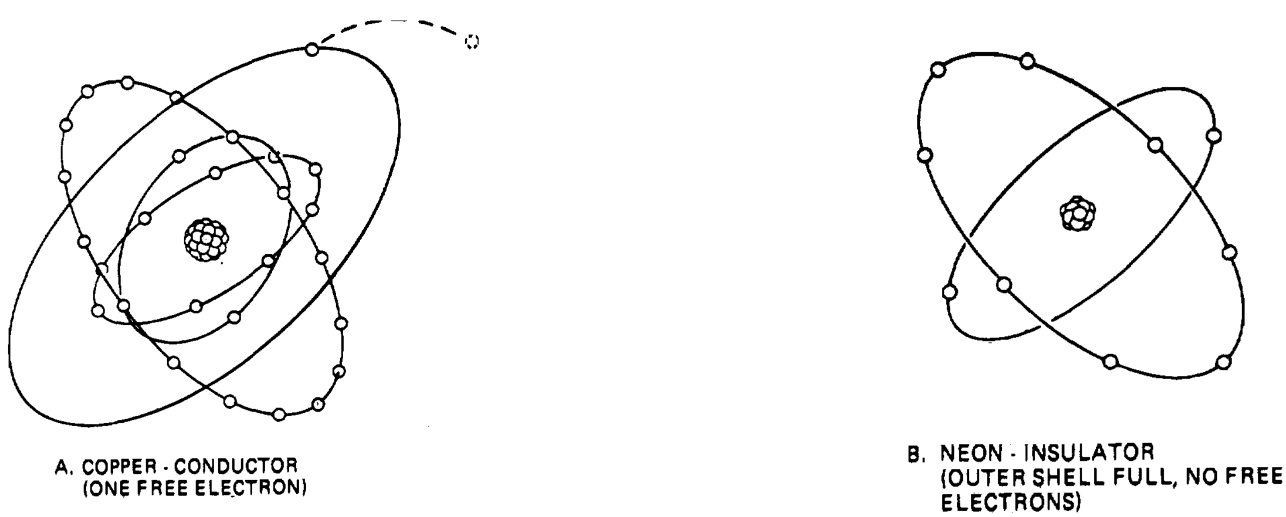


Figure 11-3. Conductors and Insulators.

them out of their orbits. The replaced electrons repeat this process in nearby atoms until the movement is transmitted throughout the entire length of the conductor, thus creating a current flow. Copper is an example of a good conductor because it only has one free electron. This electron is not held very strongly in its orbit and can get away from the nucleus very easily. Silver is a better conductor of electricity but it is too expensive to be used in any great quantity. Because of this, copper is the conductor used most widely in automotive applications.

c. Insulators (B, Fig. 11-3). Whenever there are more than four electrons in the outer orbits of the atoms of a substance, these electrons will tend to be bound, causing restriction of free electron movement, making it an insulator. Common insulating substances in automotive applications are rubber, plastic, Bakelite, varnish, and fiberboard.

Section II. SEMICONDUCTOR DEVICES

11-5. Fundamental Principles.

a. Description. Paragraph 11-4 explains that any substance whose atoms contain less than four electrons in their outermost orbits is classified as an electrical conductor. It also is explained that any substance whose atoms contain more than four electrons in their outermost orbits is classified as an electrical insulator. A special case exists, however, when a substance contains four electrons in the outermost orbits of its atoms. This type of substance is known as a semiconductor and is the basis for all modern electronic equipment. The most popular of all semiconductors is silicon.

b. Characteristics of Semiconductors. in its pure state, silicon is neither a good conductor or insulator. But by processing silicon in the following ways, its conductive or insulative properties can be adjusted to suit just about any need.

(1) When a number of silicon atoms are jammed together in crystalline (glasslike) form, they form a covalent (sharing) bond. Therefore, the electrons in the outer ring of one silicon atom join with the outer ring electrons of other silicon atoms, resulting in a sharing of outer ring electrons between all of the atoms. It can be seen in figure 11-4 that covalent sharing gives each atom eight electrons in its outer orbit, making the orbit complete. This makes the material an insulator because it contains more than four electrons in its outer orbit.

(2) When certain materials such as phosphorus are added to the silicon crystal in highly controlled amounts the resultant mixture becomes a conductor (fig. 11-5). This is because phosphorus, which has five electrons in forming a covalent bond with silicon (which has four electrons in its outer shell), will yield one free electron per molecule, thus making the material an electrical conductor. The process of adding impurities to a semiconductor is called doping. Any semiconductor material that is doped to yield free electrons is called N-type material.

(3) When boron, which has three electrons in its outer ring, is used to dope the silicon crystal, the resultant covalent bonding yields seven electrons in the outer shell. This leaves an opening for another electron and is illustrated in figure 11-6. This space is called a hole and can be considered a positive charge just as the extra electrons that exist in N-type semiconductor material are considered a negative charge. Materials that have holes in their outermost electron shells are called positive or P-type materials. In order to understand the behavior of P-type semiconductors, it is necessary to look upon the hole as a positive current carrier, just as the free electron in N-type semiconductors are considered negative current carriers. Just as electrons move through N-type semiconductors, holes move from atom-to-atom in P-type semiconductors. Movement of holes through P-type semiconductors, however, is from the positive terminal to the negative terminal. For this reason, any circuit analysis of solid-state circuitry is done on the basis of positive to negative (conventional) current flow.

c. Hole Movement Theory (Fig. 11-7). When a source voltage, such as a battery, is connected to N-type material, an electric current will flow through it. The current flow in the N-type semiconductor consists of the movement of free

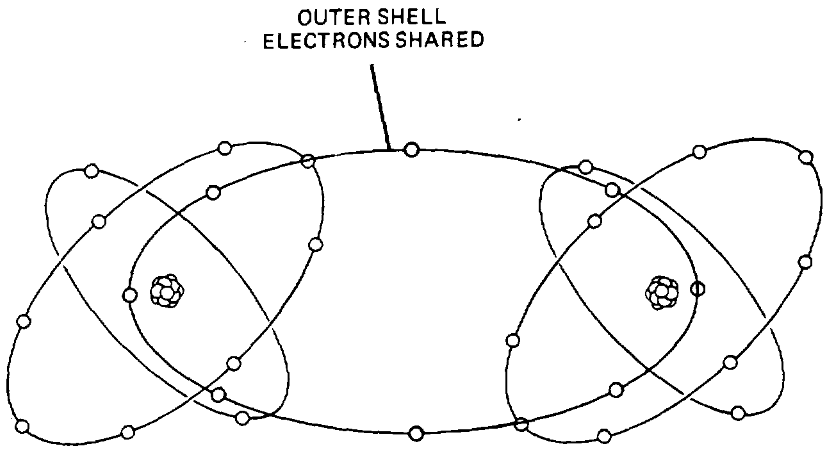


Figure 11-4. Covalent Bonding OF Silicon.

electrons, the same as the current flow through a natural conductor such as copper. When a current source of sufficient voltage is connected across a P-type material, an electric current will also flow through it, but any current flow in a P-type semiconductor is looked upon as the movement of positively charged holes. The holes appear to move toward the negative terminal as the electrons enter the material at the negative terminal, fill the holes, and then move from hole to hole toward the positive terminal. As is the case with N-type semiconductors, the movement of electrons through P-type semiconductors toward the positive terminal is motivated by the natural attraction of unlike charges.

11-6. Diodes(Fig. 11-8).

a. Purpose. A diode is a device that will allow current to pass through itself in only one direction. A diode can be thought of as an electrical checkvalve.

b. Construction. A diode is made by joining N-type material and P-type material together. The negative electrical terminal is located at the N-type material and the positive terminal is located on the P-type material.

c. Operation. When a diode is placed in a circuit, the N-material is connected to the

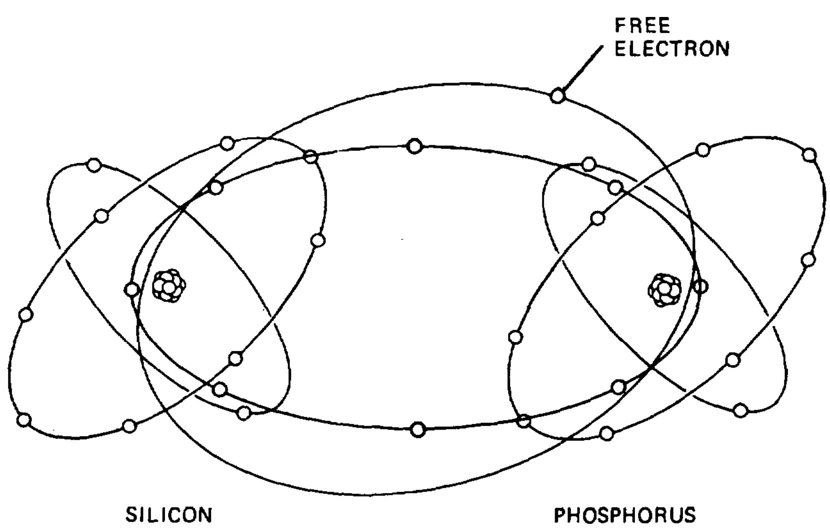


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Figure 11-5. Phosphorus-Doped Silicon.

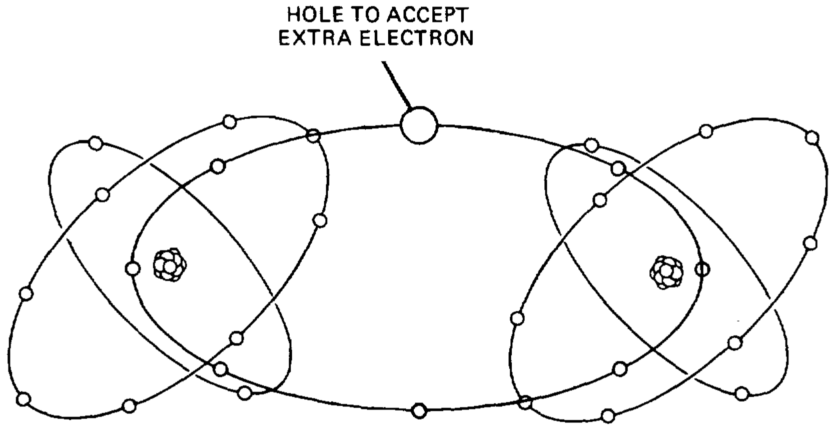

Figure 11-6. Boron-Doped Silicon.

negative side of the circuit and the positive side of the circuit is connected to the P-material. In this configuration, which is known as forward bias, the diode is a good conductor. This is because the positively charged holes in the P-type material move toward the junction with the negatively charged N-material so that electrons may cross the junction and fill these holes using them to move across the P-material. If the connections to the diode are reversed, current flow will be blocked. This configuration is known as reverse bias. When the diode is connected backwards, the positively charged holes are attracted away from the junction to the negative terminal and the free electrons in the N-material are attracted away from the junction to the positive terminal. Without the presence of holes at the junction, the electrons cannot cross it.

11-7. Zener Diodes (Fig. 11-9). The diode, as described in paragraph 11-6, is a semiconductor device that allows current to flow only in one direction. A zener diode, however, is a special type that allows reverse current to flow as long as the voltage is above a value that is built into the device when it is manufactured. As an example, a certain zener diode may not conduct current if the reverse bias voltage is below 6 volts. As the voltage increases to 6 volts or more, the diode suddenly will begin to conduct reverse bias current. This device is used in control circuits such as voltage regulators.

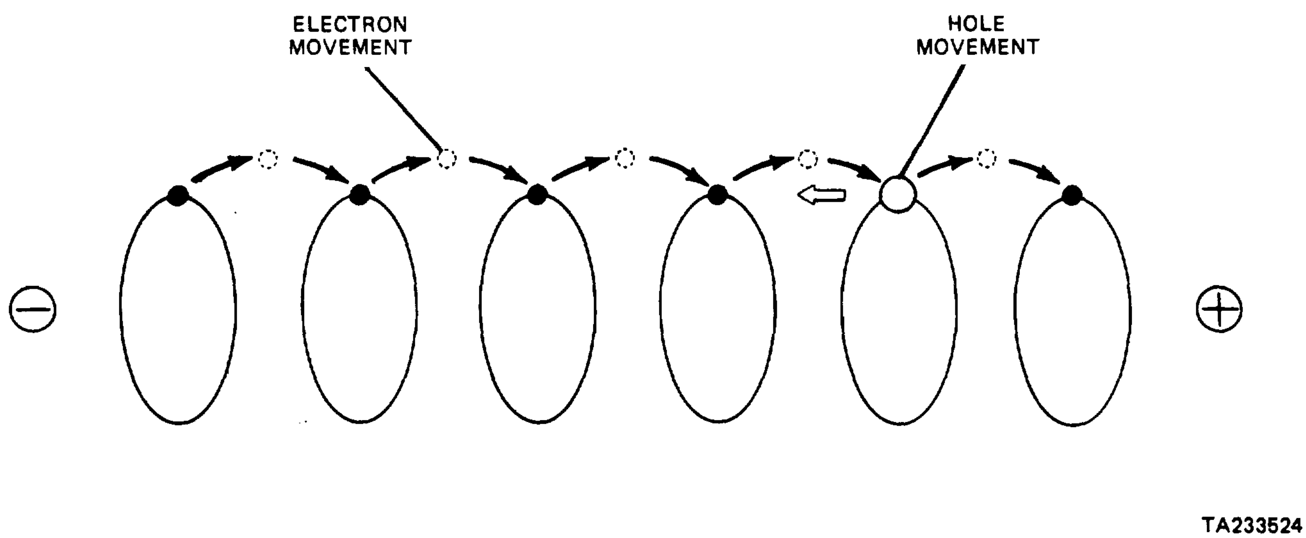

Figure 11-7. Hole Movement Theory.

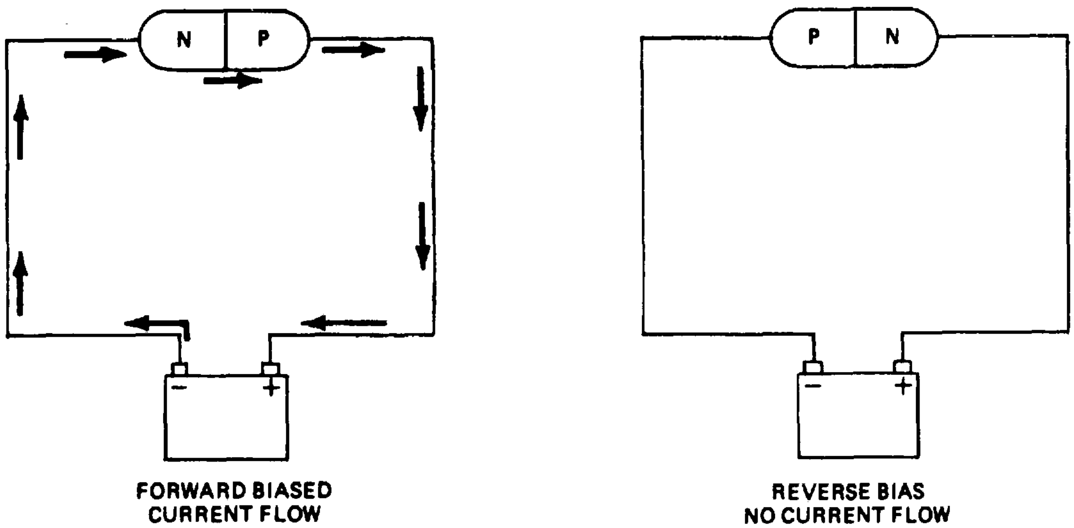

Figure 11-8. Diode Operation.

11-8. Transistors.

a. General (Fig. 11-10). Transistors, as they apply to automotive applications, are switching devices. They can switch large amounts of electric current on and off using relatively small amounts of electric current. Because transistors operate electronically, they last much longer than the relays they replace. This is because they have no contact points to burn. The major automotive applications of transistors are for electronic ignition systems and voltage regulators.

b. PNP Transistors (Fig. 11-11). The PNP transistor is the most common configuration in automotive applications. It is manufactured by sandwiching an N-type semiconductor element between two P-type semiconductor elements. A positive charge is applied to one of the P-type elements. This element is called the emitter. The other P-type element connects to the electrical component. This element is called the collector. The third element, which is in the middle, is made of N-type material and is called the base. The application of a low-current negative charge to the base will allow a heavy current to flow between the emitter and the collector. Whenever the current to the base is switched off, the current flow from the emitter to the collector is interrupted also.

c. NPN Transistors (Fig. 11-11). The NPN transistor is similar to the PNP transistor. The difference is that it is used in the negative side of the circuit. As the name NPN implies, the makeup of this transistor is two elements of N-type material (collector and emitter) with an element of P-type material (base) sandwiched in between. The NPN transistor will allow a high-current negative charge to flow from the collector to the emitter-whenever a relatively low current positive charge is applied to the base.

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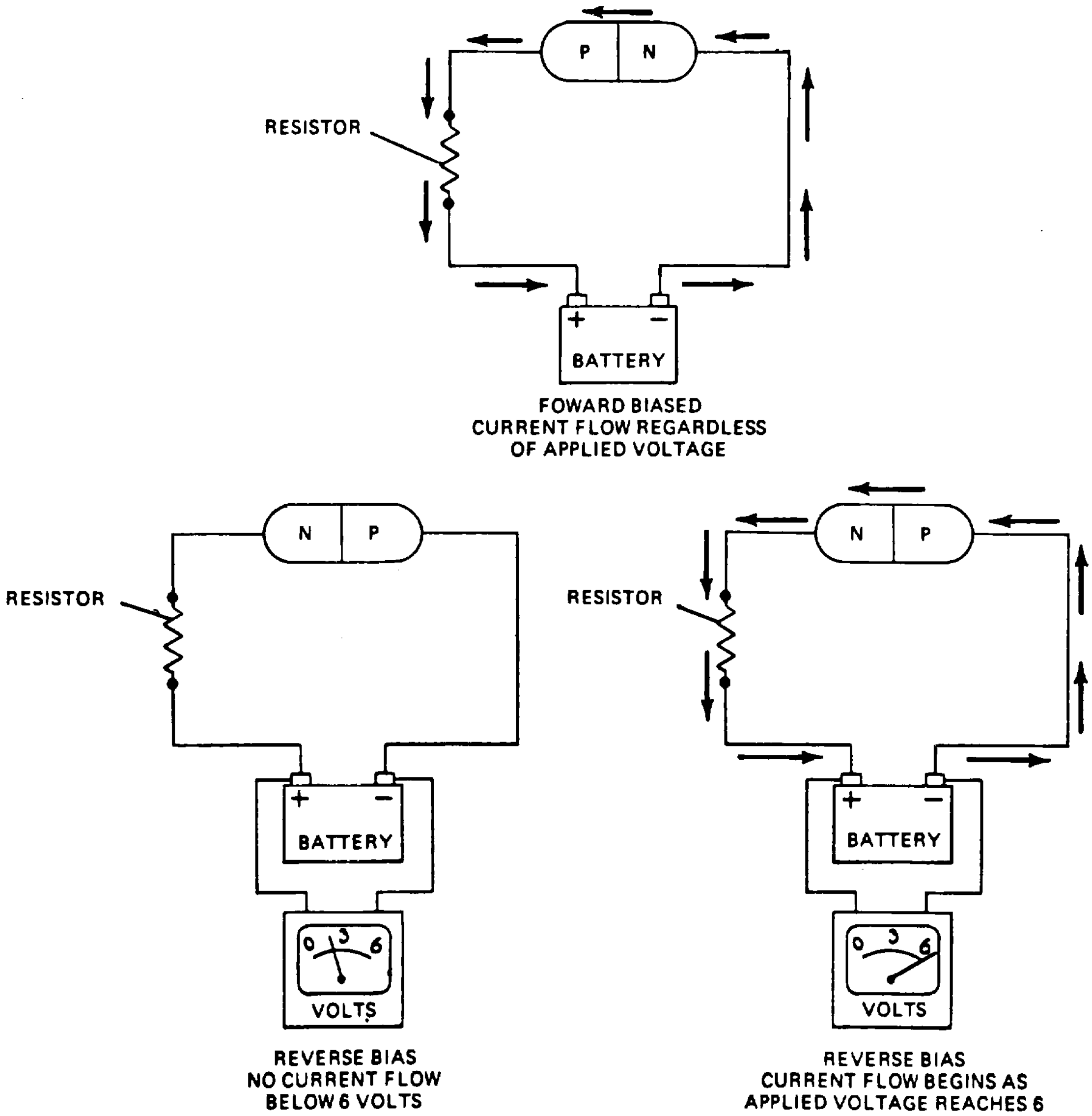

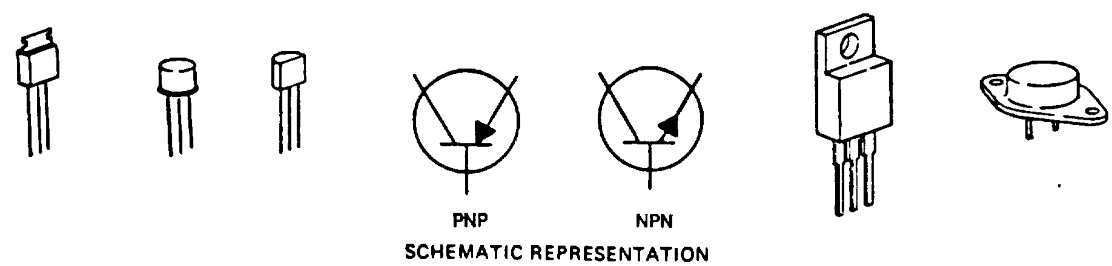

Figure 11-9. & Figure 11-10. Transistor Configurations.

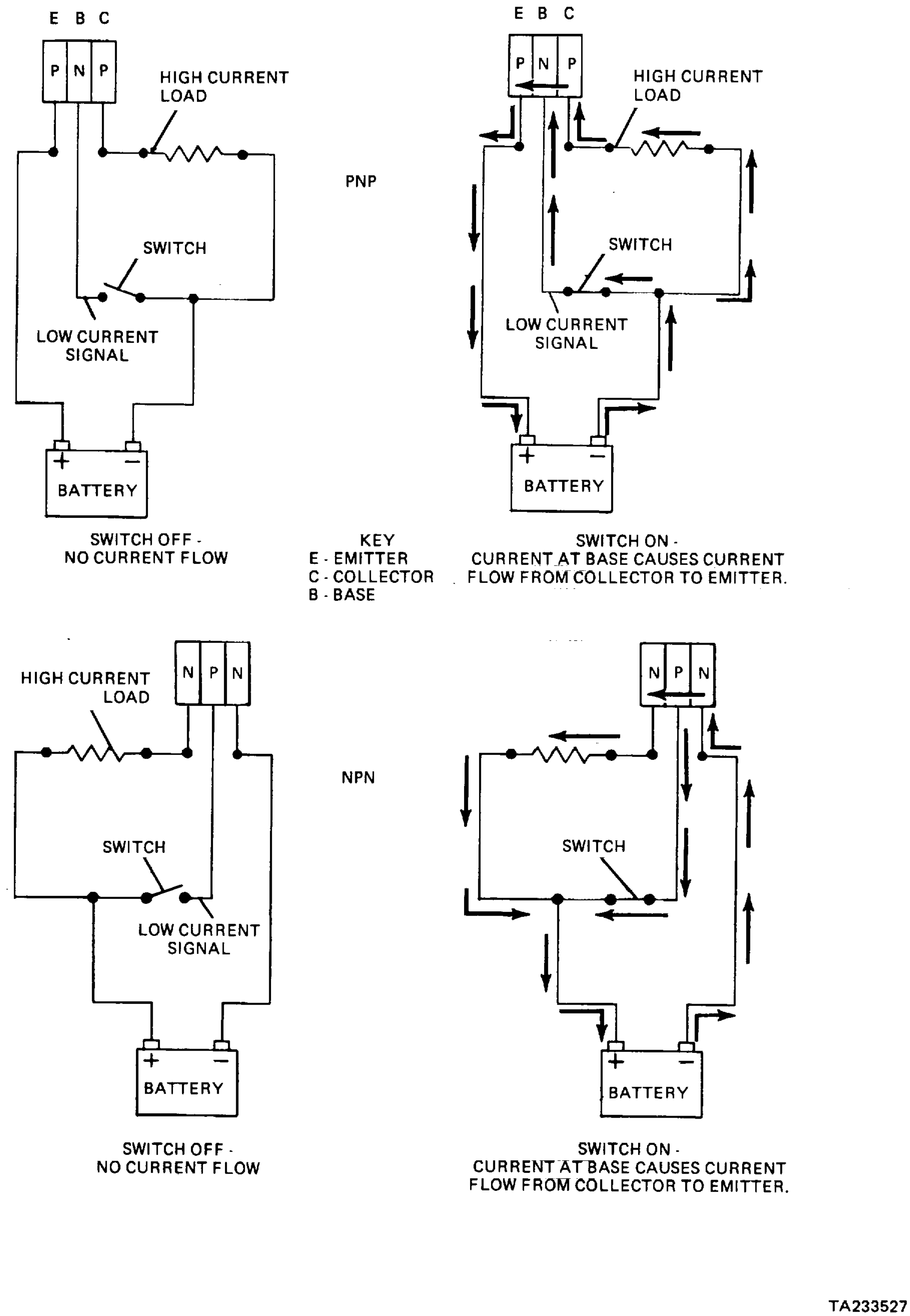

Figure 11-11. Transistor Operation.

Section III. 11-9. Amperage(Current) and Voltage.

a. Amperes. Current flow, or electron flow, is measured in amperes. While it is normally considered that one ampere is a rather small current of electricity (approximately what a 100-watt light bulb would draw), it is actually a tremendous flow of electrons. More than 6 billion billion electrons a second are required to make up one ampere.

b. Voltage. Electrons are caused to flow by a difference in electron balance in a circuit; that is, when there are more electrons in one part of a circuit than in another, the electrons move from the area where they are concentrated to the area where they are lacking. This difference in electron concentration is called potential difference, or voltage. The higher the voltage goes, the greater the electron imbalance becomes. The greater this electron imbalance, the harder the push on the electrons (more electrons repelling each other) and the greater the current of electrons in the circuit. When there are many electrons concentrated at the negative terminal of a generator (with a corresponding lack of electrons at the positive terminal), there is a much stronger repelling force on the electrons and, consequently, many more electrons moving in the wire. This is exactly the same as saying that the higher the voltage, the more electric current will flow in a circuit, all other things, such as resistance (para 11-10), being equal.

11-10. Resistance.

a. Even though a copper wire will conduct electricity with relative ease, it still offers resistance to electron flow. This resistance is caused by the energy necessary to break the outer shell electrons free, and the collisions between the atoms of the conductor and the free electrons. It takes force (or voltage) to overcome the resistance encountered by the flowing electrons. This resistance is expressed in units called ohms. The resistance of a conductor varies with its length, cross-sectional area, composition, and temperature.

b. A long wire offers more resistance than a short wire of the same cross-sectional area. The electrons have farther to travel.

c. Some elements can lose electrons more readily than other elements. Copper loses electrons easily, so there are always many free electrons in a copper wire. Other elements, such as iron, do not lose their electrons quite as easily, so there are fewer free electrons in an iron wire (comparing it to a copper wire of the same size). Thus, with fewer free electrons, fewer electrons can push through an iron wire; that is, the iron wire has more resistance than the copper wire.

d. A small wire (in thickness or cross-sectional area) offers more resistance than a large wire. in the small wire, there are fewer free electrons (because fewer atoms), and thus fewer electrons can push through.

e. Most metals show an increase in resistance with an increase in temperature, while most nonmetals show a decrease in resistance with an increase in temperature. For example, glass (a nonmetal) is an excellent insulator at room temperature but is a very poor insulator when heated to red heat.

11-11. Ohm's Law.

a. The general statements about voltage, amperage, and ohms (para 11-9 and 11-10) can all be related in a statement known as ohm's law, so named for the scientist Georg Simon Ohm who first stated the relationship. This law says that voltage is equal to amperage times ohms. Or, it can be stated as the mathematical formula:

$$E = I \times R$$

where E is volts, I is current in amperes, and R is resistance in ohms. For the purpose of solving problems, the ohms law formula can be expressed three ways:

(1) To find voltage: $E = IR$

(2) To find amperage: $I = E/R$

(3) To find ohms: $R = E/I$

b. This formula is a valuable one to remember because it makes understandable many of the things that happen in an electric circuit. For instance, if the voltage remains constant, the current flow goes down if the resistance goes up. An example of this would be the lighting circuit that is going bad in a truck. Suppose the wiring circuit between the battery and the lights has deteriorated due to connections becoming poor, strands in the wire breaking, switch contacts becoming dirty, or other, similar problems. All of these conditions reduce the electron path or, in other words, increase resistance. And, with this increased resistance, less current will flow. The voltage of the battery stays the same (for example, 12 volts). if the resistance of the circuit when new (including light bulbs) was 6 ohms, then 2 amperes will flow. To satisfy the equation, 12 (volts) must equal 12 (amperes times ohms resistance). But if the resistance goes up to 8 ohms, only 1.5 amperes can flow. The increased resistance cuts down the current flow and, consequently, the amount of light.

c. A great majority of electrical troubles on automotive vehicles result from increased resistance in circuits due to bad connections, deteriorated wiring, dirty or burned contacts in switches, or other such problems. With any of these conditions, the resistance of the circuit goes up and the ampere flow through that circuit goes down. Bad contact points in the ignition circuit will reduce current flow in the circuit and cause weak sparks at the spark plugs. This will result in engine missing and loss of power.

d. If the resistance stays the same but the voltage increases, the amperage also increases. This is a condition that might occur if a generator voltage regulator became defective. In such a case, there would be nothing to hold the generator voltage within limits, and the voltage might increase excessively. This would force excessive amounts of current through various circuits and cause serious damage. If too much current went through the light bulb filaments, for example, the filaments would overheat and burn out. Also, other electrical devices probably would be damaged.

e. On the other hand, if the voltage is reduced, the amount of current flowing in a circuit will also be reduced if the resistance stays the same. For example, with a run-down battery, battery voltage will drop excessively with a heavy discharge. When trying to start an engine with a run-down battery, the voltage will drop very low. This voltage is so low that it cannot push enough current through the starter for effective starting of the engine.

11-12. Circuit Configurations.

a. General (Fig. 11-12). A very basic circuit consists of a power source, a unit to be operated, and a wire to connect the two together. if the unit to be operated is to be controlled, a switch will be included in the circuit also.

b. Automotive Circuits (Fig. 11-13). The body and chassis in an automobile are made of steel. This feature is utilized to eliminate one of the wires from all of the automobile's circuits. By attaching one of the battery terminals to the body and chassis, any electrical component can be connected by hooking up one side, by wire, to the car battery and the other side to the body. The practice of connecting one side of the battery to the automobile body is called grounding. Virtually all current automotive manufacturers ground the negative side of the battery. This is referred to as an electrical system with a negative ground. Vehicles with a positive ground are very uncommon at the present time.

c. Series Circuits (A, Fig. 11-14). A series circuit consists of two or more resistance units (electrically operated components) that are connected together in an end-to-end manner so that any current flow in the circuit is dependent on a complete path through all of the units. The following characteristics of series circuits are important:

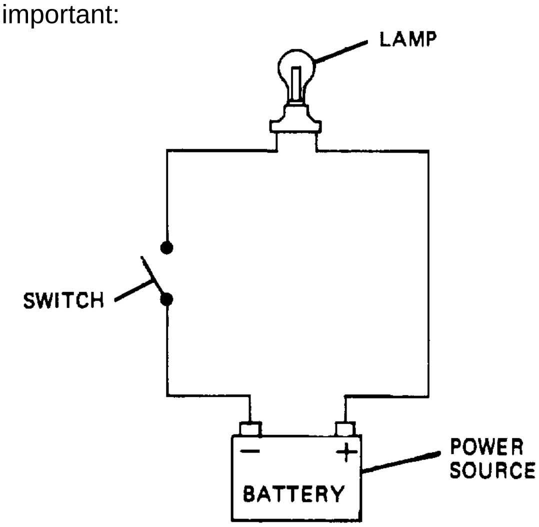

Figure 11-12. Basic Electrical Circuit.

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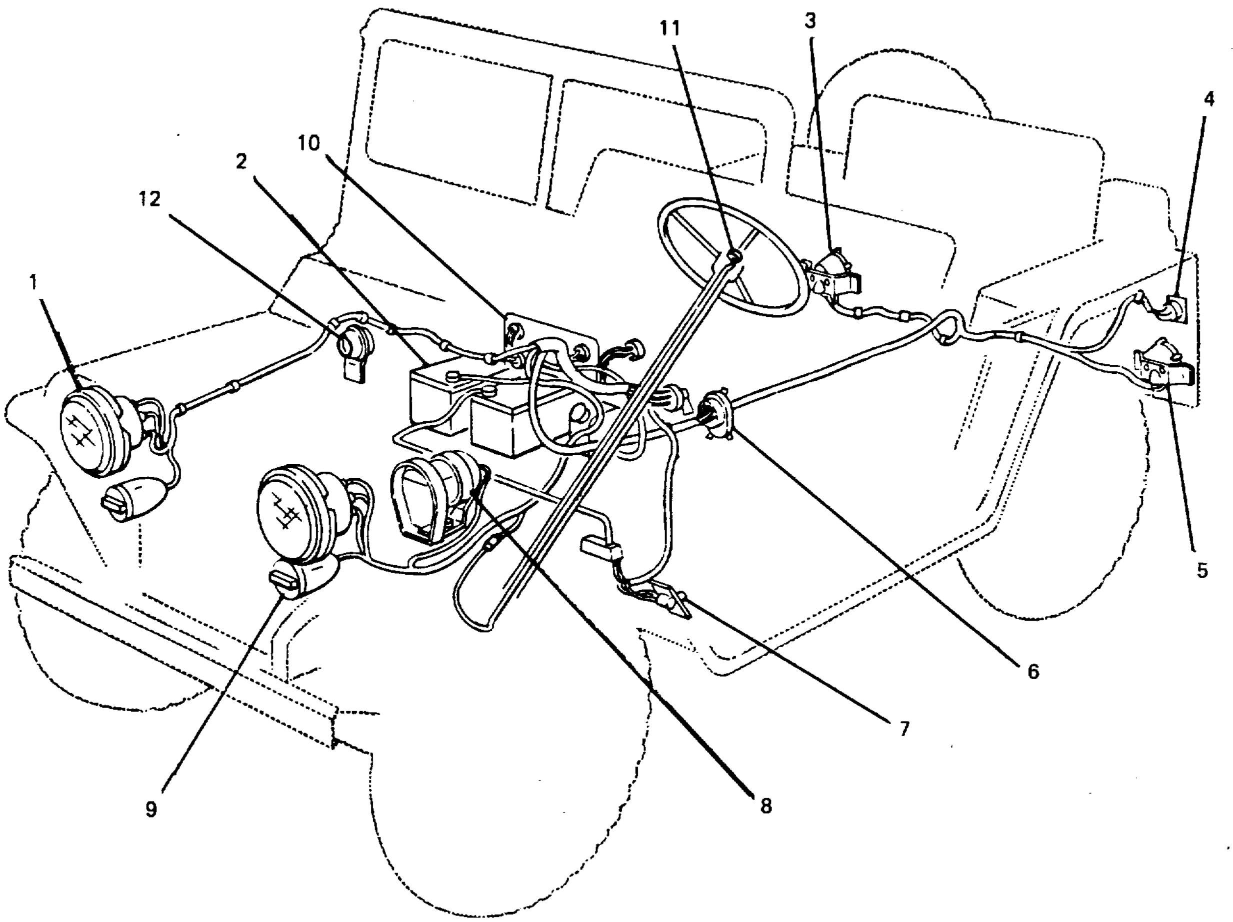

1. HEADLIGHT
2. BATTERIES
3. BLACKOUT AND SERVICE TAILLIGHT
4. TRAILER RECEPTACLE
5. BLACKOUT TAILLIGHT, SERVICE TAILLIGHT, AND SERVICE STOPLIGHT
6. LIGHT SWITCH
7. DIMMER SWITCH
8. BLACKOUT DRIVE LIGHT
9. BLACKOUT SERVICE LIGHT
10. INSTRUMENT CLUSTER
11. HORN BUTTON
12. HORN

Figure 11-13. Typical Automotive Circuit.

(1) Any break in the circuit (such as a burned-out light bulb) will render the entire circuit inoperative.

(2) The current (amperage) will be constant throughout the circuit.

(3) The total resistance of the circuit is equal to the sum of the individual resistances.

(4) The total voltage of the circuit is equal to the sum of the individual voltage drops across each component.

d. Parallel Circuits (B, Fig. 11-14). A parallel circuit consists of two or more resistance units (electrically operated components) connected in separate branches. In a parallel circuit, each component receives full voltage from the source. The following characteristics of parallel circuits are important.

(1) The total resistance of the circuit will always be less than the resistance of any individual component.

(2) The disconnection or burning out of any individual component in the circuit will not affect the operation of the others.

(3) The current will divide itself among the circuit branches according to the resistances of

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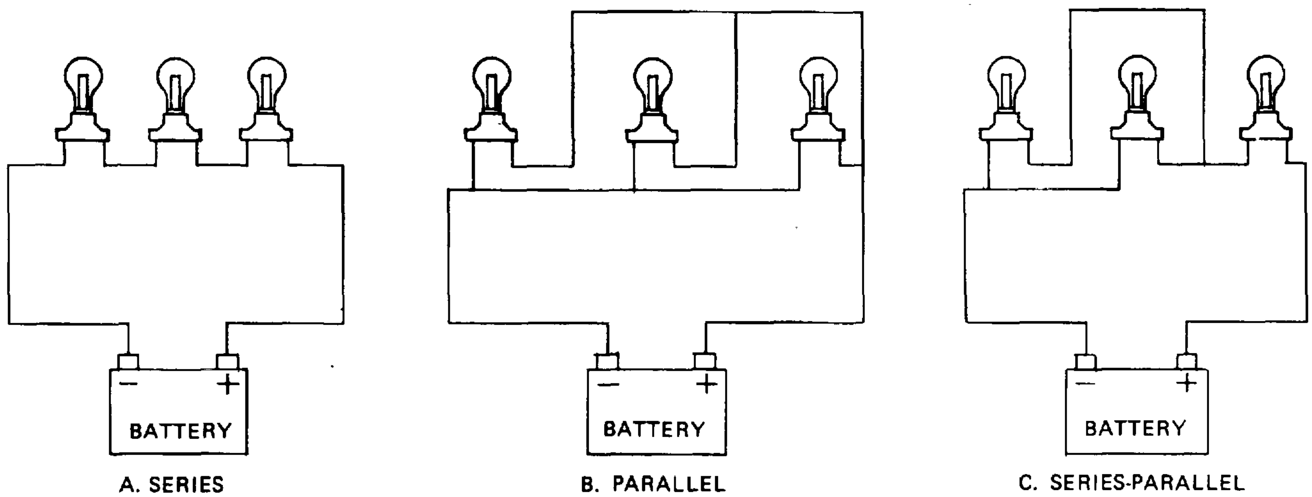

Figure 11-14. Circuit Configurations.

the individual components. The sum of the individual amperages will be equal to the total circuit current.

(4) The voltage will be constant throughout the circuit when measured across the individual branches.

e. Series-Parallel Circuit (C, Fig. 11-14). The series-parallel circuit is a combination of the two configurations. There must be at least three resistance units to have a series-parallel circuit. The following characteristics of series-parallel circuits are important.

(1) The total circuit voltage will be equal to the sum of the total parallel circuit voltage drop plus the voltage drops of the individual series circuit components.

(2) The total circuit resistance will be equal to the sum of the total parallel circuit resistance plus the individual resistances of the series circuit components.

(3) Current flow through the total parallel circuit will be equal to the current flow through any individual series circuit component.

(4) The disconnection or the burning out of any of the series components will completely disable the entire circuit, whereas a failure of any of the parallel circuit components will leave the balance of the circuit still functioning.

Section IV. MAGNETS

11-13. Magnetic Field.

a. General. It was stated in paragraph 11-9 that electric current is a flow of electrons and that the imbalance of electrons in a circuit (that causes electrons to flow) is called voltage. Magnets will be studied to learn what causes a generator to concentrate electrons at the negative terminal and take them away from the positive terminal.

b. Magnetic Lines of Force. If iron filings were sprinkled on a piece of glass on top of a bar, magnet, the filings would become arranged in curved lines (fig. 11-15). These curved lines, extending from the two poles of the magnet (north and south), follow the magnetic lines of force surrounding the magnet. Scientists have formulated the following rules for these lines of force.

(1) The lines of force (outside the magnet) pass from the north to the south pole of the magnet.

(2) The lines of force act somewhat as rubberbands and try to shorten to a minimum length.

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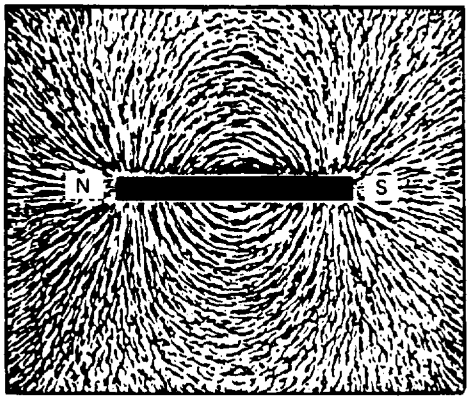

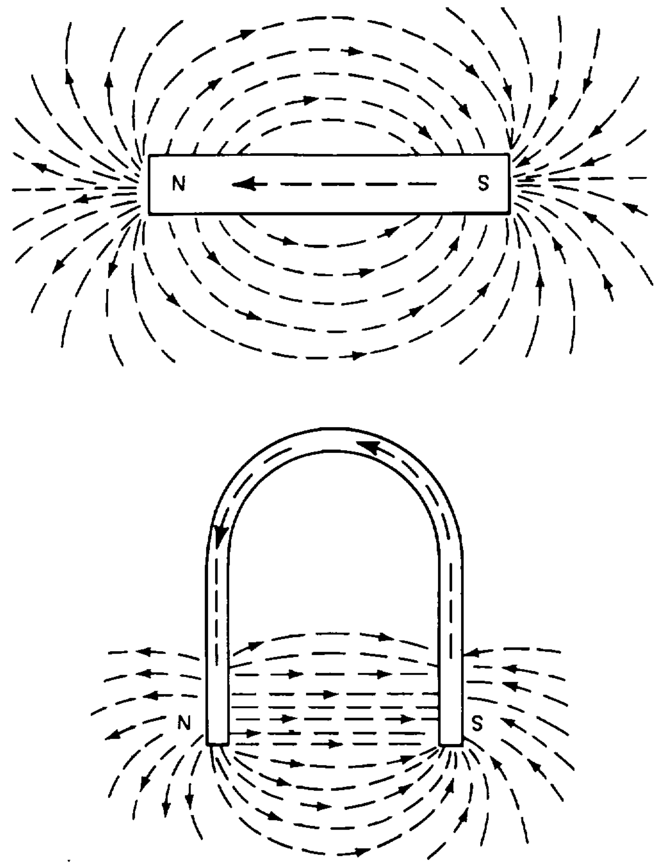

Figure 11-16. Bar and Horseshoe Magnet.

Figure 11-15. (3) The lines of force repel each other along their entire length and try to push each other apart.

(4) The rubberband characteristic opposes the push-apart characteristic.

(5) The lines of force never cross each other.

(6) The magnetic lines of force, taken together, are referred to as the magnetic field of the magnet.

c. Bar and Horseshoe Magnets. The magnetic fields of a bar and of a horseshoe magnet are shown in figure 11-16. In each, note how the lines of force curve and pass from the north to the south pole.

d. Effects Between Magnetic Poles (Fig. 11-17). When two unlike magnetic poles are brought together, they attract. But when like magnetic poles are brought together, they repel. These actions can be explained in terms of the rubberband and the push-apart characteristics. When unlike poles are brought close to each other, the magnetic lines of force pass from the north to the south poles. They try to shorten (like rubberbands), and, therefor try to pull the two poles together. On the other hand, if like poles are brought close to each other, lines of force going in the same direction are brought near each other. Because these lines of force attempt to push apart, a repelling effect results between the like poles.

11-14. Electromagnetism.

a. An electric current (flow of electrons) always produces a magnetic field. In the wire

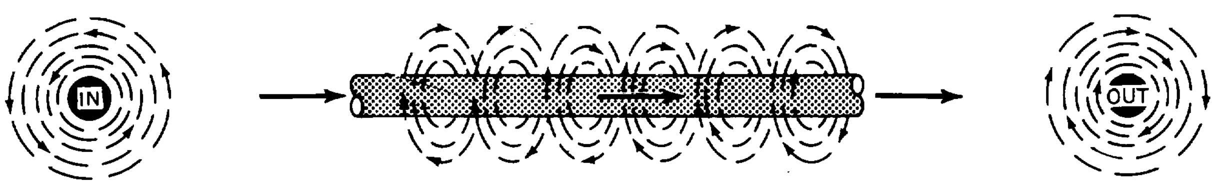

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Figure 11-17. Effects Between Magnetic Poles.

shown in figure 11-18, current flow causes lines of force to circle the wire. It is thought that these lines of force result from the movement of the electrons along the wire. As they move, the electrons send out the lines of force. When many electrons move, there are many lines of force (the magnetic field is strong). Few electrons in motion means a weak magnetic field or few lines of force.

b. Electron movement as the basis of magnetism in bar and horseshoe magnets can be explained by assuming that the atoms of iron are so lined up in the magnets that the electrons are circling in the same direction. With the electrons moving in the same direction, their individual magnetic lines of force add to produce the magnetic field.

c. The magnetic field produced by current flowing in a single loop of wire is shown in figure 11-19. The magnetic lines of force circle the wire, but here they must follow the curve of the wire. If two loops are made in the conductor, the lines of force will circle the two loops. In the area

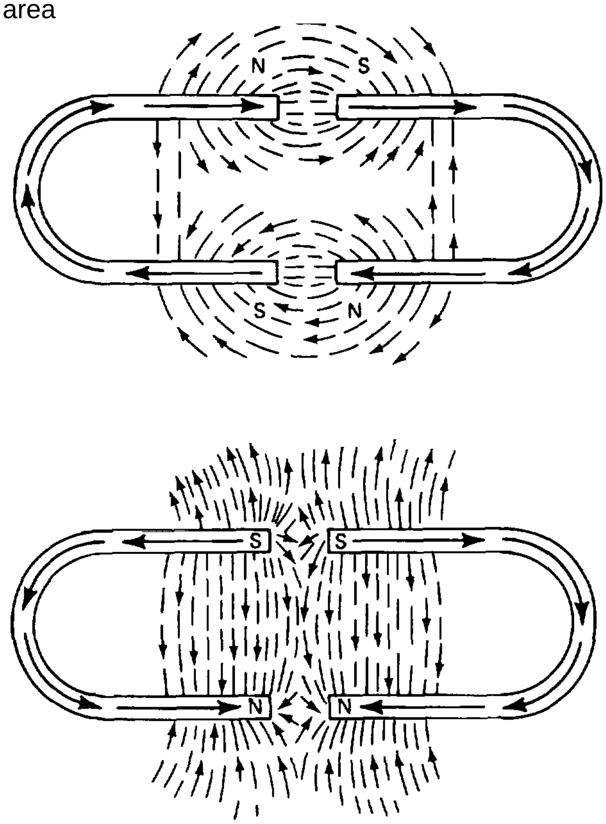

Figure 11-18. Electromagnetism.

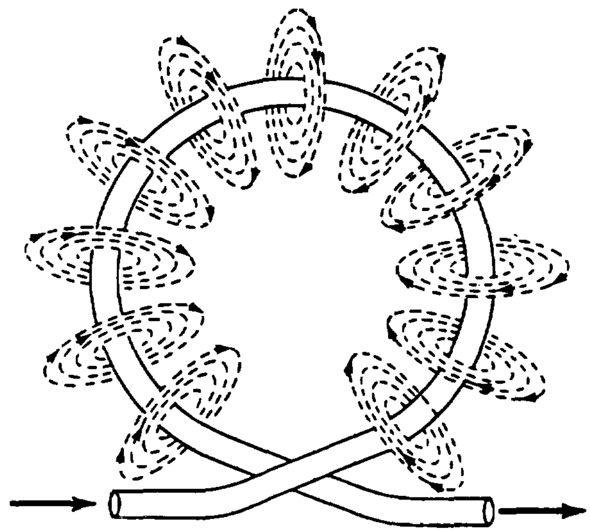

Figure 11-19. Electromagnetism in a Wire Loop.

between the adjacent loops, the magnetic lines are going in opposite directions. In such a case, because they are of the same strength (from same amount of current traveling in both loops), they cancel each other out. The lines of force, therefore, circle the two loops almost as though they were a single loop. However, the magnetic field will be twice as strong because the lines of force of the two loops combine.

d. When many loops of wire are formed into a coil as shown in figure 11-20, the lines of force of all loops combine into a pattern that resembles greatly the magnetic field surrounding a bar magnet. A coil of this type is known as an electromagnet or a solenoid. However, electromagnets can be in many shapes. The field coils of generators and starters, the primary winding in an ignition coil, the coils in electric gages, even the windings in a starter armature, can be considered to be electromagnets. All of these produce magnetism by electrical means, as discussed in paragraph 11-15.

e. The north pole of an electromagnet can be determined, if the direction of current flow (from negative to positive) is known, by use of the left- handed rule (fig. 11-21). The left hand is held around the coil with the fingers pointing in the direction of current flow. The thumb will point to the north pole of the electromagnet. This rule is based on current, or electron, flow from negative to positive

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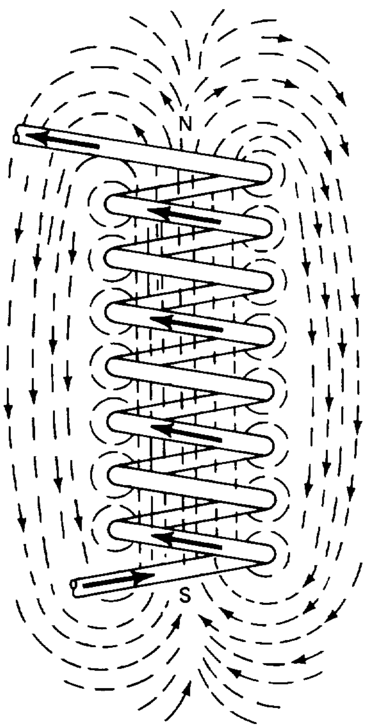

Figure 11-20. Electromagnetism in a Wire Coil.

f. The left-handed rule also can be used to determine the direction that lines of force circle a wire-carrying current if the direction of current is known. This is done by circling the wire with the left hand with the thumb pointing in the direction of current flow (negative to positive). The fingers will then point in the direction that the magnetic field circles the wire.

g. The strength of an electromagnet can be increased greatly by wrapping the loops of wire around an iron core. The iron core passes the lines of force with much greater ease than air.

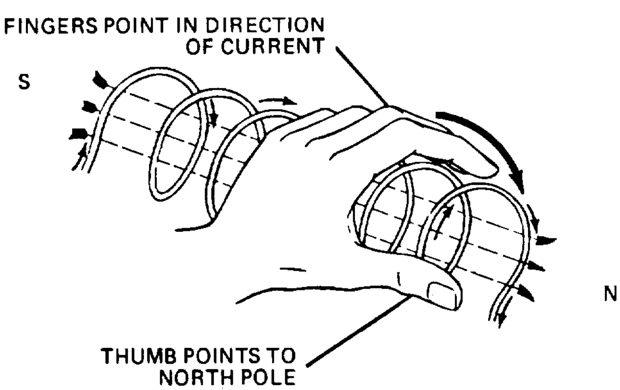

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Figure 11-21. Left-Handed Rule.

This effect of permitting lines of force to pass through easily is called permeability. Wrought iron is 3,000 times more permeable than air. In other words, it allows 3,000 times as many lines of force to get through. With this great increase in the number of lines of force, the magnetic strength of the electromagnet is increased greatly, even though no more current flows through it. Practically all electromagnets use an iron core of some kind.

11-15. Electromagnetic Induction.

a. Current can be induced to flow in a conductor if it is moved through a magnetic field. In figure 11-22 the wire is moved downward through the magnetic field between the two magnetic poles. As it moves downward, cutting lines of force, current is induced in it. The reason for this is that the lines of force resist cutting, and tend to wrap around the wire as shown. With lines of force wrapping around the wire, current is induced. The wire movement through the magnetic field produces a magnetic whirl around the wire, which pushes the electrons along the wire.

b. If the wire is held stationary and the magnetic field is moved, the effect is the same; that is, current will be induced in the wire. All that is required is that there be relative movement between the two so that lines of force are cut by the wire. It is this cutting and whirling, or wrapping, of the lines of force around the wire that produces the current movement in the wire.

c. The magnetic field can be moved by moving the magnet or, if it is a magnetic field from an electromagnet, it can be moved by starting and stopping the current flow in the electromagnet. Suppose an electromagnet such as the one shown in figure 11-20 has a wire held close to it. When the electromagnet is connected to a battery, current will start to flow through it. This current, as it starts to flow, builds up a magnetic field. In other words, a magnetic field forms because of the current flow. This magnetic field might be considered as expanding (like a balloon, in a sense) and moving out from the electromagnet. As it moves outward, its lines of force will cut through the wire held close to the electromagnet. This wire, therefore, will have current induced in it. The current will result from the lines of force cutting across the wire. If the electromagnet is

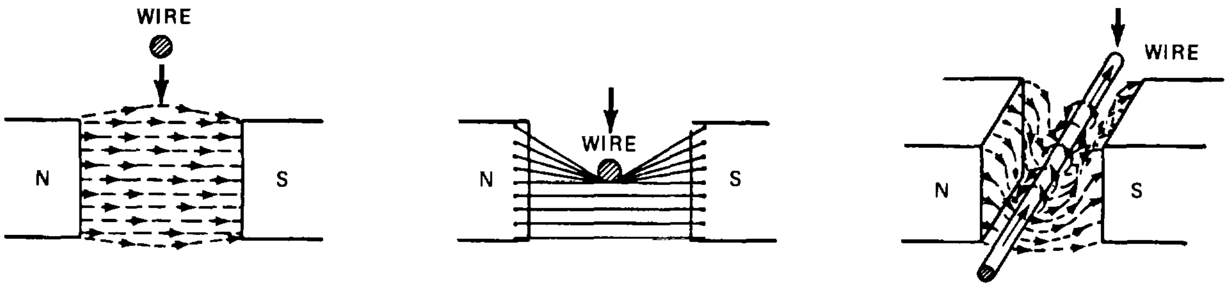

Figure 11-22. Electromagnetic Induction.

disconnected from the battery, its magnetic field will collapse and disappear. As this happens, the lines of force move inward toward the electromagnet. Again, the wire held close to the electromagnet will be cut by moving lines of force and will have a current induced in it. This time, the lines of force are moving in the opposite direction and the wire, therefore, will have current induced in it in the opposite direct ion.

d. Thus it can be seen that current can be induced in the wire by three methods: the wire can be moved through the stationary magnetic field; the wire can be held stationary and the magnet can be moved so the field is carried past the wire; or the wire and electromagnet both can be held stationary and the current turned on and off to cause the magnetic field buildup and collapse, so the magnetic field moves one way or the other across the wire.

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CHAPTER 13

CHARGING SYSTEMS

Section I PRINCIPLES OF OPERATION

13-1. General. The generator is a machine in which the principle of electromagnetic induction is used to convert mechanical energy into electrical energy. The generator restores the current used in cranking the engine to the battery. It also supplies, up to the limit of its capacity, current to carry the electrical load of the lights, ignition, radio, and horn. A generator and a motor are basically the same in construction and use the same electrical principles; however, their operation is opposite. In the generator, mechanical motion is converted into electrical energy. In the motor, electrical energy is converted into mechanical motion.

13-2. Simple Single-Loop Generator.

a. Induced Current. If a single loop of wire is rotated in the magnetic field between a north and a south pole, there will be an electrical pressure produced in the two sides of the loop. The voltage and current produced will relate to the direction of the magnetic field and the direction of rotation. If each end of the loop is connected to a metal segment of a commutator on which brushes rest (fig. 13-1), this electrical pressure will cause a current to flow through any external circuit that may be connected across the two brushes.

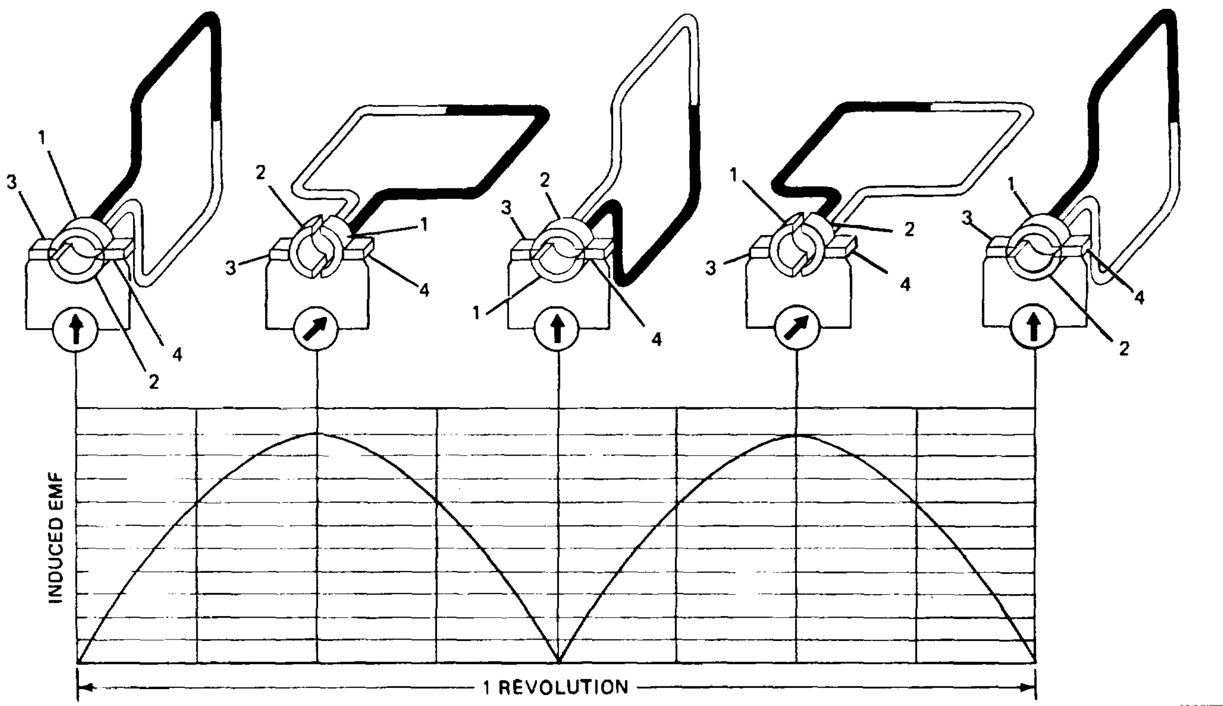
b. Commutation. If the loop is rotated through a complete revolution (fig. 13-1), sides 1 and 2 will cut magnetic lines of force in first one direction and then in the other. This will produce current in each side of the loop, first in one direction and then in the other. That is, in side 1, current will flow in one direction when it is passing the north pole and in the other direction when it is passing the south pole. However, because the commutator segments also rotate with the loop, the current always will leave the right-hand brush (4) and enter the left-hand brush (3). The directions of current produced in each side of the loop can be determined by use of the left-handed rule, described in paragraph 11-14.

13-3. Multiple-Loop Generator. The advantages of a multiple-loop generator are explained below.

a. More Current Induced. In the simple, single-loop generator (fig. 13-1), the current produced in each side of the loop reaches a maximum when the sides are cutting the lines of force in a perpendicular direction. This is the position in which the loop is shown. As the loop moves away from this position, it cuts fewer and fewer lines of force and less and less current is produced. By the time the loop has turned 90 degrees from the position shown, the sides are moving parallel to the lines of force and are cutting no lines, therefore no current is being produced. The current produced from the single loop is shown in graph form in figure 13-1. Many loops, or turns, of wire are required in the conductor in order for the generator to produce an appreciable amount and even flow of current. The rotating member that contains the wire loops and the commutator is called an armature. Figure 13-2 shows an armature in place in a generator. Note that many turns are used in the armature windings.

b. Smoother Current Flow. The windings are assembled in a soft iron core because iron is more permeable than other substances that could be used. The windings are connected to each other and to the commutator segments in such a way that the current impulses overlap and produce a smooth flow of current. This could be compared to the overlapping of power impulses in an 8- or 12-cylinderenglne.

13-4. Generator Speed. In order for the generator to provide rated output, it must be operated at sufficient speed. Because military vehicles spend a large amount of time at engine idle, it is important to note that during these periods the generator may be required to supply full rated current on a large portion thereof. Therefore, the requirement for establishing the speed at which full rated output must be delivered is the controlling factor for optimizing the size of the generator. As a general rule, engines have a speed ratio between four and five to one from idle to maximum speed; that is, the typical engine idles at 650 rpm and has a maximum speed of 3,000 rpm. Typical



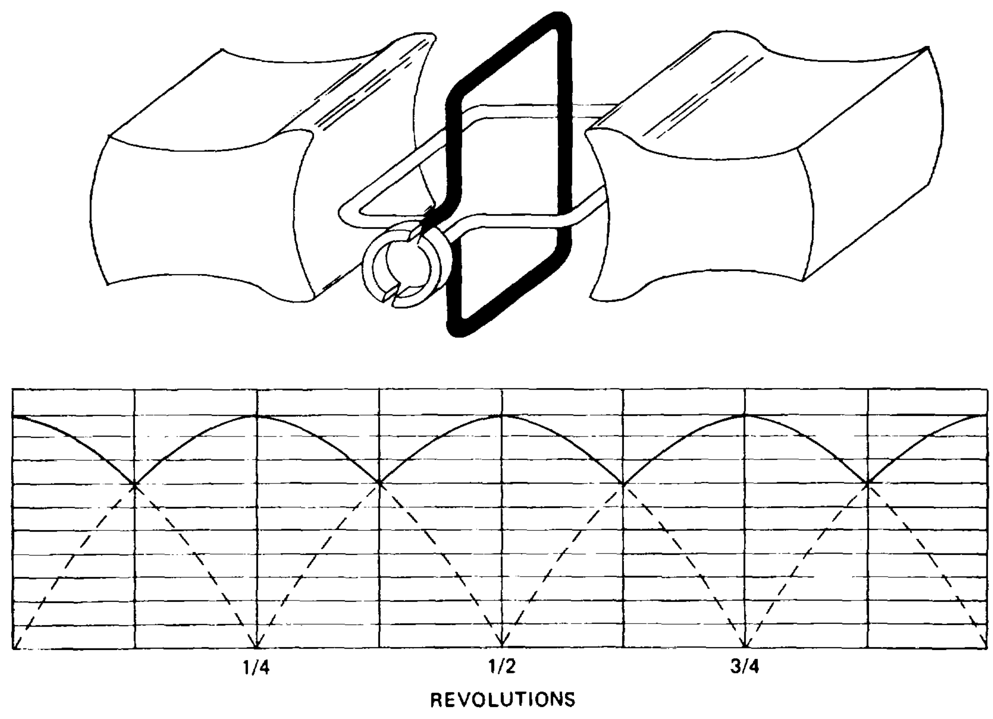


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Figure 13-1. & Figure 13-2. Multiple -Loop Generator.

generator speeds can be two to four times engine rpm.

13-5. Field Intensity. The magnetic lines of force that are created by the generator field are critical to the generator's output. The more lines of force that there are for the armature to cut, the more output the generator will produce. Generator field coils are designed to produce the most intense field that is possible. The key factors that affect field intensity are:

a. The number of wire turns in the coil.

b. The ratio of the coil's length to its width.

c. The type of material used in the core.

13-6. AC and DC Current Flow.

a. General. There are two basic forms of electrical current flow: Direct current (dc) and alternating current(ac).

b. Alternating Current. Alternating current forces electrons from one terminal to the other and then back again (the direction of current flow alternates). A graph of the voltage versus time for alternating current is shown in figure 13-3. It can be seen that the value of the voltage rises in the positive direction, reaches a peak, falls in the negative direction, reaches a negative peak, and then rises to zero. This is a constantly repeating cycle. Generators normally produce alternating current.

c. Direct Current. Direct current flow forces electrons from the negative terminal to the positive terminal (current flow is always in one direction or direct). Direct current voltage versus time is shown in figure 13-3.

d. Compatibility. An automotive electrical system, due to the need for a storage battery that produces dc flow, must also have a dc flow, because ac and dc flow are incompatible in the same circuit. To correct this problem, the generator output therefore must be changed to dc through a process called rectification. By its design, a dc generator is self-rectifying, but an ac generator must have its output rectified electronically. The processes of rectification are respectively covered in their related sections.

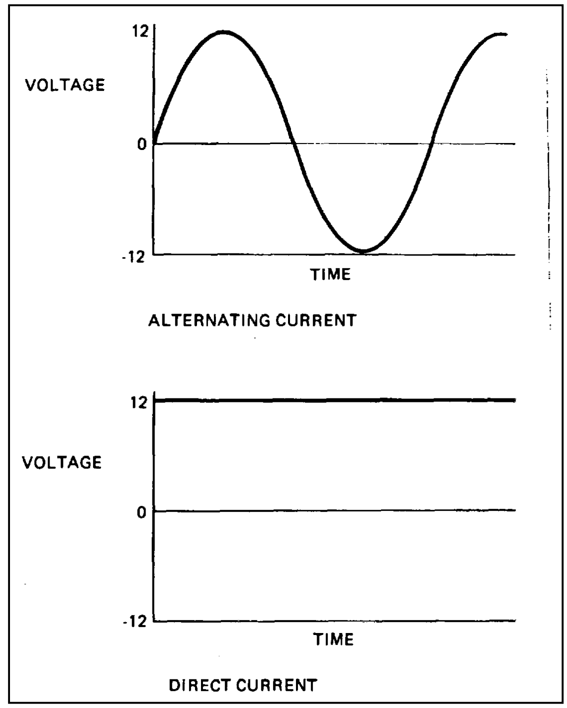

Figure 13-3. AC and DC Flow.

Section II. DC GENERATOR PRINCIPLES

13-7. Field Winding Configurations (Fig. 13-4). The purpose of the field windings is to create the lines of force electromagnetically that induce a current flow in the armature. The field winding usually is connected in parallel with the armature winding (that is, across the brushes). This is called shunt-field winding. The shunt-field winding usually is connected only at one end to the brushes. The other end of the field winding then is made to pass through a voltage regulation circuit (para 13-13). In this manner, the output of the generator is controlled. Depending on the

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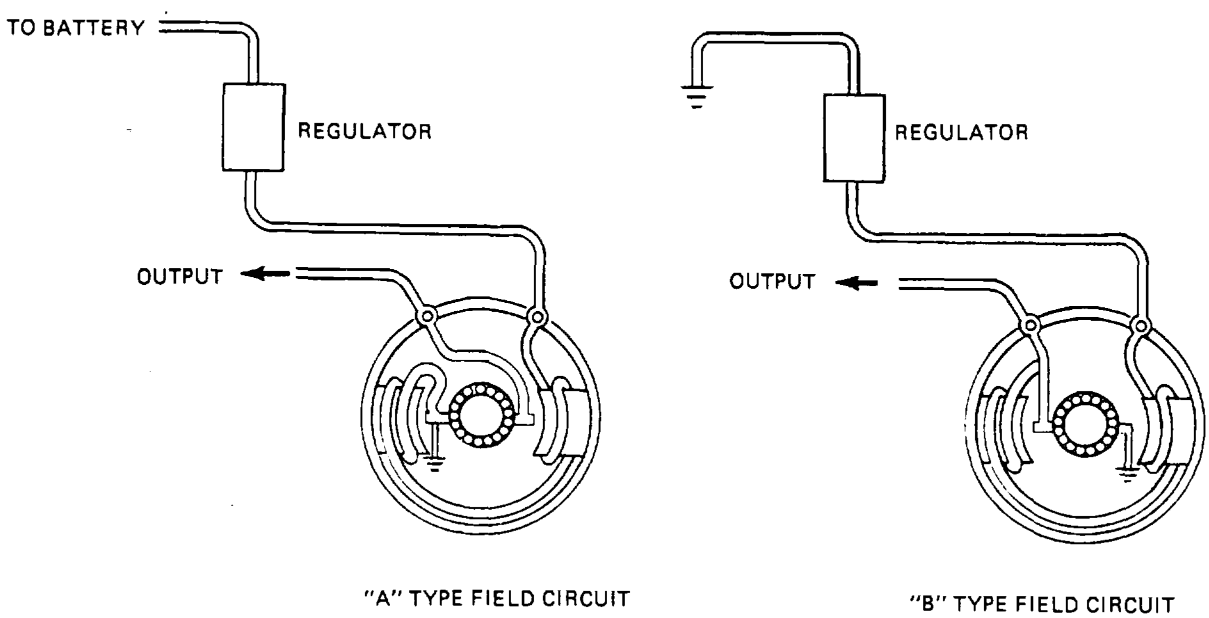

Figure 13-4. Field Winding Configurations.

regulation circuitry used, the field windings may be connected in one of two ways.

a. A-Type Field Circuit. The A-type field circuit shunts one end of the field winding to the negative generator brush and controls output through the regulation circuitry to the positive (battery) connection.

b. B-Type Field Circuit. The B-type field circuit shunts one end of the field winding to the positive generator brush and controls output through the regulation circuitry to the negative (ground) connection.

13-8. Shunt-Wound Generator (Fig. 13-5).

a. General. Most motor vehicle generators are shunt wound, with an outside means of regulating the voltage output. Approximately 8 to 12 percent of the total current generated by the armature is shunted (sent) through the field coils for producing the magnetic field.

b. Components. The generator essentially consists of an armature, a field frame, field coils, and a commutator with brushes to establish electrical contact with the rotating element. The magnetic field of the generator usually is produced by electromagnets or poles magnetized by current flowing through the field coils. Soft iron pole pieces (or pole shoes) are contained in the field frame that forms the magnetic circuit between the poles. Although machines may be designed to have any even number of poles, two-and four-pole frames are the most common.

c. Field Frames. In the two-pole type frame, the magnetic circuit flows directly across the armature, while in the four-pole type each magnetic circuit flows through only a part of the armature core. Therefore, the armature must be constructed in accordance with the number of field poles because current is generated when the coil, winding on the armature, moves across each magnetic circuit.

d Brushes and Commutator. The current is collected from the armature coils by the brushes (usually made of carbon) that make rubbing contact with a commutator. The commutator consists of a series of insulated copper segments mounted on one end of the armature, each segment connecting to one or more armature coils. The armature coils are connected to the external circuit (battery, lights, or ignition) through the commutator and brushes. Current induced in the armature coils thus is able to flow to the external circuit.

e. Principle of Operation. In figure 13-6, assume that the magnetic field flows from the north pole piece (N) to the south pole piece (S), as indicated by the arrows. When the armature is

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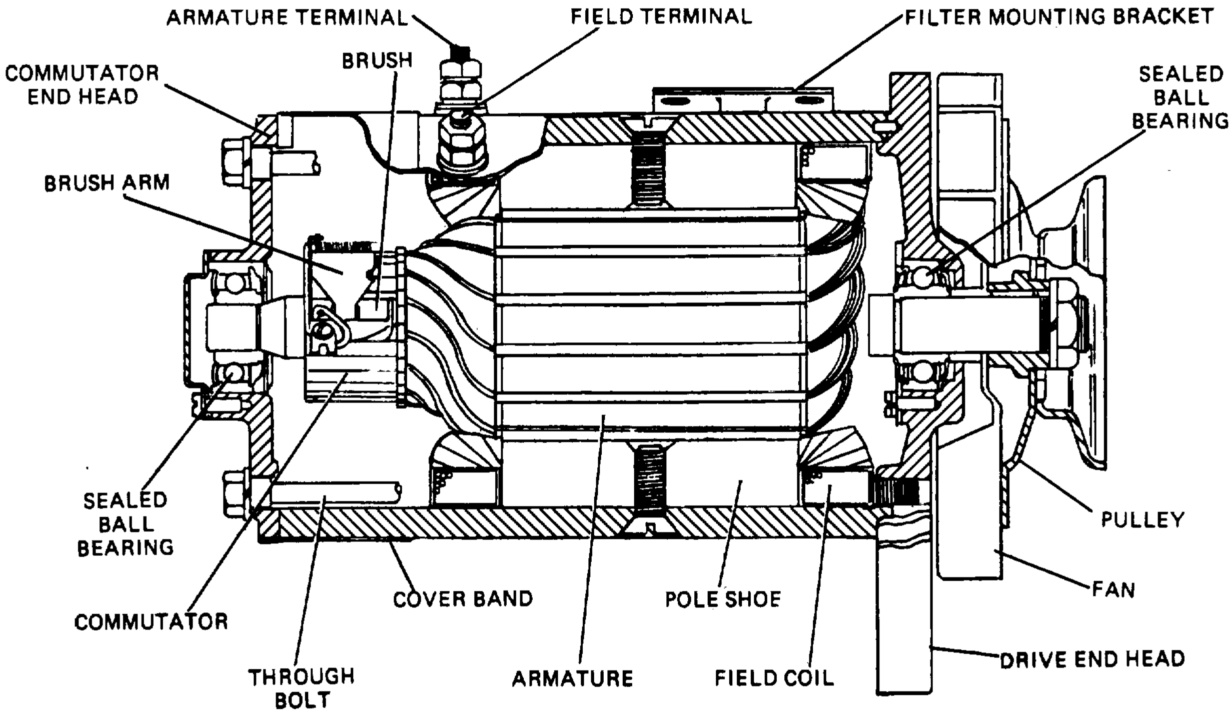

Figure 13-5. Shunt-Wound Generator.

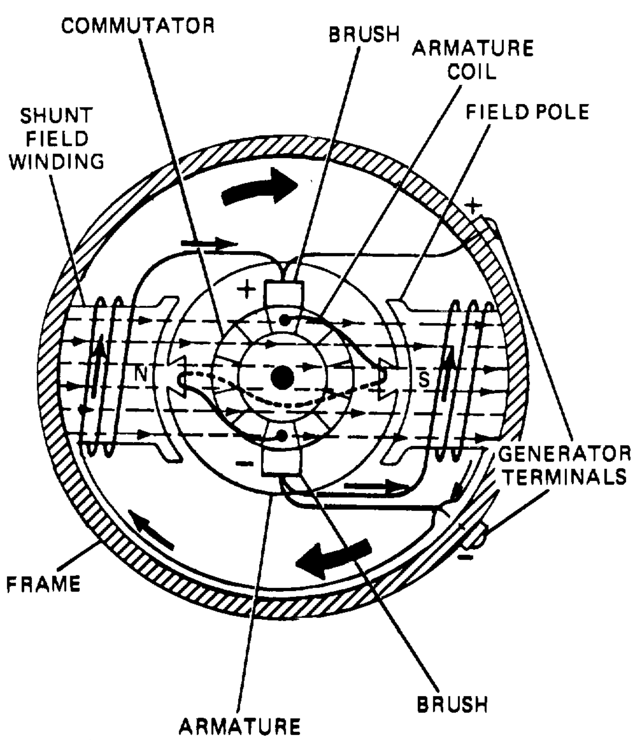

Figure 13-6. Shunt-Wound Generator Operation.

rotated, the armature coils will cut the weak magnetic field (residual magnetism) retained by the poles and set up a slight voltage, usually 1 to 1 ½ volts, across the brushes. In this particular case, the upper brush will be positive (+) and the lower brush will be negative (-). This voltage is sufficient to cause a small current to flow from the negative brush through the field winding around the pole pieces to the positive brush. If the magnetic effect of this field current is of the same polarity as the remaining magnetism, the pole strength will be increased. This, in turn, will increase the magnetic field through the armature. Because the armature coils then will be cutting more magnetic lines of force per revolution, the voltage across the brushes will be increased. An increase in brush voltage increases the field strength which, in turn, increases the armature output. The armature voltage helps the field and the field helps the armature voltage until the generator reaches its normal operating volt- age at the specific running speed. This process is called building up the generator voltage.

f. Residual Magnetism. The importance of the magnetism retained by the poles should be noted in the description of generator operation because it serves as a foundation for building up the generator voltage. Residual magnetism is

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the magnetism remaining in the pole pieces after the field-magnetizing current has stopped. If there is no residual magnetism in the pole pieces, there will be no initial output of the generator, and it will not build up voltage to push current. If the pole pieces lose residual magnetism through long storage, or by being newly rebuilt, subjected to extreme heat or cold, dropped, vibrated, or struck by a sharp blow, it can be restored by passing direct current through the field winding in the proper direction. If current is passed through the field windings in the reverse direction, the generator will be polarized in reverse. This reverse polarity will cause the generator to discharge the batteries instead of charging them, and also could cause damage to some of the vehicle accessories. Several conditions are necessary for the generator to build up a voltage. Two of the most important requirements are that the pole pieces have residual magnetism as a foundation on which to build, and that the current in each field coil be in a direction around the pole that it will produce magnetism to assist, and not oppose, the residual magnetism. If the field current opposes it, the voltage built up will not be higher than that produced by the residual magnetism.

g. Construction. The armature core is made of sheets of iron insulated from each other so that the magnetic field will not induce eddy currents in the core. Eddy currents are currents that are induced within the core by the constant variation in the lines of force. Making the armature core in one piece would allow eddy currents to become large enough to create a counter-voltage, which would result in a large portion of the generator's output to be converted to heat. The armature core is wound with coils of copper wire and mounted on a shaft with a commutator on one end. Field coils are made of many coils of fine wire arranged for shunt connection. The field frame, usually two or four poles with brushes, brush holders, and end housings with bearings, completes the essential parts of the generator.

h. Generator Drives (Fig. 13-7). The method of mounting and driving the generator depends to a large extent on the construction and design of the engine. It usually is mounted on the side of the engine and driven by belts or

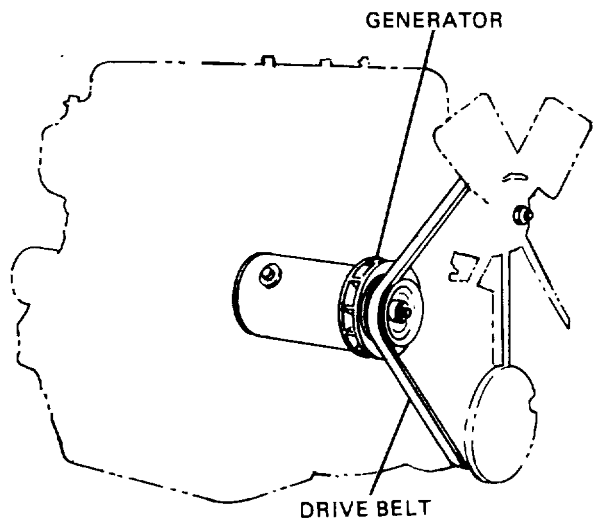

Figure 13-7. Generator Drive Systems.

gears at one to one and one-half times the crankshaft speed. The present trend is to have the water pump and generator driven by a V-type drive belt from the pulley on the forward end of the crankshaft. Pivoting the generator on the generator mounting studs allows adjustment of the belt tension. A rotary fan usually is contained on the generator pulley to draw cooling air through the generator.

13-9. Waterproofed Generator Systems. The generators, as well as other electrical components are made watertight on military vehicles that ford bodies of water. This is done by completely sealing the generator so that water cannot enter. In addition, stainless steel bearings are used to prevent corrosion. The commutator-end bearing is packed with heat-resistant grease on assembly, while the drive-end bearing is lubricated by a pickup gear rotating in an oil reservoir. Neither bearing requires attention or lubrication between generator overhauls. Other types of sealed bearings also may be used. The generator leads are carried in a waterproof conduit that is connected by plug-ins to the generator terminals. The conduit is attached to the generator terminal assembly by a waterproof coupling.

13-10. Circuit Breaker or Cutout Relay (Fig. 13-8).

a. Purpose. The circuit breaker is simply an

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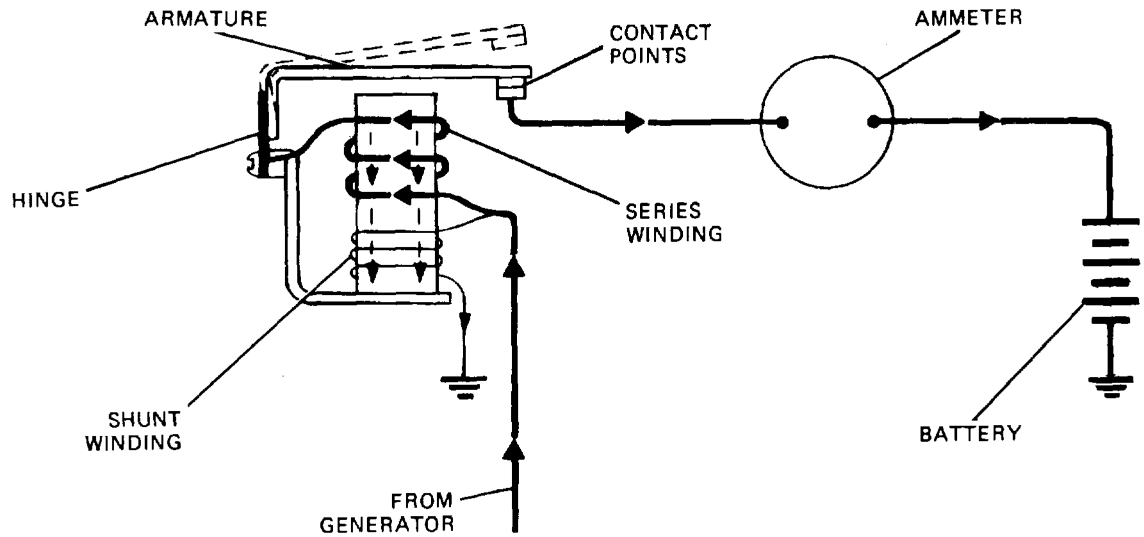

Figure 13-8. Cutout Relay.

automatic electromagnetic switch connected in the battery charging circuit between the generator and the storage battery of the electrical system. Its function is to connect the generator automatically to the battery when the voltage of the generator is sufficient to charge the battery. It also must disconnect the generator and battery when the generator is not running or when its voltage falls below that of the battery, to prevent the battery from discharging through the generator windings. In these respects, the action of the circuit breaker is very similar to that of a check valve between a pump and a reservoir.

b. Construction. The circuit breaker consists of two windings: a shunt winding and a series winding. These are assembled on a single core, above which is placed an armature. The shunt winding consists of many turns of fine wire, and is connected across the generator. The series winding consists of a few turns of heavy wire designed to carry full generator output, and is connected to the charging circuit. The armature operates a moving contact point that is positioned above a stationary matching point. Common practice is to place the cutout relay inside the voltage regulator.

c. Operation. When the generator is not operating, the armature is held away from the winding core by spring tension, and the points are separated. As soon as the generator begins to operate at a speed sufficient to produce enough voltage to charge the battery, this voltage, which is impressed on the relay windings, creates enough magnetism to overcome the armature spring tension and close the points. As long as the generator charges the battery, the points are held closed. When the generator slows or stops, so that current flows from the battery to the generator, the points open. They open because the series-winding magnetic field reverses as the current in it reverses, so that the two windings no longer help each other. The magnetic fields buck, causing a reduction of the total magnetic field to a point where it can no longer hold the armature down and the points closed. The spring tension pulls the armature up and opens the points. The air gap between the armature and the iron core of the relay has little or no effect upon the voltage at which the circuit breaker opens, because the spring tension governs this almost entirely. On the other hand, the voltage at which the circuit breaker closes is governed by both the air gap and the spring tension.

13-11. Regulation of Generator Output. The fields of the generator depend upon the current from the armature of the generator for magnetization. Because the current developed by the generator increases in direct proportion to its speed, the fields become stronger as the speed increases and correspondingly, more current is generated by the armature. The extreme variations in speed of the automotive

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engine make it necessary to regulate the output of the generator to prevent excessive current or voltage overload. On the average motor vehicle, a charging current in excess of 12 to 15 amperes may be harmful to a fully charged battery if continued too long. With the increased use of electrical accessories, generators have been increased in output until they are capable of producing far more than 15 amperes. Some heavy-duty generators, for example, may produce as much as 150 amperes.

13-12. Reverse-Series Field Generator (Fig. 13-9). The reverse-series field generator is self-regulating.

a. Operation. Because the output of the generator depends on the number of conductors in the armature, their speed of rotation, and the strength of the magnetic field in which they rotate, varying the strength of this field is the only convenient method of regulation. One of the simplest methods, used on special applications, is the use of a reverse-series field for differential action. A shunt field is connected across the brushes to produce the magnetizing action.

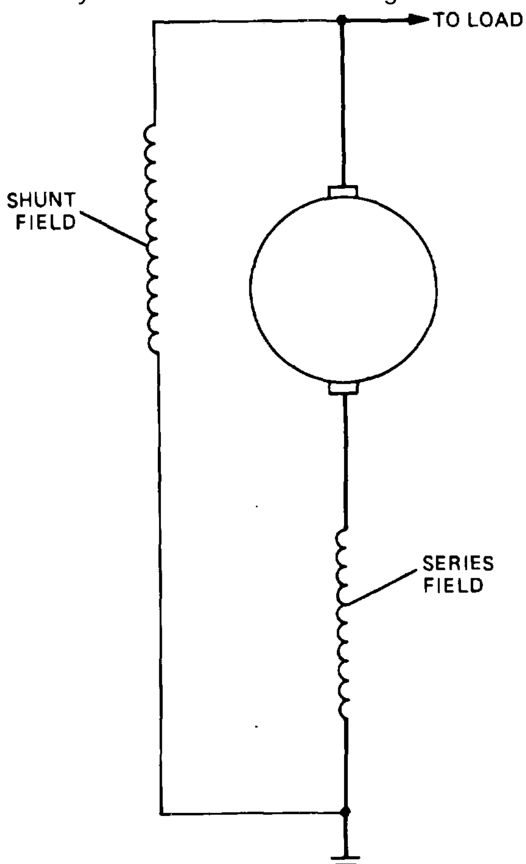

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Figure 13-9. Reverse-Series Field

Charging current going through the reverse-series field, however, has a demagnetizing action so that, as the current increases, it tends to restrict the rise of current above a reasonable value.

b. Disadvantages. This type of differentially wound generator has disadvantages that limit its use on motor vehicles without some additional external regulator. If a break should occur in the charging circuit (except during normal circuit breaker operation), destroying generator regulation by the series field, the voltage will become excessive. This usually results in damage to the field and armature winding and to the voltage winding of the circuit breaker. Therefore, such generators usually have some form of external voltage regulation.

13-13. Vibrating Point Regulator.

a. Current Regulation.

(1) The vibrating regulator (fig. 13-10) can be used to regulate the current or the voltage, depending on how the regulator coil is connected. A circuit diagram of a typical vibrating regulator used for limiting the current from the generator is shown in figure 13-11. The regulator consists of a soft iron core, a heavy winding or current coil around the core, a set of regulator contact points normally held closed by spring tension, and a resistance unit connected across the two regulator contact points.

(2) As the generator output increases, the current regulator prevents the current output of the generator from exceeding its rated maximum. It does this by cutting a resistance intermittently in and out of the shunt-field circuit as the regulator contact points open and close, due to the varying magnetic pull of the core. The resistance is connected in the shunt-field circuit, but normally is short circuited by the regulator contacts when they are closed. One of these is mounted on a soft iron contact armature, to which the spring for holding the points in contact is attached. The

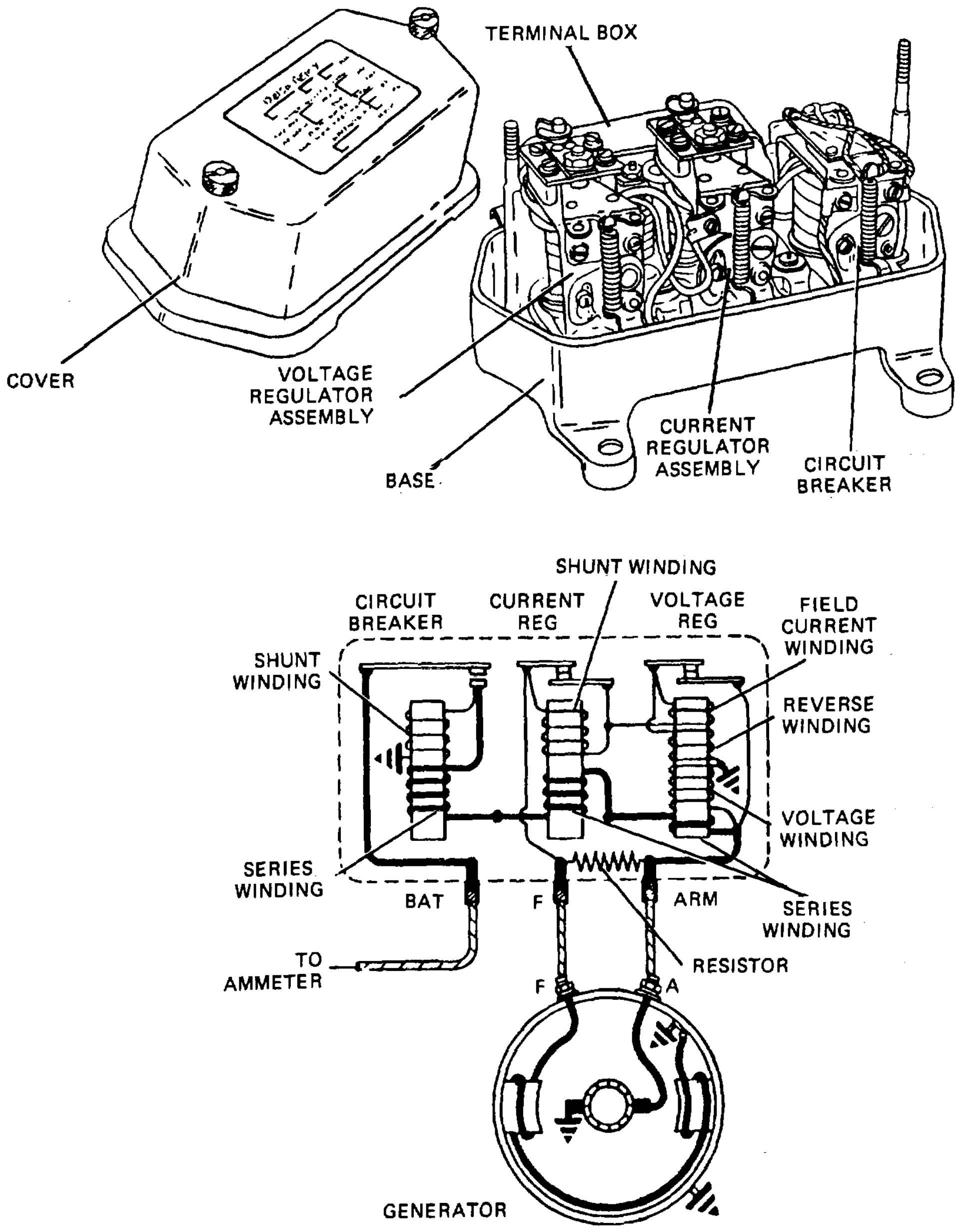

Figure 13-10. Vibrating Point Voltage Regulator.

generator, when driven by the engine, builds up as a simple shunt-wound generator. When the speed and voltage of the generator are increased sufficiently to close the circuit breaker, the generator will begin to charge the battery, the charging current flowing through the regulator winding. This current flowing through the regulator winding will magnetize the core. It, in turn, exerts a magnetic pull on the regulator contact armature, which tends to separate the contacts. When the battery-charging current reaches the value for which the regulator is adjusted, the core is sufficiently magnetized to attract the armature overcoming the pull of the regulator spring. This separates the contact points and inserts the resistance unit in series with the shunt-field winding and weakens the field strength. This causes a drop in voltage generated in the

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armature, which then decreases the charging current. When the current decreases to a predetermined amount, the current coil does not magnetize the core sufficiently to overcome the pull of the spring, which then closes the contacts. With the contacts closed, the resistance unit is once more short circuited and the full field strength is restored, causing the charging current to increase again. The regulator will continue to repeat this cycle. Under operating conditions, the armature vibrates rapidly enough to keep the generator output constant. As a result, the generator will never produce more than the predetermined rate (for example, 40 amperes), no matter how high the speed of the car. This will be true regardless of the connected electrical load.

(3) This method of generator regulation is termed current regulation, because the current output of the generator is used for regulation. It is very important, therefore, that no breaks occur in the charging circuit after the generator reaches a voltage that will operate the circuit breaker. If a break does occur, no current will flow through the current coil to operate the vibrating points and, due to lack of regulation, the generator will build up an excessive voltage at high speeds. A voltage regulator is used to prevent excessive voltage.

(4) The charging rate of the generator can be adjusted easily in all electrical systems controlled by a vibrating regulator. To increase the maximum charging rate, the spring tension on the vibrating armature should be increased slightly. To decrease the maximum charging rate, the spring tension should be decreased. Care must be taken that the generator output does not exceed the value for which it was designed.

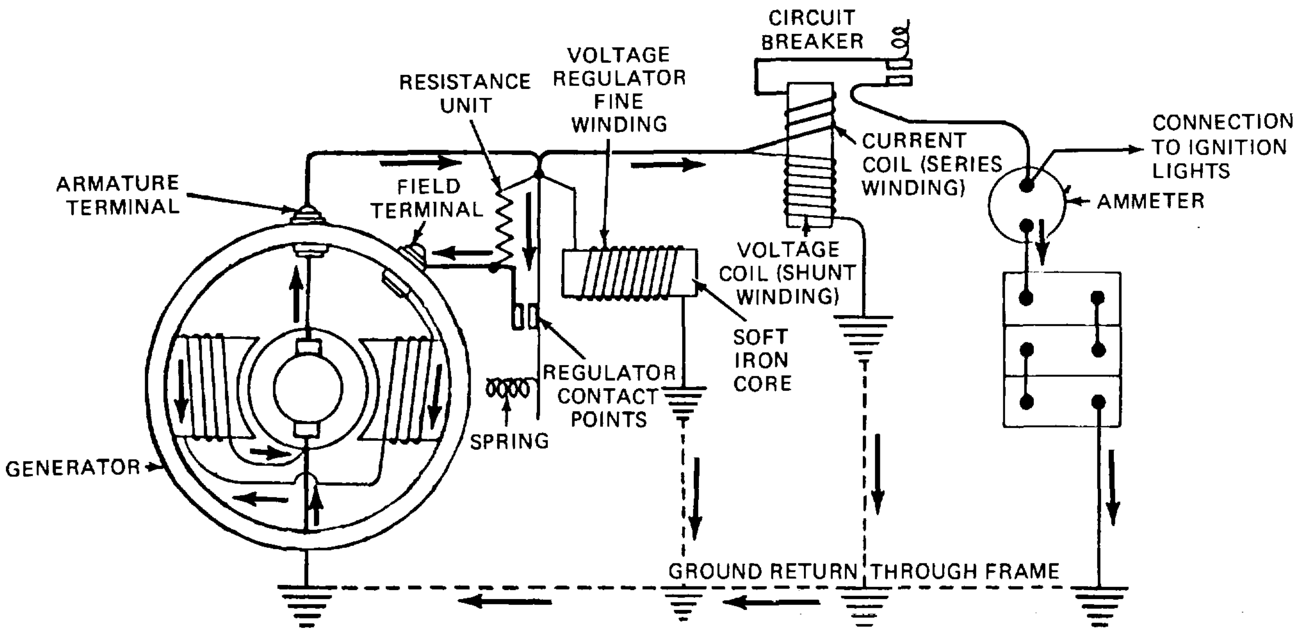
b. Voltage Regulation.

(1) A circuit diagram of a typical vibrating voltage regulator is shown in figure 13-11. Although the construction of this relay does not differ materially from that of the current regulator, the principle of operation is somewhat different. With this regulator, the voltage output of the generator is used for automatic regulation. By comparing both circuits, it will be seen that the principal difference in the two regulators is in the winding of the controlling coil and its connections. In the voltage regulator, the charging current does not flow through the regulator winding. The winding on the core consists of a voltage coil of fine wire. The two ends of the voltage coil are connected across the generator brushes and in parallel with the battery instead of in series with it. The iron core, regulator points, and resistance unit, however, are practically the same; the only important exception is that the voltage regulator resistance is considerably higher than that used with the current regulator.

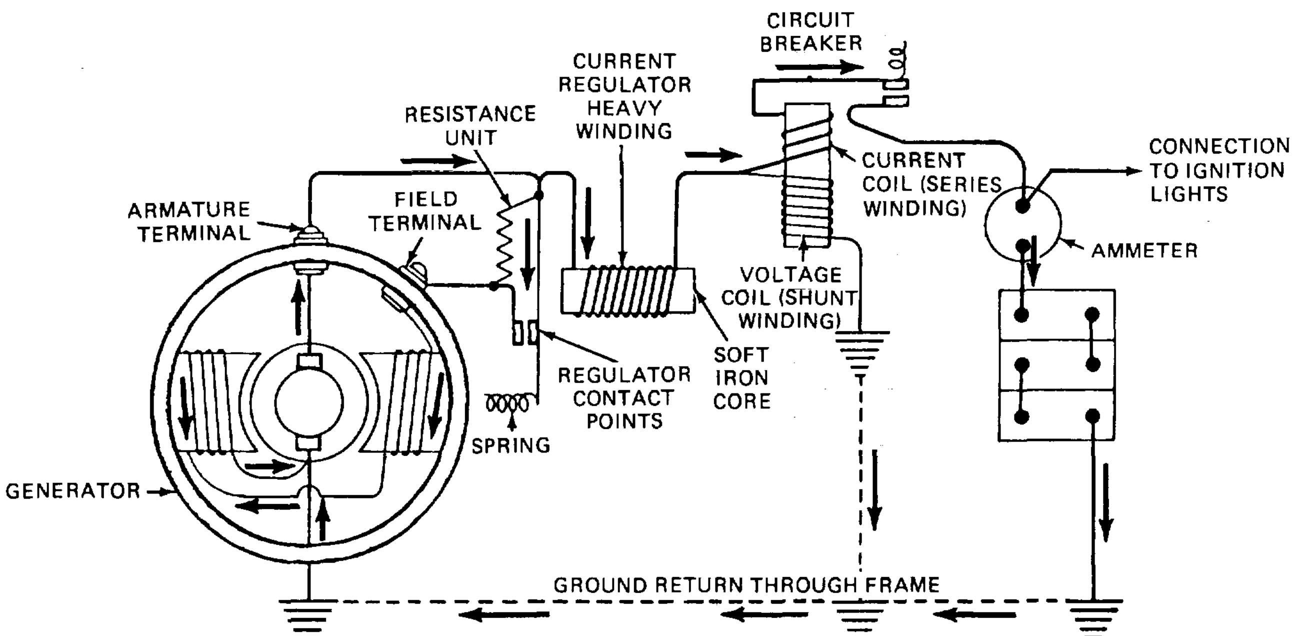
(2) The current flowing in the regulator coil and resultant magnetic pull of the core on the contact armature depend on the voltage developed by the generator. For an example of regulator operation, assume that the regulator is adjusted to operate at 12.8 volts. With increasing generator speed, the voltage tends to rise above 12.8 volts. However, if this value is exceeded by a small amount, the increased magnetic pull of the core on the contact armature due to the current flowing in the voltage coil will overcome the spring tension and pull the armature toward the core. This action will open the contacts and insert a resistance in the generator field circuit. This added resistance decreases the current in the field winding, and the voltage developed by the armature drops below 12.8 volts.

(3) When the voltage drops, the pull of the spring on the regulator armature overcomes the magnetic pull of the core and closes the contacts. This short-circuits the resistance unit and allows the field current to increase. The cycle of operation is repeated rapidly, preventing the generator voltage from rising above that for which the regulator is set. The regulator on most late-type military equipment will prevent the generator from building up an excessive voltage if a break occurs in the charging circuit. But this is not true on standard passenger cars and light-duty equipment. In these, if a break occurs in the voltage regulator circuit, regulation of the generator may be lost and at high speeds an excessive charging rate will result.

(4) It is obvious that increasing the tension of the regulator spring will increase the output voltage of the generator. Under no circumstances should the regulator spring tension be increased in an attempt to have the generator charge at a higher rate at lower speeds. The generator cannot begin to charge until the circuit breaker closes. The closing of the circuit breaker



VOLTAGE REGULATOR CIRCUIT



CURRENT REGULATOR CIRCUIT

Figure 13-11. Vibrating Point Regulator Circuit.

is independent of the action of the regulator. Increasing the tension of the regulator springs so that the generator will develop an excessive voltage will send excessive current to the battery, overcharging it. It also will cause the generator to overheat, possibly burning it out.

c. Charging Rate.

(*1) Current Regulator.* With the vibrating current regulator, the maximum possible charging current remains constant for any one setting of the regulator, regardless of the condition of the battery. To vary this maximum generator output, the spring tension of the regulator must be adjusted. The setting must never exceed the rated maximum of the generator.

(*2) Voltage Regulator.*

*(*a) The main advantage of the voltage regulator is that the output of the generator is controlled to a great extent by the amount of charge in the battery. When the generator reaches a speed at which it develops the regulated voltage, there will be no further increase in voltage with increasing speed. The voltage will be maintained constant at all loads and at all higher speeds.

*(*b) During the time the generator is connected to the battery, the difference in voltage between the two is the voltage available for sending current into the battery. In a discharged battery, the difference in voltage between the generator and the battery will be relatively great, so that a comparatively high charging current will pass from the generator to the battery. As the charge continues, the voltage of the battery increases, so that the difference in voltage between the generator and the battery is diminishing continually. With a fully charged battery, the voltage is equal nearly to that of the generator so that the difference between the two is very slight. As this slight difference in voltage is all that is available for sending current into the battery, the charging current will be small. The charging current, therefore, is variable and depends upon the charge in the battery. In practice, the charging current with the constant voltage regulator varies from a maximum of 25 to 35 amperes for a discharged battery to a minimum of 4 to 6 amperes for a fully charged battery.

13-14. Carbon-Pile Regulator (Fig. 13-12).

a. General. In the vibrating-contact type regulator, a set of contacts open and close to insert and remove a resistance in and from the generator field circuit. This, in effect, inserts a variable resistance into the field circuit that controls the generator. When only a small output is required, the voltage regulator maintains the resistance in the field circuit most of the time. When output requirements increase, the resistance is in the field a smaller part of the time. This same variable-resistance effect can be achieved by a carbon-pile regulator.

b. Construction. The carbon-pile regulator consists essentially of a stack of carbon disks held together by spring pressure. The spring pressure is applied by an armature. The resistance through the carbon pile is relatively small with full spring pressure applied. But with less pressure, the resistance increases. The carbon pile is connected to the generator field circuit so that its resistance is in series with the field. With full pressure applied, there is no regulation and generator output can increase to a high value. To

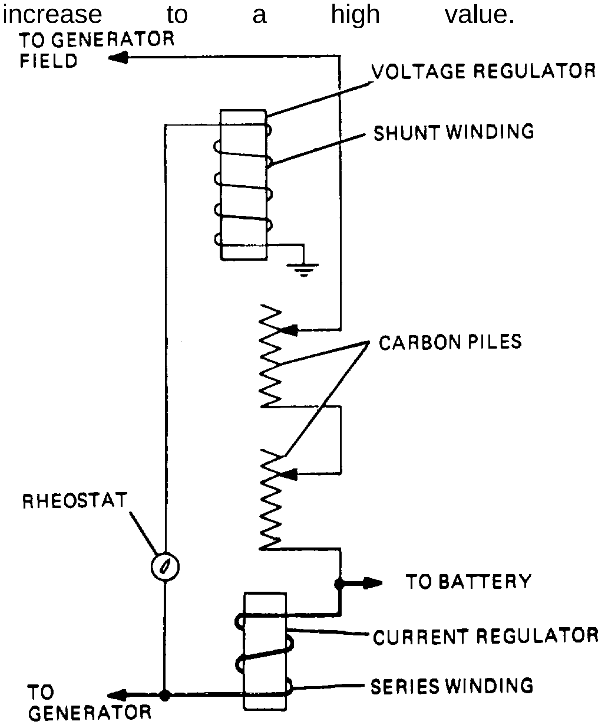


Figure 13.12. Carbon-Pile Regulator and Circuit.

limit current output to a safe value, or to provide voltage regulation, the armature pressure can be adjusted to vary the resistance.

c. Current Regulation. To limit current, or to provide current regulation, the carbon-pile regulator has a heavy winding through which all current from the generator must pass. This winding produces a magnetic pull as current asses through it, which opposes the armature spring pressure. When the output reaches the value for which the generator is rated, the magnetic pull overcomes the spring pressure sufficiently to reduce the pressure on the carbon disks and thereby increase the resistance of the pile. This increased resistance, which is in the generator field circuit, prevents any further increase of output.

d. Voltage Regulation. A winding is incorporated in the carbon-pile voltage regulator to regulate voltage. This shunt winding is connected across the generator so that generator voltage is forced on it. When this voltage reaches the value for which the regulator is set, the winding produces enough magnetic pull on the armature to reduce the armature spring pressure. This causes the resistance of the voltage-regulator carbon pile to increase. The increased resistance, which is in the generator field circuit, prevents any further generator voltage increase and thereby reduces generator output. The rheostat is connected to the shunt-winding circuit of the voltage regulator. Its purpose is to permit adjustment of the voltage regulator setting. When all resistance in the rheostat is cut out (by turning the knob), the full generator voltage is imposed in the shunt winding. But when some of the rheostat resistance is cut in, less than full generator voltage is imposed on the shunt winding (part of it being in the rheostat). In the latter case, generator voltage must go higher before voltage regulation commences. Thus, accurate setting of the regulator can be made.

13-15. Third-Brush Regulation (Fig. 13-13).

Third-brush regulation is much simpler in operation and less expensive to manufacture than other methods of control. However, it can be used only for relatively small and specialized applications. Generators with this type of control have an extra brush called the third brush, located between the two main brushes.

a. Arrangement. Arrangement of a typical two-pole, third-brush generator is shown in figure 3-13. One end of the shunt-field winding is connected to the third brush, the other end is grounded. Only a part of the total voltage generated is supplied to the field by the third brush.

b. Operation.

(1) When the generator is running at a low speed and little or no current is flowing in the

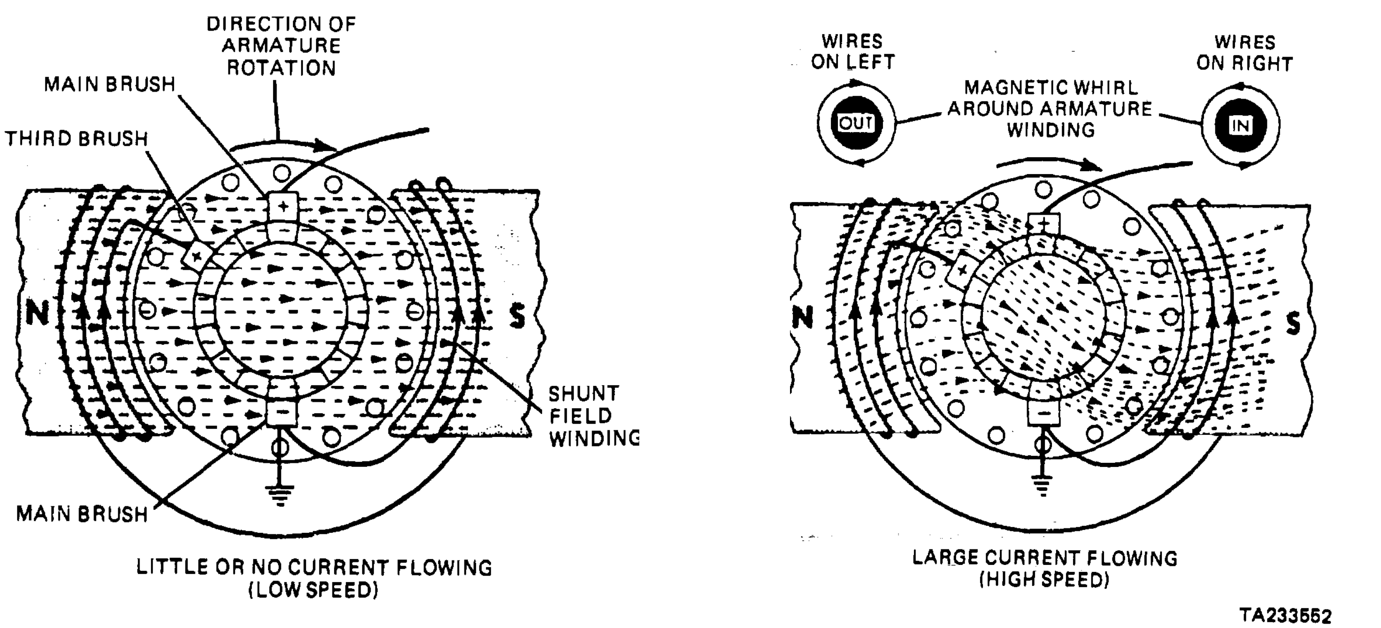


Figure 13-13. Third-Brush Regulation.

armature winding, the magnetic field produced by the field windings is approximately straight through the armature from one pole piece to the other. The voltage generated by each armature coil is then practically uniform during the time the coil is under the pole pieces.

(2) As the generator speed and current increase, the armature winding acts like a solenoid coil to produce a cross-magnetic field. The magnetic whirl around the armature winding distorts the magnetic field produced by the shunt-field windings so that the magnetism is not distributed equally under the pole pieces. With this distortion of the magnetic field, the armature coils no longer generate a uniform voltage while passing under the different parts of the pole. Although the voltage across the main brushes remains nearly the same, a greater proportion of this voltage is generated by the coils between the positive brush and the third brush than was generated between them when little current was flowing through the armature winding. This is due to the distortion of the magnetic field, which crowds more magnetic lines of force between the positive and the third brush.

(3) The coils that connect the commutator between the negative and the third brush are in the region of the weakened field and generate a lower proportion of the voltage. The result is a dropping off of the voltage between the negative and third brushes, which is applied to the shunt-field winding, thereby weakening the field strength. As the field strength decreases with increased generator current, the result will be an automatic regulation of the current output.

c. Output.

(1) One of the outstanding characteristics of generators with third-brush regulation is that the output of the generator increases gradually up to an intermediate speed. After this, due to obvious field distortion, the output falls off as the speed continues to increase. At high generator speeds, the output is approximately one-half its maximum value.

(2) In practically all generators that have third-brush regulation, provision is made for changing the output to suit the conditions under which the generator is operated. This can be done by moving the position of the third brush on the commutator. The average voltage applied to the field winding will depend upon the number of armature coils spanned by the brushes that collect the field current. Thus, moving the third brush in the direction of the armature rotation increases the average current delivered to the shunt-field winding and, consequently, the output of the generator. Moving the brush against the direction of armature rotation decreases the output. When this brush is moved, care should be taken to see that it makes perfect contact with the commutator.

(3) Because the third-brush generator depends upon the current flowing through the armature winding to produce the field distortion necessary for regulation, it is obvious that it is current-regulated internally (as distinct from external current regulation). Therefore, it must have a complete circuit available through the battery at all times. Otherwise, regulation would be destroyed and excessive field currents would burn out the generator windings. The generator terminals must be grounded in case the third- brush generator is disconnected from the battery.

13-16. Control of Third-Brush Generator. A fuse is sometimes provided in the field circuit to guard against the possibility of the third-brush generator burning up. When used, it is placed either in the generator end plate or in the regulator control unit. If the battery becomes disconnected, there is a rise in voltage at the generator. This, in turn, sends an abnormally heavy current through the field winding and this field current burns out the fuse. As soon as the fuse is blown, the field circuit is open and no current can flow through it. The generator then merely turns, producing practically no voltage, and does no harm. The third-brush generator provides current regulation only and does not take battery voltage into consideration. In fact, a fully charged battery that has a high voltage actually will get more current from a third-brush generator than a battery that is completely discharged, because the high voltage holds up the voltage at the generator, makes the field stronger, and causes the generator output to increase. This, combined with the varying demands of radio sets and other current-consuming devices, necessitates more accurate regulation than a third-brush generator alone can give.

a. Switch Control. Practically all systems of regulation provide a means for inserting a resistance in series with the third-brush field.

A simple way of accomplishing this is shown in figure **13-14.** A resistance is mounted on the back of the lighting switch and connected in series with the field. When the lights are off, the generator output current is limited by the resistance in the field circuit. When the lights are turned on, the resistance is shorted so that the generator delivers full current to take care of the additional lighting circuit load. This is just a two-step arbitrary system of regulation, however, that will not meet the varied load requirements of normal vehicle operation.

b. Step-Voltage Control.

(1) The purpose of step-voltage control is to increase or decrease the output of a third- brush generator in accordance with the requirements of the battery and the connected electrical load. It is really a two-stage regulator in which the change from one output to the other is controlled by the generator voltage. The generator voltage is control led then by battery voltage.

(2) A step-voltage control unit is shown in figure 13-15. A fine-winding voltage coil, connected to the generator armature terminal so that it receives the armature voltage, is the controlling element. Contacts are connected in series with the field terminal and have a resistance unit connected across them. When the battery is fully charged, its voltage raises the generator to such a value that sufficient magnetizing current flows through the fine winding on the control unit to pull the contact points apart. When this happens, the resistance across the contacts is connected in series with the field winding to lower the field strength and, consequently, to reduce the generator voltage and the current output. When the voltage is lowered sufficiently, spring tension will close the contact points and the higher charging rate will be restored.

(3) When there is sufficient electrical load (such as lights, radio, or heater) to require a higher generator output, the contact points will close, because the load will lower the generator voltage and the generator will produce maximum output for the selected position of the third brush and the speed at which it is driven.

c. Vibrating Regulator Control. A vibrating regulator (para 13-13) also can be used with a third-brush generator. Such a regulator is controlled by a voltage coil that operates vibrating contacts. When the battery is discharged, there is insufficient voltage to operate the regulator. The generator output is controlled then only by the third brush. As the battery becomes charged, the voltage of the system will increase and more current will be forced through the regulator coil. The regulator points then begin to vibrate, connecting a resistance in the generator field circuit and cutting down the output to a fairly constant value.

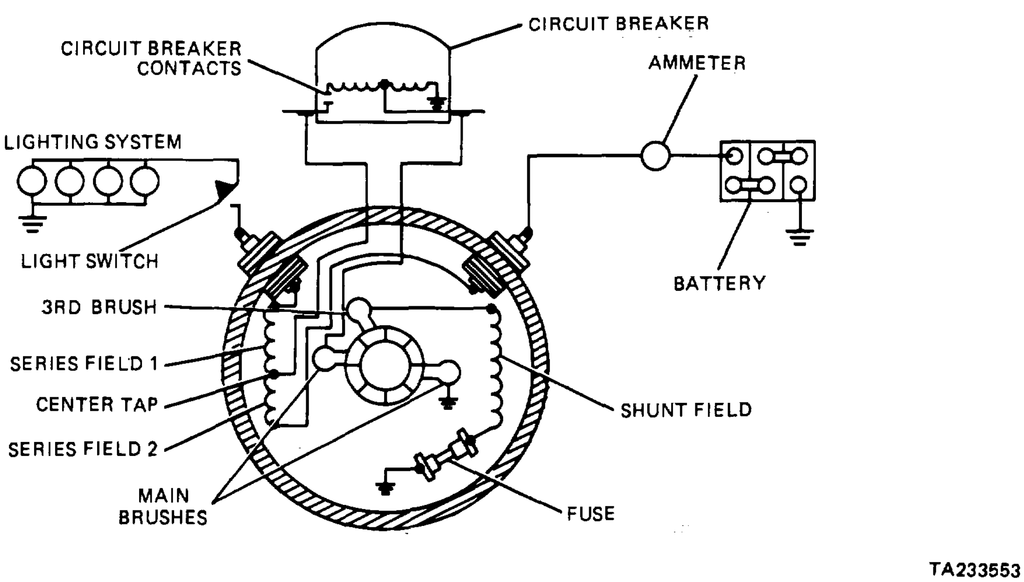


Figure 13-14. Light Switch Control of a Third-Brush Generator.

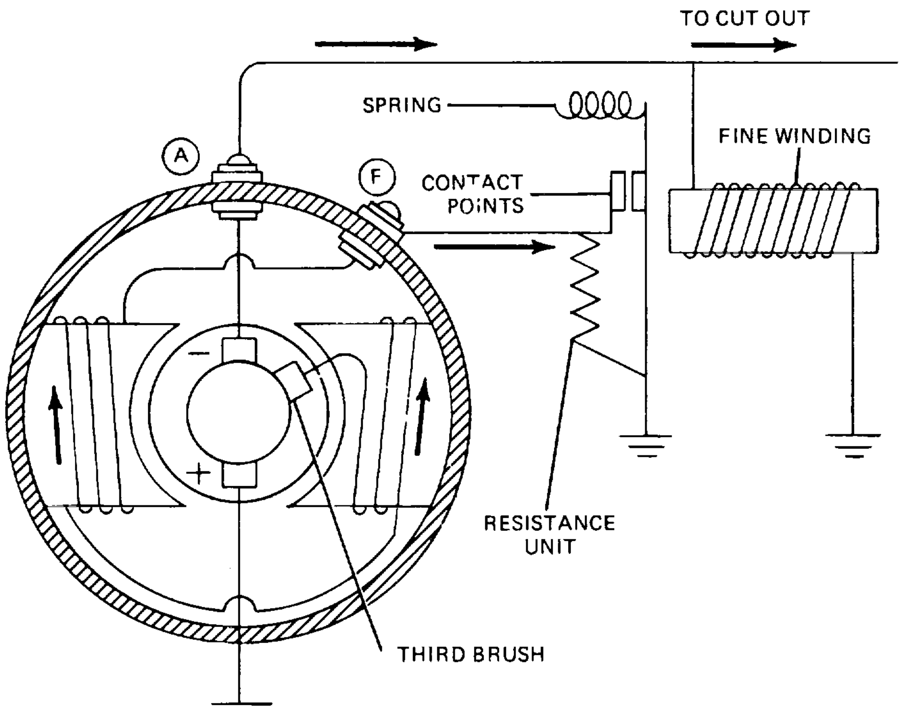


Figure 13-15. Thermostatic Control of Third-Brush Generator.

d. Thermostatic Control.

(1) Another type of control for the third-brush generator uses a thermostat blade to control the field strength. If the generator is set to give the greatest possible current to take care of demands during the winter, the battery would be in a constant state of overcharge in warm weather and soon be ruined. The thermostat blade automatically takes care of the changing current demands under different conditions.

(2) The control consists of a bimetal thermostat blade made of a strip of spring brass welded to a strip of nickel steel. The blade warps or bends when heated, due to the greater expansion of the brass side. The blade is set so that a contact on its end is held firmly against a fixed contact at low temperatures. When the temperature rises to approximately 1600 to 1650F, the blade bends and separates the contacts.

(3) The thermostat is connected in the third-brush field circuit (fig. 13-16) so that the full field current passes through the thermostat contacts when closed, permitting full current from the generator. After the engine has been run long enough for the high charging rate to heat the generator, the thermostat contacts open (due to the bending of the thermostat blade), causing a resistance unit across the contacts to be connected in series with the third-brush field and thereby reducing the current output. The charging rate is reduced approximately 30 percent when the thermostat contacts are opened.

(4) The chief advantages of thermostatic control are that it gives a large battery-charging rate in cold weather when the efficiency of the battery is lower than in warm weather, and also a larger charging rate when the vehicle is being driven intermittently and the demands on the battery are greater because of frequent use of the starter. This control also prevents the generator and battery from overheating in summer by reducing the charging rate when the temperature rises.

13-17. Split-Series Field Generators (Fig. 13-17

a. Generator regulation sometimes is accomplished by means of a split-series field. A generator with this method of regulation combines third-brush, reversed-series (differential), and cumulative-compound principles.

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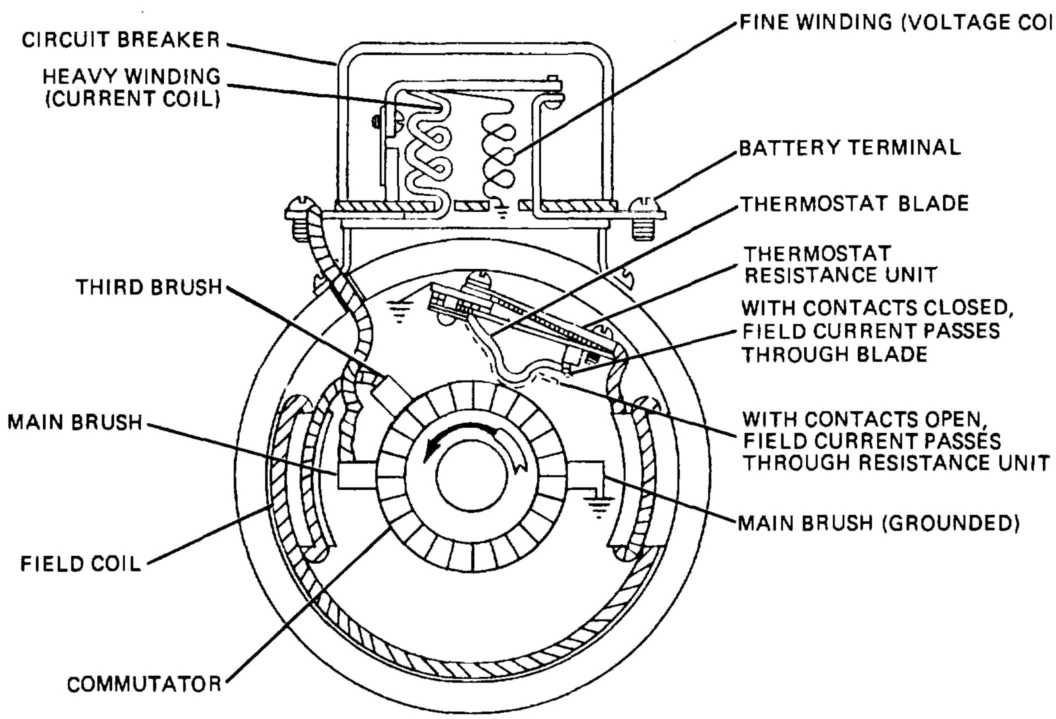

Figure 13-16. Thermostatic Control of Third-Brush Generator.

The series-field winding is divided so that the generator output is changed according to the load.

b. With lights off, no current flows through one part of the series field (1, fig. 13-17). The current going to the battery flows through the remainder of the series field (2, fig. 13-17) in the opposite direction to the shunt-field current. This weakens the total field strength, keeping the generator output down for the delivery of a reasonable charging rate.

c. When the lighting switch is closed, the entire lighting current flows through section 1 of the series field in the same direction as the shunt

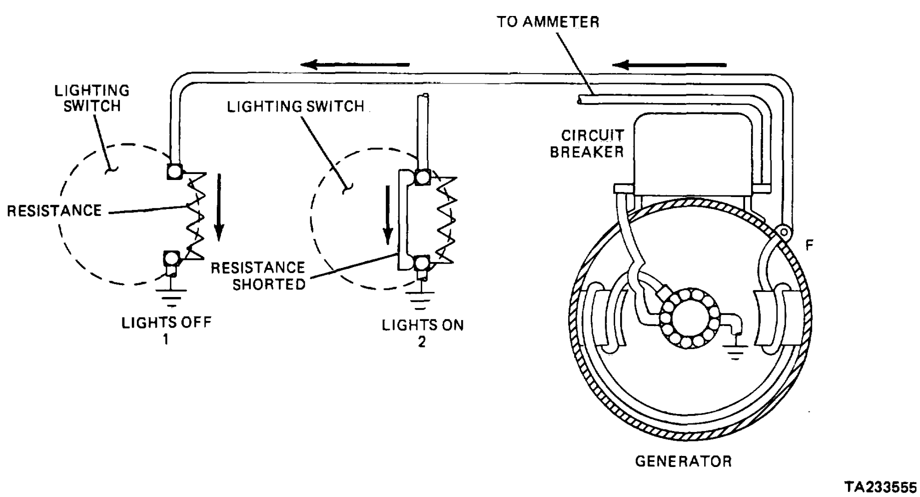

Figure 13-17. Split-Series Field Regulation.

field. The strength of the field is thereby increased, giving a higher generator output to take care of the lighting load.

d. If the lights are turned on before the generator circuit breaker closes, the entire lighting current is supplied by the battery. This current then flows through all of the series field, instead of through section 1 only, in the same direction as the shunt field, making the total field strength still greater. This will build up the generator voltage to close the circuit breaker. The entire current output of the generator that passes through the circuit breaker flows to the center tap of the series field, where it divides. Part of the current then flows in one direction through to the battery and the remainder flows to the lights.

e. As soon as the circuit breaker closes, the generator begins to pick up the lighting load. This lessens the drain on the battery and thereby reduces the current flowing through section 2 of the series field. When the generator output just equals the lighting current, the current in section 2 is zero and, as the generator output increases further, current begins to flow in the reverse direction through section 2 to the battery. This tends to weaken the field built up by the shunt winding and section 1 of the series winding. By obtaining the proper relationship between the shunt winding and the two sections of the series winding, results quite similar to those obtained from voltage regulation are secured, and the battery is kept in a charged condition.

f. The charging rate of the split-series field generator may be adjusted by shifting the third brush as in the regular third-brush generator. In some generators of this type, separate coils are used for the two sections of the series field. In others, the two sections are combined into one coil. Generators of this type do not have standard connections and must not be confused with the ordinary third-brush generator. Neither terminal should be grounded under any circumstances.

13-18. Paralleling Generators.

a. General. Some military vehicles have two separate power plants, each with its own generator and regulator working into a common set of batteries. Certain combat vehicles have a single power plant, but they also carry an auxiliary generator. Where two generators are working in a Single set of batteries and a single electrical System, the problem of paralleling exists. That is, the two generators must be connected in parallel. Unless special provision is made, trouble may result if two generators are parallel. The reason for this is that one generator may attempt to carry most or all of the load while the other generator might use current or act like a motor. The problem is further complicated if one of the generators varies in speed (as the unit on the power plant might).

b. System Description. To provide effective paralleling, each of the voltage regulators contains an additional paralleling winding. These windings become connected to each other through two paralleling relays when both generators are operating. With this condition, the paralleling windings can increase the voltage and thus the output) of the generator that is producing more than its share. Therefore, the two generators can be kept in step.

13-19. Generator System - Main and Auxiliary Generators.

a. General. A wiring circuit of a combat vehicle using a main and auxiliary generator is shown in figure 13-18 in schematic form. This system uses two generators, two carbon-pile regulators, plus various relays and switches. The following chart identifies the circuits in figure 13-18.

CIRCUIT	CIRCUIT NAME
1	Main Generator Feed
2	Main Gen Positive Line
7	Battery Ground
10	Instrument Panel Feed
61	Auxiliary Generator Field
62	Aux Gen Positive Line
65	Auxiliary Engine Starter
81	Battery - Positive Line
421	Aux Eng Fuel Cutoff Valve
422	Aux Eng Magneto Ground
459	Master Relay Control
459B	Master Relay Feed
478A	Aux Gen Equalizing
478M	Main Gen Equalizing
506	Main Gen Warning Light
508	Aux Gen Warning Light

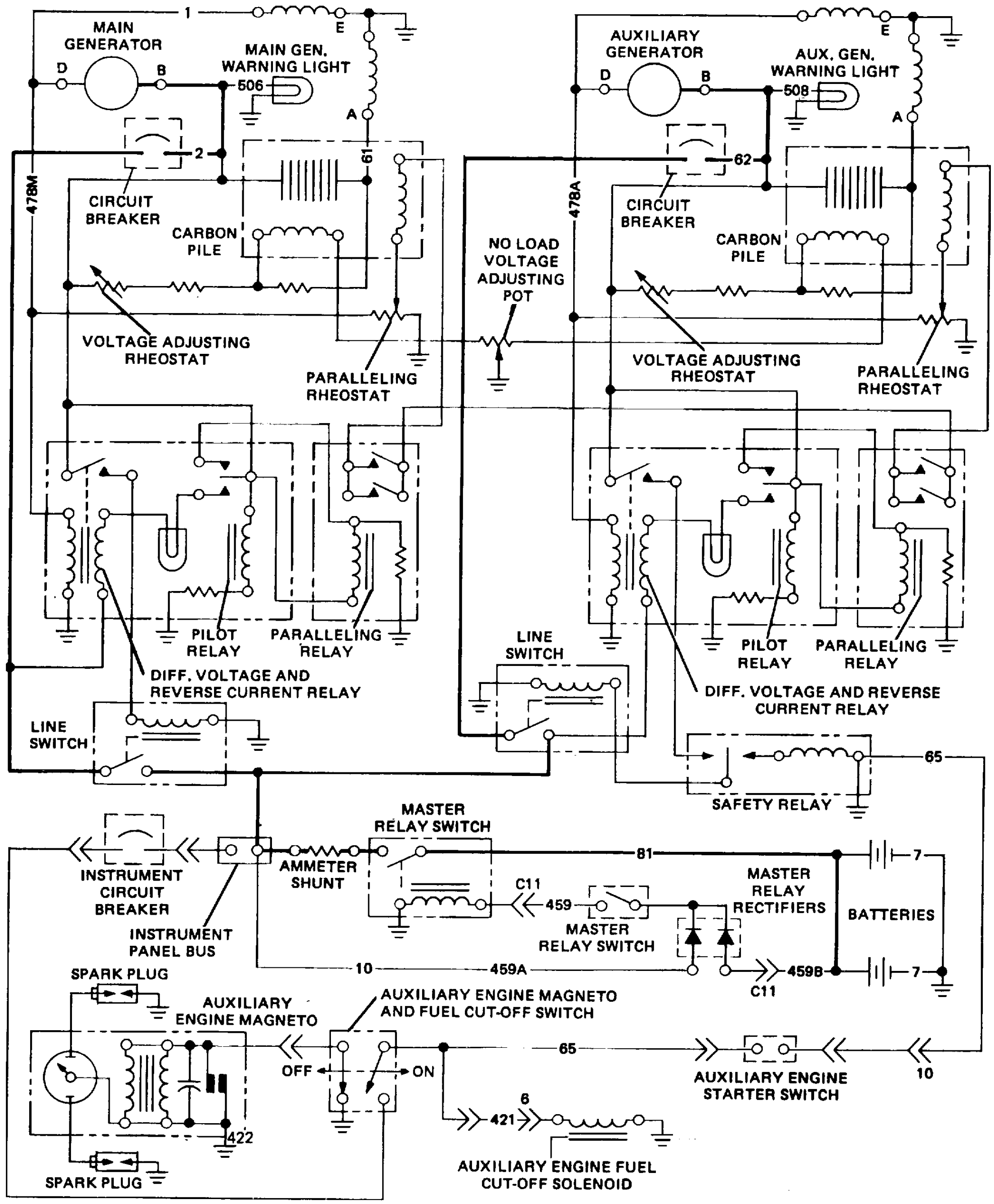

Figure 13-18. Main and Auxiliary Generators.

b. Generator. The generator is a shunt generator with a maximum output of 150 amperes, and is used with a 24-volt battery set. The generator contains an additional field winding of a few turns of very heavy wire through which the entire generator output passes. This is a series winding. It is wound so that its magnetic field opposes the magnetic field from the shunt windings. This acts as a current-limiting device because the higher the output, the greater the opposition from the series-winding magnetic field. When the output reaches the rated maximum, the series-winding field is so strong that it effectively prevents any further increase in output. More increases would strengthen the series-winding field, thus further opposing the shunt- winding field and causing a decreased total field and, consequently, a drop-off of output. This series-field winding in the generator also plays an important part in the operation of the regulators and certain relays in the control system (para c and d, below).

c. Pilot Relay. There is a pilot relay for each generator. Because both operate the same, the one used with the main generator will be discussed. It contains a shunt winding that is connected across the main generator terminals. In addition, it has two sets of contacts: an upper set and a lower set. The upper set is used in conjunction with the paralleling system, so consider the lower set first. This lower set is open when the generator is not operating. But when the generator begins to run and its voltage increases sufficiently to charge the battery, then the lower set closes. The shunt winding in the relay produces this action because, with sufficient voltage, it has a strong enough magnetic pull to pull down the relay armature and close the lower contacts. When the lower contacts close, this causes the differential-voltage-and-reverse-current relay to operate.

d. Differential-Voltage-and-Reverse-Current Relay.

(*1) Closing.* When the pilot relay closes its points, one of the windings in the differential- voltage-and-reverse-current relay becomes connected between the insulated battery terminal and the installed generator terminal. If the generator voltage is greater than the battery voltage, the difference (or differential) between the two causes current to flow in the winding (which is called the differential-voltage winding). As this current flows, a magnetic field is produced that pulls the relay armature down and causes relay contacts to close. When the relay contacts close, the line-switch winding is connected across the generator so that it closes, thereby directly connecting the generator to the battery.

(*2) Opening.* With the relay and line switch closed so the generator charges the battery, current flows through the battery and back to the generator by means of ground wire and the series winding in the generator field. Because the current is flowing through the series winding, there is a voltage difference between the two ends of this winding. This voltage varies with the rate of current. With a high generator output, a high current is flowing and the voltage across the series winding is greater. This voltage is applied to the differential-voltage-and-reverse-current relay. When the generator is charging and the relay is closed, this voltage is imposed across a second winding in the relay (the reverse-current winding) in such a direction as to help the differential-voltage winding hold the relay contacts closed. But when the generator voltage falls below the battery voltage, the battery begins to discharge through the generator. In other words, the current reverses. This means that the current in the series-field winding, and thus the voltage across the series-field winding, also reverses. The resultant reverse voltage, which is applied to the reverse-current winding, causes the magnetic field of this winding to reverse. This winding then no longer helps the differential-voltage winding, but opposes it. As a result, the total magnetic field is so weakened that the relay armature is pulled up by its spring tension and the contacts open. This then opens the line switch winding circuit so the line switch opens. This disconnects the generator from the battery.

e. Line Switch. The line switch is a simple magnetic switch. When its winding is electrically energized, it pulls the armature down so the switch is closed. When the winding is disconnected, the spring pressure under the armature moves the armature up so the switch opens.

f. Paralleling Relays.

(*1) Connections.* In operation, the contacts of the paralleling relays are connected in series with the paralleling windings in the two voltage regulators and to the two series-field windings in the two generators. Whenever a generator begins to charge, the armature on the pilot relay moves from the upper to the lower position, opening the upper and closing the lower contacts. When the upper contacts are closed (meaning that the generator is not charging), the paralleling relay winding is shorted through them and no paralleling relay action can take place. But when the pilot relay opens these upper contacts and closes the lower contacts, the winding of the paralleling relay becomes connected across the generator. Now, generator voltage can energize the winding and cause the paralleling relay to close its contacts. Only one paralleling relay will be actuated if only one generator is operating. This means that no paralleling can take place. But when both generators are operating so that both paralleling relays are in action, then the contacts of the relays, the paralleling windings in the regulators, and the series-field windings in the generator are all in series.

(*2) Operation.* When all are in series, current will flow in the circuit if one generator is putting out more current than the other. To understand how this might be, refer to figure 13-19, which is a simplified sketch of the generator series-field windings and the regular paralleling windings connected in series. The paralleling relay contacts are not shown here because they are closed and are therefore a part of the circuit. Suppose that the main generator is putting out more current than the auxiliary generator. This means that more current flows through the series-field winding of the main generator than through the series-field winding of the auxiliary generator. Under these conditions, there will be a greater voltage across the main generator series-field winding. This means that current will flow from this winding, through the paralleling windings, and the auxiliary generator series-field winding. The current flow through the paralleling windings in the regulators helps the regulating winding in one regulator and opposes the regulating winding in the other. it helps in the main generator regulator; this means that the spring pressure on the carbon-pile armature is lightened further so that the carbon-pile resistance increases, cutting down the main generator output. On the other hand, the paralleling winding in the auxiliary generator regulator opposes the regulating winding. This means that the spring pressure on the carbon-pile armature is increased. Carbon-pile resistance is reduced and the auxiliary generator output goes up.

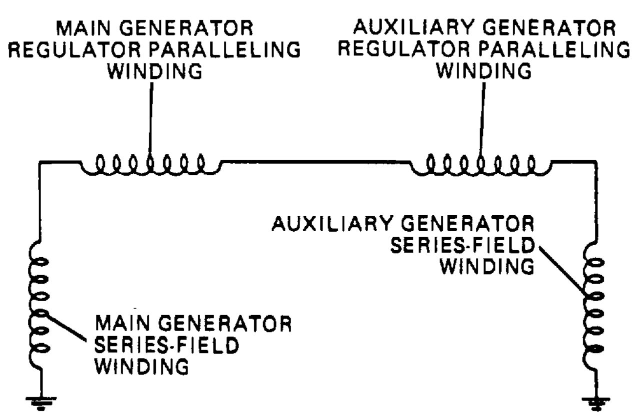

Figure 13-19. Paralleling Relays.

(3) Paralleling. With paralleling, if one generator tries to produce more output than the other, its output is cut down immediately while the output of the low generator is increased. The action is entirely automatic once the system has been adjusted correctly. In order to achieve adjustment, the voltages of the two carbon-pile regulators must first be set, then the voltages perfectly balanced by means of the no-load voltage-adjusting potentiometer, or pot. Finally, the two paralleling rheostats must be adjusted. All these adjustments must be made by authorized personnel and according to instructions supplied in the applicable technical manual.

g. Regulators. The carbon-pile regulators, one for each generator, operate on generator voltage (para 13-16). A simplified sketch of one carbon-pile regulator circuit is shown in figure 13-20 (paralleling winding not shown). Some special features of this circuit will be of interest.

The carbon pile is connected between the insulated generator brush and the generator shunt field. The regulator winding is connected across the generator brushes so that full generator voltage is imposed on it. It therefore regulates on generator voltage as explained in paragraph 13-16. There is a voltage-adjusting rheostat connected in series with the winding so that voltage adjustment can be made. In addition, the circuit goes to ground through an adjustable resistor called a potentiometer. The potentiometer permits accurate balancing of the two voltage regulator settings.

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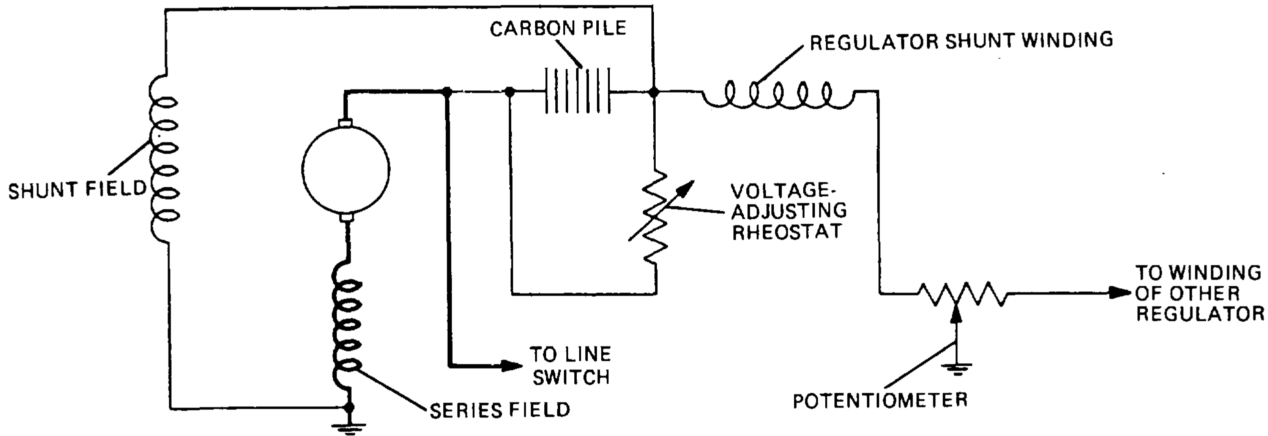

Figure 13-20. Carbon-Pile Regulation of Generators.

For instance, if one regulator is slightly higher than the other, but both are within specifications, balance can be achieved by turning the potentiometer knob slightly. This puts more resistance into one regulating winding circuit and takes it out of the other, thus achieving the desired results.

Section III.13-20.General. Most of the military vehicles are now equipped with an ac charging system. The reason for changing to the ac system is that an alternator is capable of producing a higher voltage at idle speed, whereas a dc generator produces very little voltage at idle speed. Many of the military vehicles are equipped with radios, firing devices, and other high-current-drawing equipment. When this equipment is in operation and the vehicle's engine is at a low rpm, a dc generator will not produce the required current and voltage to keep the batteries charged and supply the current required to operate the accessories properly.

13-21. The Basic Alternator.

a. Construction (Fig. 13-21). The alternator is composed of the same basic parts as a dc generator. There is a field that is called a rotor and a generating part known as the stator. The purpose of the alternator is to produce more power and operate over a wider speed range than that of a generator. Because of this, the construction of the functional parts is different. The stator is the section in which the current is induced. It is made of a slotted laminated ring with the conductors placed in the slots. The current generated in the windings is transferred to the rest of the system through three stationary terminals.

b. Rectifier Bridge (Fig. 13-22). The ac generator produces alternating current at its output. As stated in paragraph 13-6, this is unacceptable for an automotive electrical system. The ac generator is fitted with a rectifier bridge to convert the output to dc. If the two output wires of a basic ac circuit are each fitted with a silicon diode (para 11-5), the alternating cur- rent can be given one direction and thus be changed to direct current. To change current direction, use diodes that allow current flow toward the alternator on one wire (positive) and away from the alternator on the other wire (negative). Because most automotive alternators have three outputs (three-phase stator), the rectifier bridge will consist of six diodes (three positive and three negative). The diodes will be connected so that they combine the three ac outputs of the alternator into one dc output.

13-22. Comparison to a DC Generator.

a. Advantages.

(1) The ac generator is configured opposite to the dc generator. The current is produced in the stator, which does not rotate. This compares with the dc generator that produces current from its armature, which must transmit its output through brushes. This means that the brushes must be very large and, therefore, will wear out

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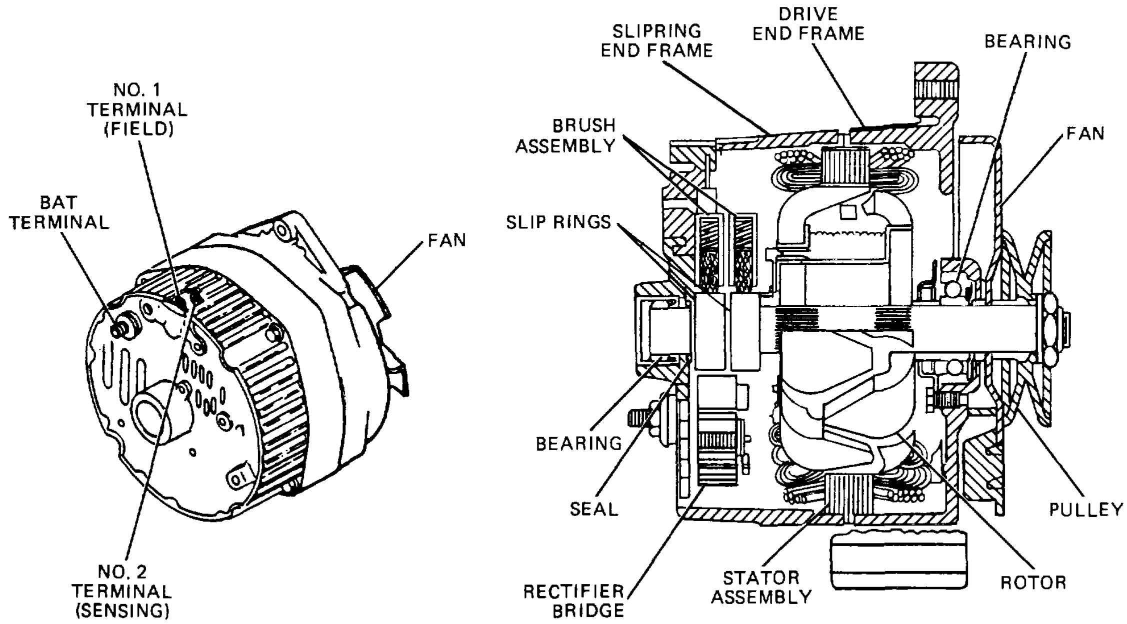

Figure 13-21. Typical Alternator.

quickly due to arcing caused by the large current carried by them.

(2) The rotating field in the ac generator is much lighter and less susceptible to centrifugal force. Because the brushes must only transmit field current, they can be much smaller and will last longer due to less arcing.

(3) The ac generator uses smooth sliprings on its rotor that produce very little arcing during use. This compares with the segmented commutator of the dc generator, which causes large efficiency losses due to drag and arcing.

(4) The ac generator is much smaller and lighter than its dc counterpart.

b. Disadvantages.

(1) The ac generator requires electronic rectification through the use of silicon diodes. Modern rectifier bridges, though extremely durable under normal conditions, are extremely sensitive to accidental polarity reversal. This can result from jump starting, battery charging, and battery installation.

(2) The ac generator does not retain residual magnetism in its field. Because of this, an ac generator-equipped vehicle cannot be push started with a completely dead battery.

c. Comparison of Output Characteristics. It can be seen from figure 13-23 that the dc generator has a much narrower speed-producing range than the ac generator. The initial startup is at a much higher rpm, which is undesirable for vehicles that operate mostly in low-speed rang-s. As high speeds are reached, the dc generator output will fall below its rated output largely due to the brushes bouncing on the commutator segments, causing poor commutation.

13-23. The Automotive Alternator.

a. The Basic Alternator. A basic alternator would consist of one winding or loop in the stator and a single pair of poles in the rotor (fig. 13-24). When the rotor of this machine is turned through 360 degrees, it will induce a single cycle of ac just as the simple generator armature did.

b. Rotor Design (Fig. 13-25). The rotor is designed with two pole pieces that sandwich the

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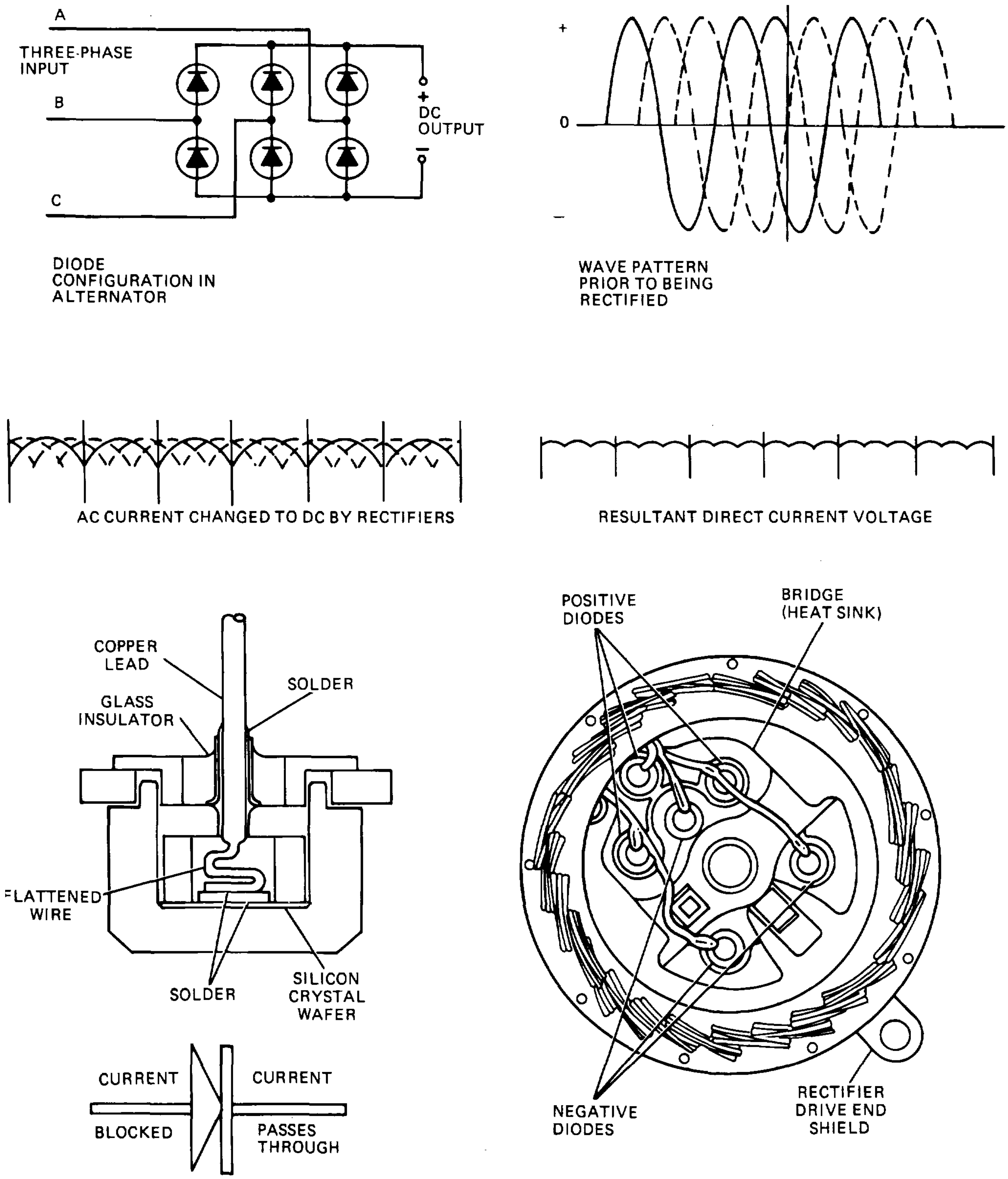

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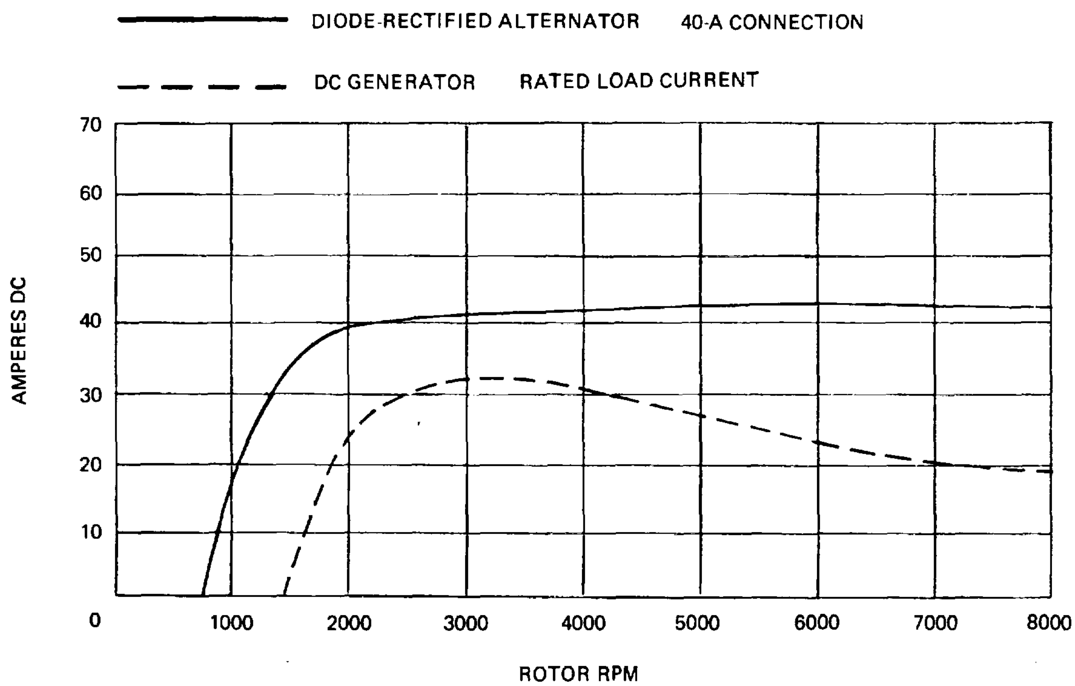
Figure 13-22. Diode Arrangement Rectifier Bridge.



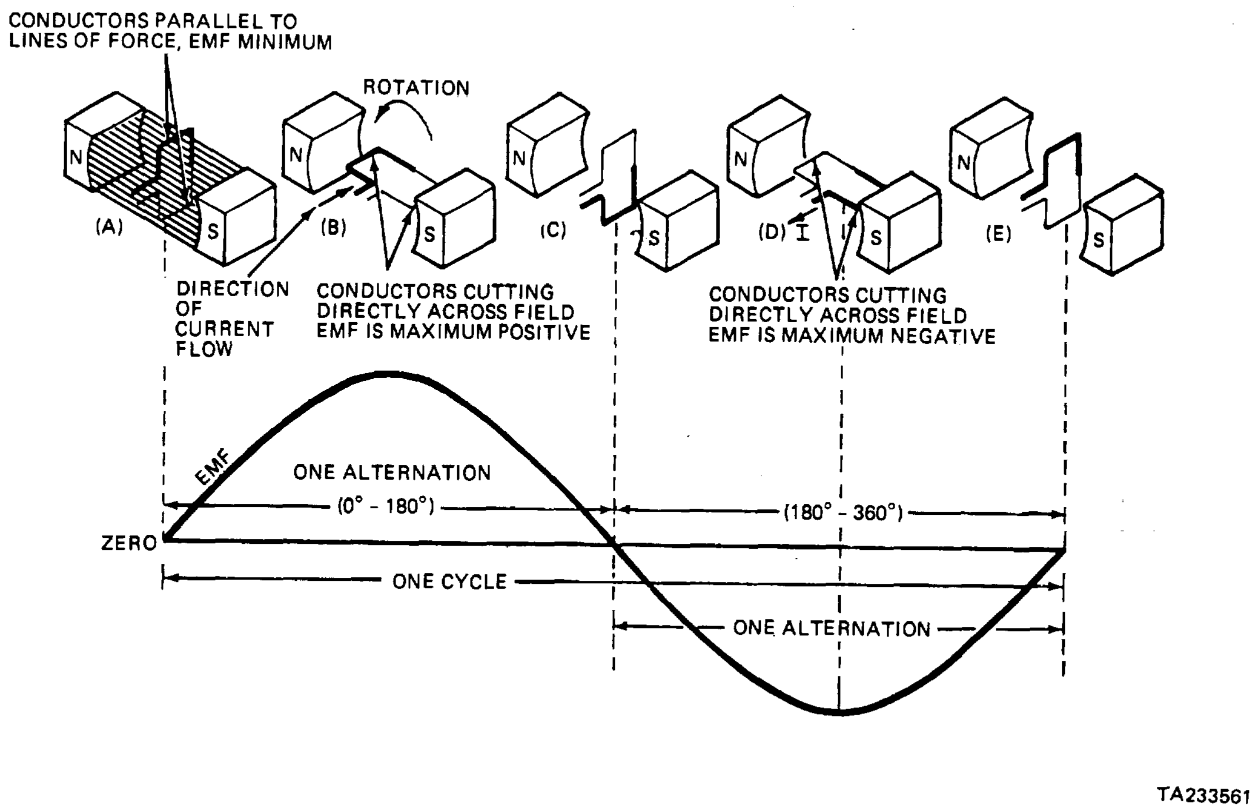


Figure 13-23. & Figure 13-24. Simple AC Generator.

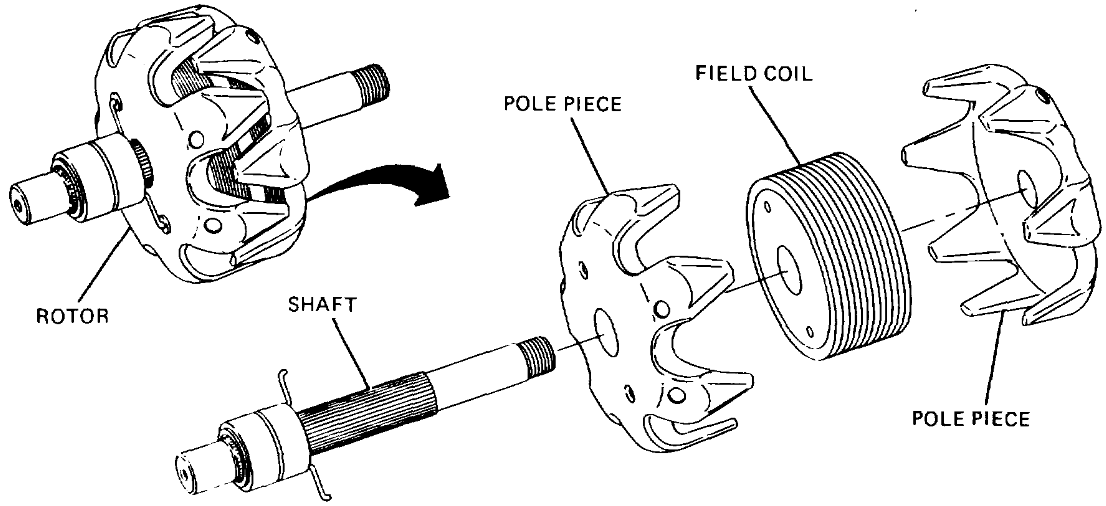


Figure 13-25. Rotor Construction.

field winding on the shaft. Each pole piece has finger - like projections. When the rotor is assembled, the projections interlock with each other. The pole pieces form north and south magnetic poles. The core of the rotor contains the axially wound field winding which is made of varnish-insulated copper wire. Each end of the field winding is connected to an individual slipring.

c. Stator Design (Fig. 13-26). The stator is' designed with three separate windings so that it produces three separate ac currents. This is known as three-phase output. Each winding is in the form of loops that are spaced at intervals on the frame. The windings then are arranged so that they are offset from each other. The three windings are all tied together at one end to form what is known as a wye wound stator.

d. Rotor-to-Stator Relationship (Fig. 13-27). The rotor is synchronized to the stator; that is, when one north pole projection is aligned with one of the loops of one-phase winding loop, the other north pole projections will also align with the other loops of that phase winding. This sequence of alignment between the rotor projections is necessary for operation. If one-phase winding was being acted on by a negative pole projection at one loop and a positive pole projection at another loop, the two loops would cancel each other out and no current would be generated.

13-24. Common Alternator Designs. The following are brief descriptions of various configurations of alternators.

a. Wound-Pole Alternator. Figure 13-28 illustrates the configuration of a typical wound- pole alternator with rotating field. Alternate

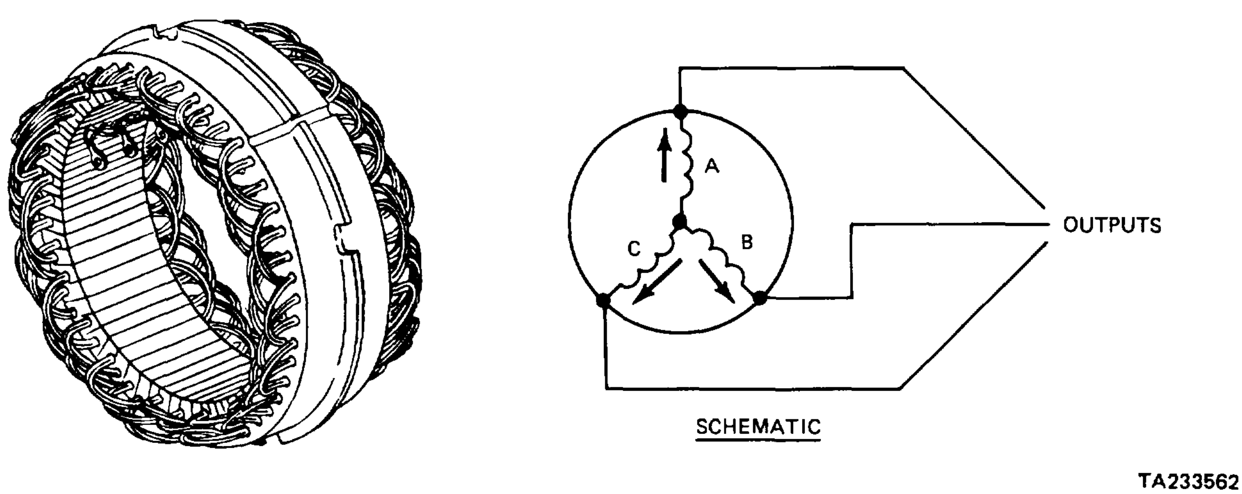


Figure 13-26. Wound-Pole Alternator.

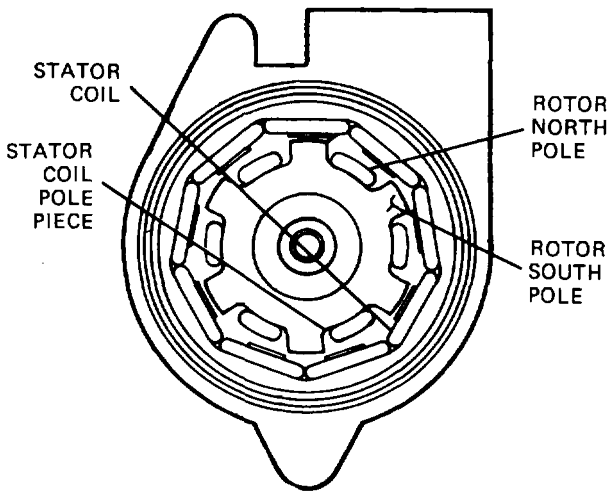


Figure 13-27. Rotor-to-Stator Relationship.

polarity occurs on successive poles. Pole excitation current is obtained through sliprings. The advantages of the wound-pole alternator are a wide speed range: output current windings are stationary, and sliprings carry low field excitation current. The following are disadvantages of the wound-pole alternators: Brushes and sliprings wear, are affected by contamination, produce contaminating carbon dust, may cause voltage modulation, and are not reliable for high-temperature, high-altitude, or high-speed applications. Brush arc is an explosion hazard; fuel or oil cannot be used safely as a coolant. The rotor winding is hard to cool and is relatively unreliable in high-speed or rough-drive applications that cause stress on rotor windings and insulation. The wound-pole alternator has an extensive history of development, but is best suited for low- speed applications in a limited range of environments.

b. Lundell Alternator. The Lundell rotor, as shown in figure 13-29, develops a field by placing the excitation windings around the axis of the rotor shaft, resulting in each end of the shaft assuming a polarity. Coupled to each end are interspaced fingers forming opposite polarities that provide an alternating field when rotated. Field excitation is achieved through slipring conduction. The following are advantages of the Lundell rotor. This rotor has a simple rotor winding construction and stationary output current windings. The disadvantages of the Lundell rotor are windage (air resistance) losses and the use of sliprings and brushes.

c. Lundell Inductor. This generator type differs from the previously described Lundell type, in

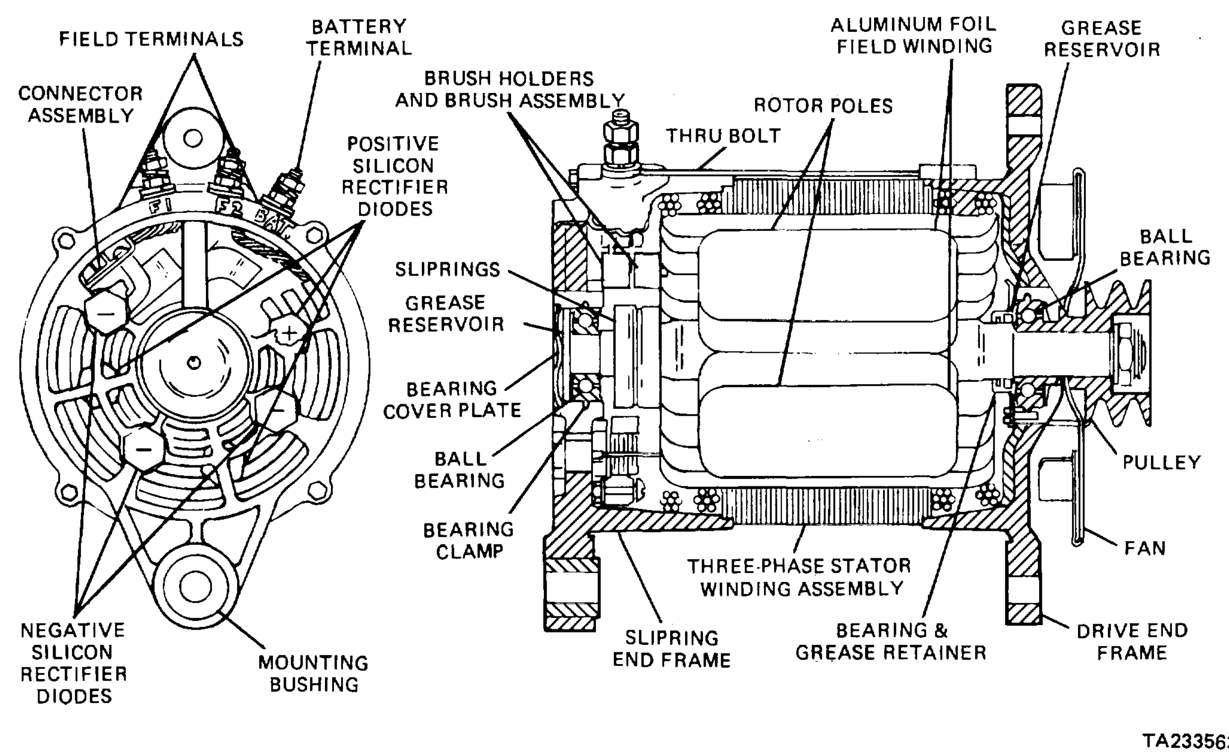


Figure 13-28. Wound-Pole Alternator.

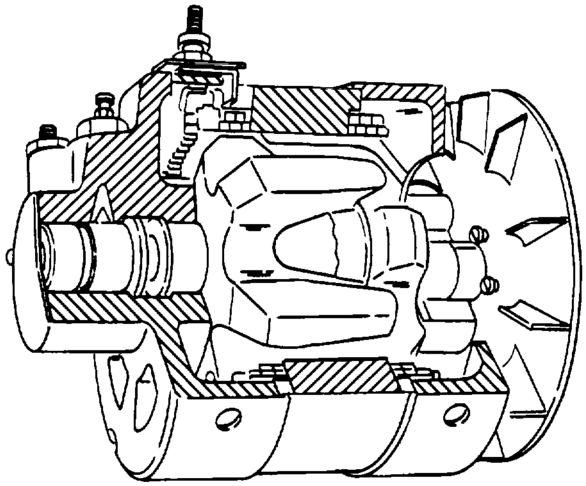


Figure 13-29. Rotor-to-Stator Relationship.

that the rotor contains no windings. Excitation is induced in the rotor poles by stationary field coils located at the ends of the rotor. This results in the elimination of sliprings and rotating windings. Further advantages can be obtained by casting a nonmagnetic material around the pole fingers, thus producing a smooth rotor with low windage losses and high speed capability. An inherent design requirement of this stationary field arrangement is the inclusion of an auxiliary air gap in the magnetic circuit. This requires greater field current for excitation. Figure 13-30 illustrates construction features. There are a variety of advantages to a Lundell inductor. There are no slipring wear or contamination problems, and the unit is inherently explosion proof. The rotor can be solid and permanently balanced. All windings are stationary and readily accessible for cooling. The low rotor mass reduces bearing loads and permits rapid acceleration. The bearing center-to-center distance is minimized by the elimination of sliprings, and this, combined with a large shaft diameter, permits high-speed operation. The field windings are simple, bobbin-wound coils permitting short mean turn length. The only disadvantage is that extra air gaps in the magnetic circuit require increased excitation power.

d. Inductor Alternator. An inductor alternator employs a fixed, non-rotating field coil that induces excitation in the central portion of the rotor as if it were a solenoid. Each end of the rotor assumes a polarity. A multilobed segment is attached to each end of the rotor. The segment varies the reluctance in the magnetic circuit as it rotates. As a result, the fixed stator poles experience a variation in magnetic strength or coupling and produce a resulting output voltage in the stator coils. In contrast to other types of generators, the iron does not experience a flux reversal. Consequently, there is only a 50-percent utilization of the iron in the stator. Figure 13-31 illustrates typical construction of the inductor alternator. The advantages of an inductor alternator are easier winding construction for field and stator coils; simplified cooling; it is brushless; and it has an integral solid rotor without windings that permits high-speed operation. The disadvantages of an inductor alternator are that it has less than 50 percent use of iron, resulting in a heavier unit and the increased total air gap in the magnetic circuit requires more excitation.

e. Brushless-Rotating Rectifier. Another means for eliminating brushes and sliprlngs is found in the rotating rectifier type of alternator. The machine consists of five main functional elements. These include a stator-mounted exciter field, the exciter armature, a main rotating field, the main output stator windings, and the output rectifier assembly.

The exciter field induces alternating current in the rotating armature and the output is rectified and directly coupled to the rotating main field, which excites the stator-mounted output windings. With this arrangement, a small amount of exciter field excitation can be amplified in the exciter stage to supply a high level of main field current. A diagram of elements is shown in figure 13-32, along with a cross section through the alternator. The advantages of the brushless rotating rectifier are that it is brushless and a low exciter field current permits a low-level regulator. However, the disadvantages of the brushless-rotating rectifier are that a wound rotor limits top speed, multiple windings contribute to complexity and cost, a large number of heat-producing rotating elements increases cooling requirements, and a large magnetic circuit limits response.

13-25. Cooling Generators. The common methods used for cooling generators use heat transfer by airflow or oil circulation. Each has its particular application based on their advantages and disadvantages.

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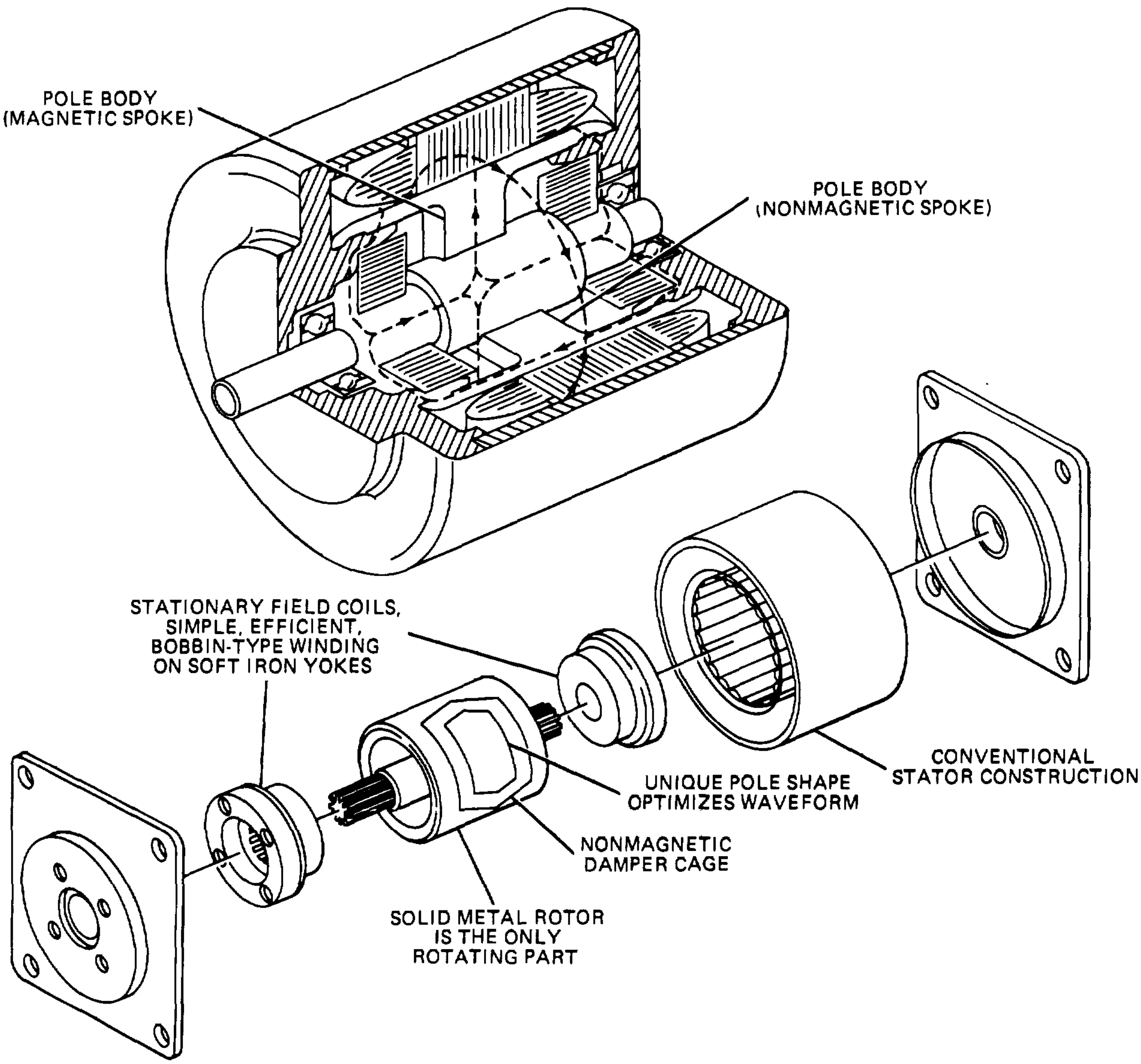

Figure 13-30. Lundell Inductor.

a. Air Cooling (A, Fig. 13-33). In tank-automotive applications, air cooling Is the most common method. The usual arrangement consists of a fan that forces air through the alternator to cool the rotor, stator, and rectifier. The major advantage of air cooling Is that the generator and cooling are self-contained, drawing air from the environment. However, fan power requirements can become excessive at high speeds because fan designs usually are structured to provide sufficient cooling at the lowest speed corresponding to rated output. Fan power at high speeds then appears as a severe reduction in generator efficiency. Another factor is that, unless it is filtered, cooling air can deliver abrasive particles, water, or other substances to the generator interior. Furthermore, rotor and stator design must permit unrestricted passage of air through the generator. This can be accomplished by designing passages through the rotor and stator. However, roughness in the surface of the rotor contributes to windage losses, further affecting unit efficiency.

b. Oil Cooling (B, Fig. 13-33). 0il cooling features a transfer of alternator heat into the circulating oil flow, followed by cooling of the hot oil in a heat exchanger. The oil supply can be part of the driving power system

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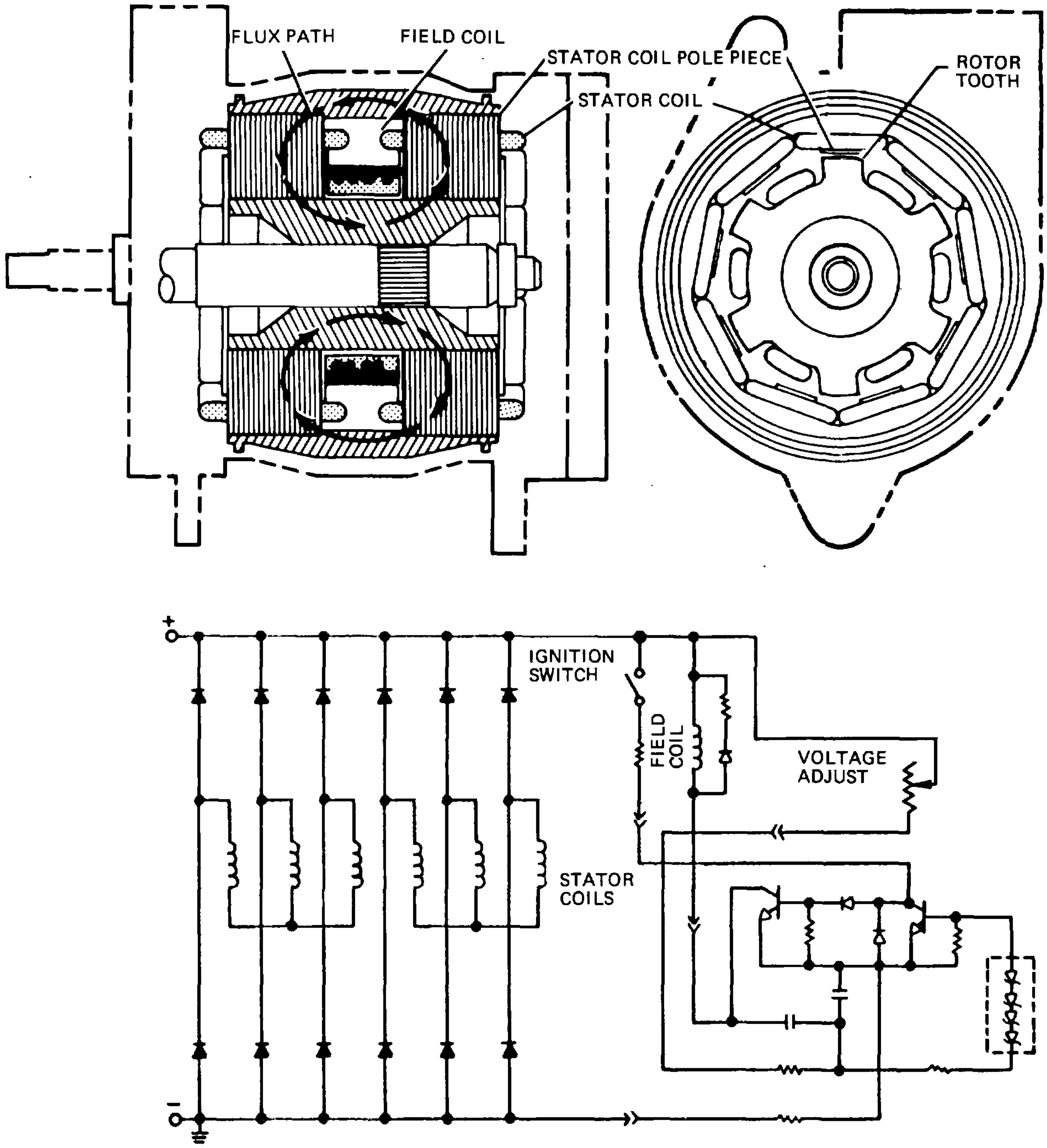

Figure 13-31. Inductor Alternator

or a separate self-contained system.

Some oil-cooled system advantages are that the generator can be sealed completely, preventing entrance of foreign matter; cooling oil can be used for bearing lubrication; the rotor can be solid, reducing windage losses; and generator efficiency can be higher because the effective losses that occur in oil circulation are constant with generator speed.

Several disadvantages encountered with oil cooling include the consideration that complex manifolding, porting, seals, and passages increase costs; and that auxiliary heat exchangers and pumps increase cost, weight, and complexity.

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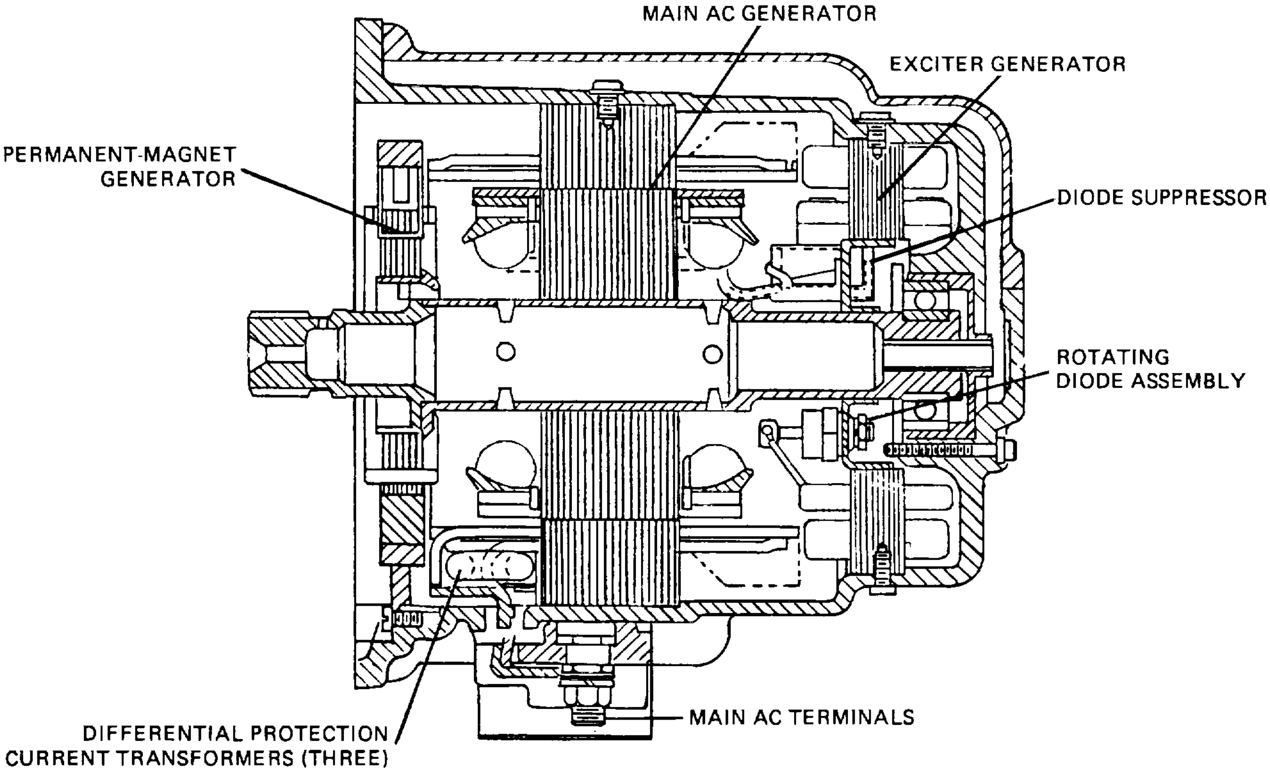

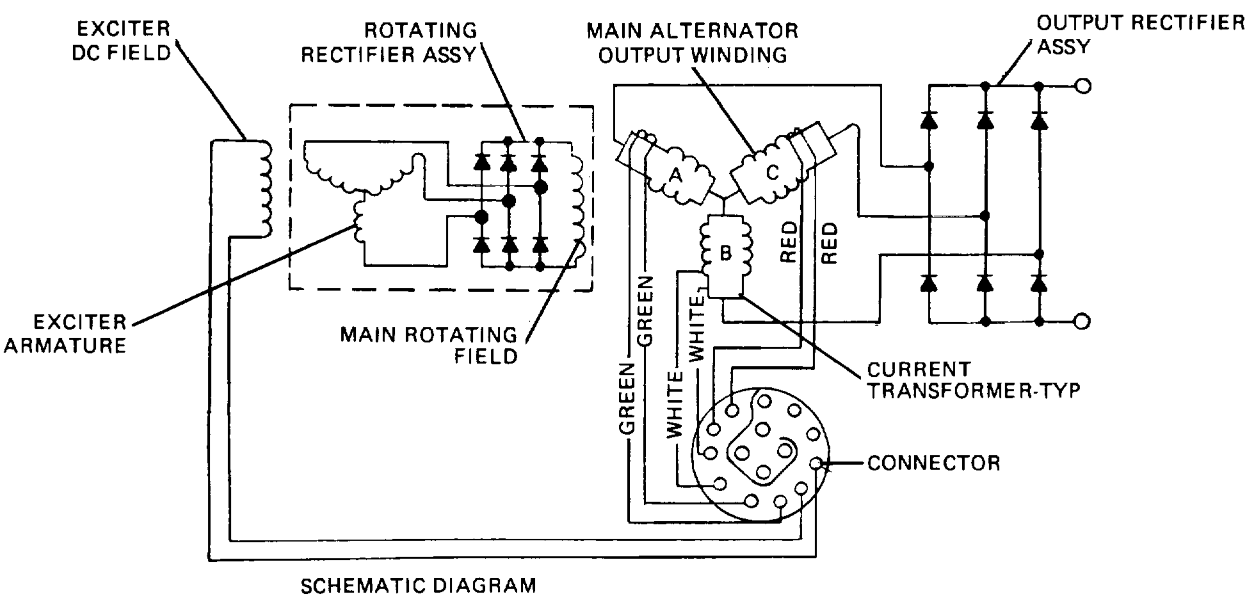

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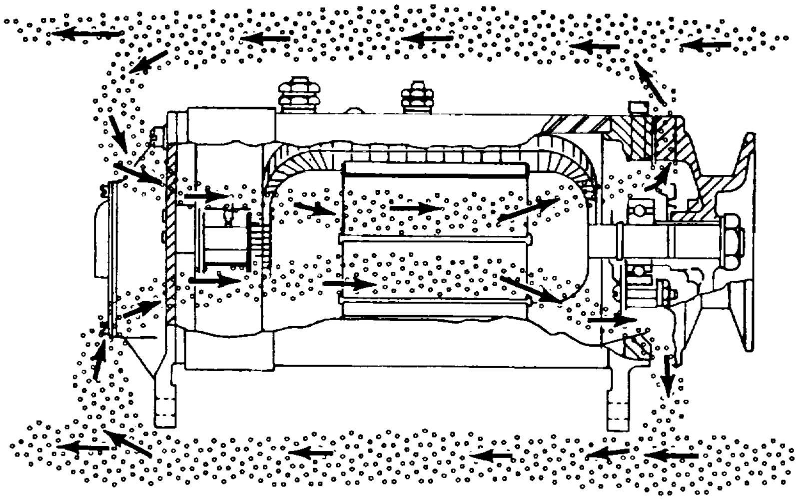
Figure 13-32. Brushless-Rotating Rectifier



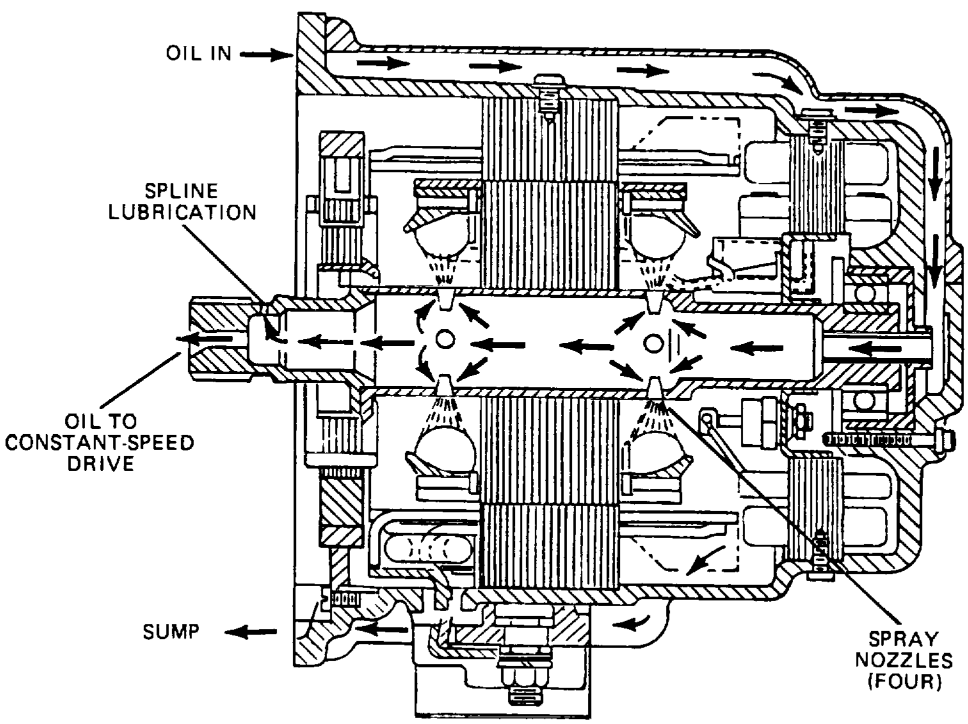


Figure 13-33. Generator Cooling.

13-26. AC Generator Regulation. The regulation of ac generator output, though just as important as the regulation of dc generator output, is much simpler for the following reasons:

a. The ac generator, because of its rectifier bridge, will not allow current to backflow into it during shutdown. This eliminates the need for a cutout relay.

b. An ac generator will limit its current automatically by regulating the voltage. A current regulator, therefore, is not needed in the voltage regulator.

Because a cutout relay and a current regulator are not necessary, an ac generator voltage regulator contains only a voltage regulation element. A typical single-element voltage regulator for an ac generator is shown in figure 13-34. For comparison, a typical three-element voltage regulator for a dc generator is also shown.

13-27. Vibrating Point Regulator.

a. Description (Fig. 13-35). The vibrating point voltage regulator is a single-element unit that limits system voltage. The element consists of a double set of contact points that are operated by a magnetic coil. The center contact is stationary and connected directly to the generator field. The upper and lower contact points are pulled downward by the magnetic coil against the force of a spring. The upper and lower contacts always maintain the same distance from each other. The upper contact is shunted directly to the ground. The lower contact connects to battery voltage as does the operating coil. A resistor is connected from the battery to the field connection.

b. Operation (Fig. 13-35). The lower contact normally is connected to the center contact because of spring tension. As the magnetic coil is energized, the movement of the upper and lower contacts will disconnect the center and lower contacts. As they move further, the upper contact will become connected to the center contact. The following describes the operation:

(1) As the operation begins, the center contact is connected to the lower contact, sending full battery voltage to the field winding. This will cause the alternator to produce full output.

(2) As the alternator raises system voltage, the force exerted by the magnetic coil increases. This causes the upper and lower contacts to move, which in turn breaks the connection between the center and lower contacts. The field then receives reduced voltage from the resistor, causing a corresponding reduction in alternator output. The resulting lower system voltage decreases magnetic coil force, allowing the lower and center points to come together again. This is a

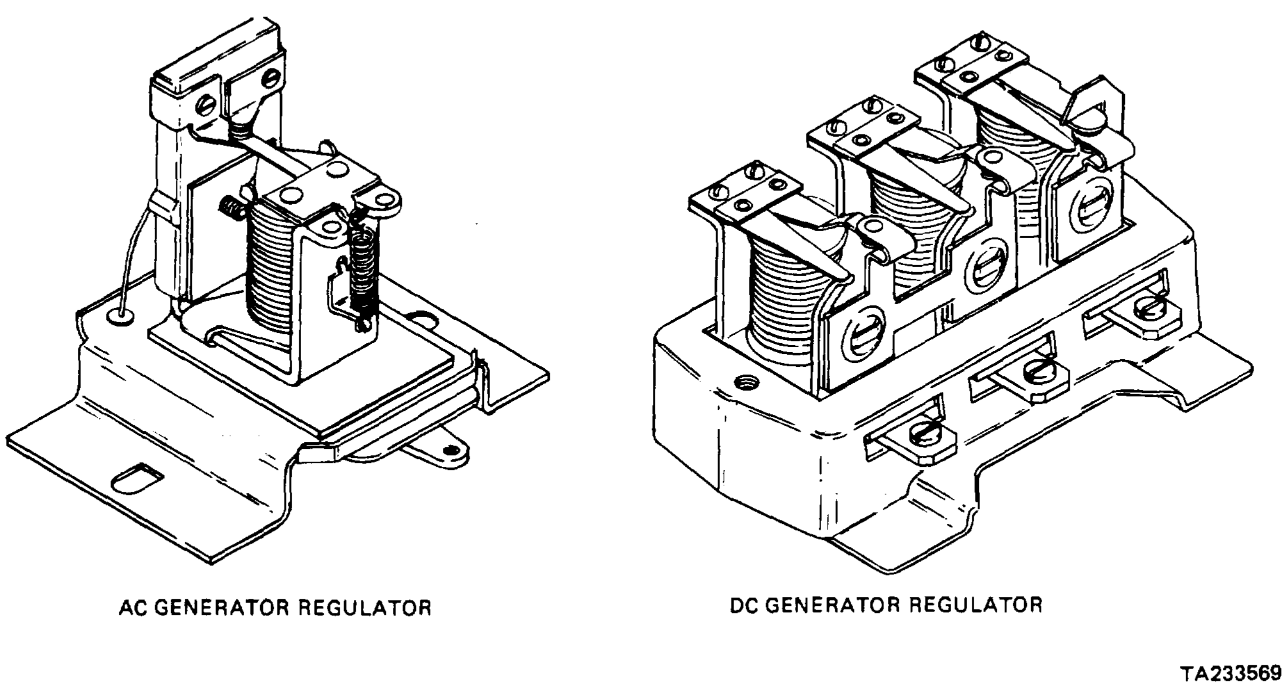


Figure 13-34. AC and DC Regulator Comparison

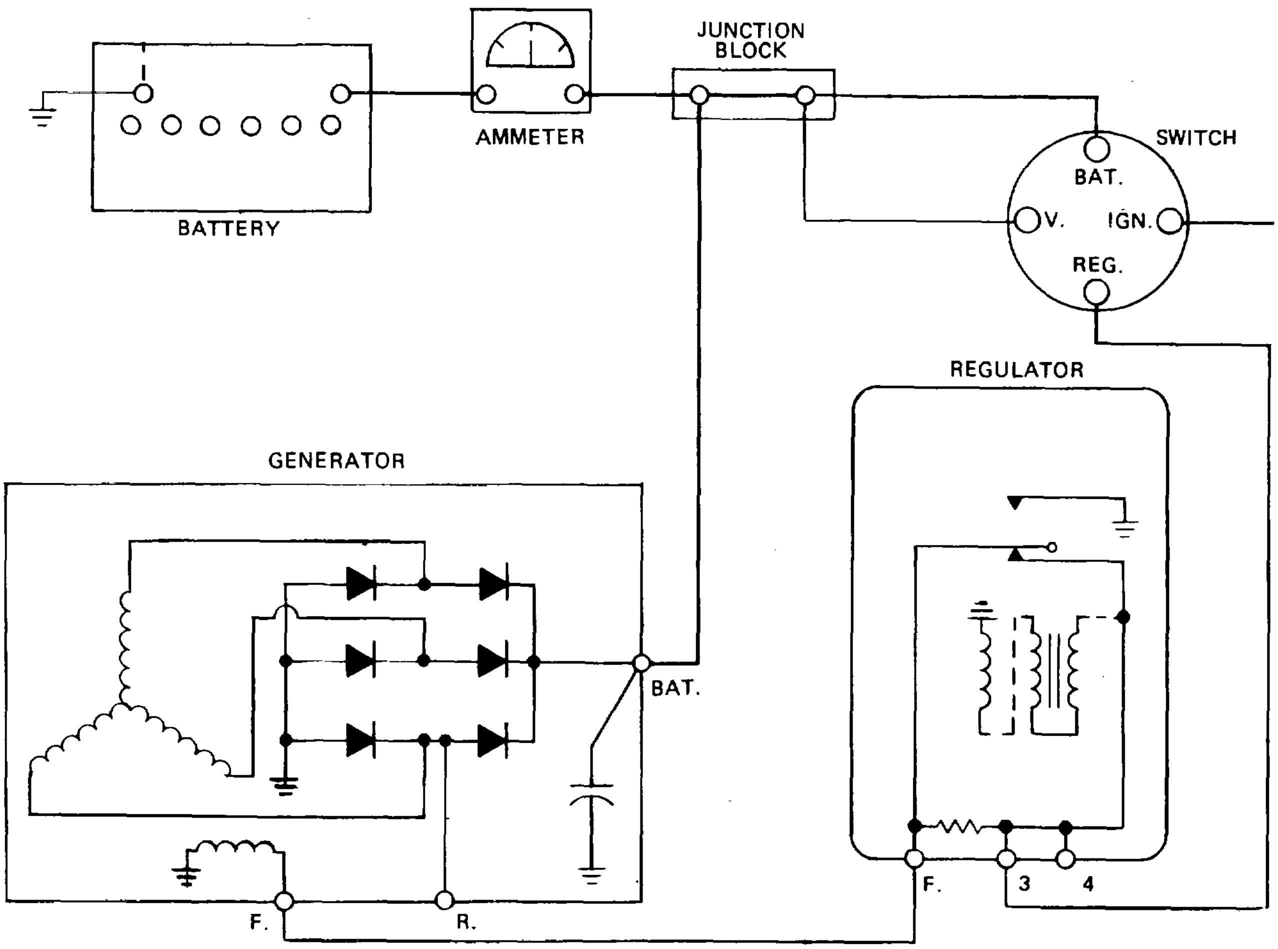


Figure 13-35. Vibrating Point Regulating Circuit

constantly repeating cycle (many times a second) that serves to limit electrical system voltage. The magnetic coil force and spring tension are calibrated to maintain the desired voltage, which is usually approximately 13.2 to 13.8volts in commercial vehicles.

(3) During periods of light electrical loads, particularly at high speeds, the system voltage may go too high even with reduced field voltage from the resistor. When this happens, the magnetic coil will pull the upper contact into connection with the center contact. This will shunt all field current to ground, causing the alternator to stop producing current.

13-28. Transistorized Point Regulator (Fig. 13-36). The operation of the regulator is essentially the same as the vibrating point regulator. The main difference is that the contacts only carry a current that is used to trigger a transistor. Based on this signal current from the points, the transistor will control and carry the field current. The advantage to this configuration is increased contact point life. This is because the signal current to the transistor is low and causes very little arcing.

13-29. Solid-State Voltage Regulator (Fig. 13-37). A solid-state voltage regulator is a static unit that is totally electronic in operation. In this configuration, the contact points are replaced by zener diodes (para 11-7). The zener diodes produce a signal to the base of a transistor whenever the electrical system voltage reaches the desired level. This signal to the base of the transistor reduces or shuts off field current to reduce or stop alternator output. When the system voltage drops again, the transistor again will allow alternator output. This cycle will repeat itself as much as 2000 times per second. Some applications utilize a rheostat to adjust the resistance of the field current, thereby regulating

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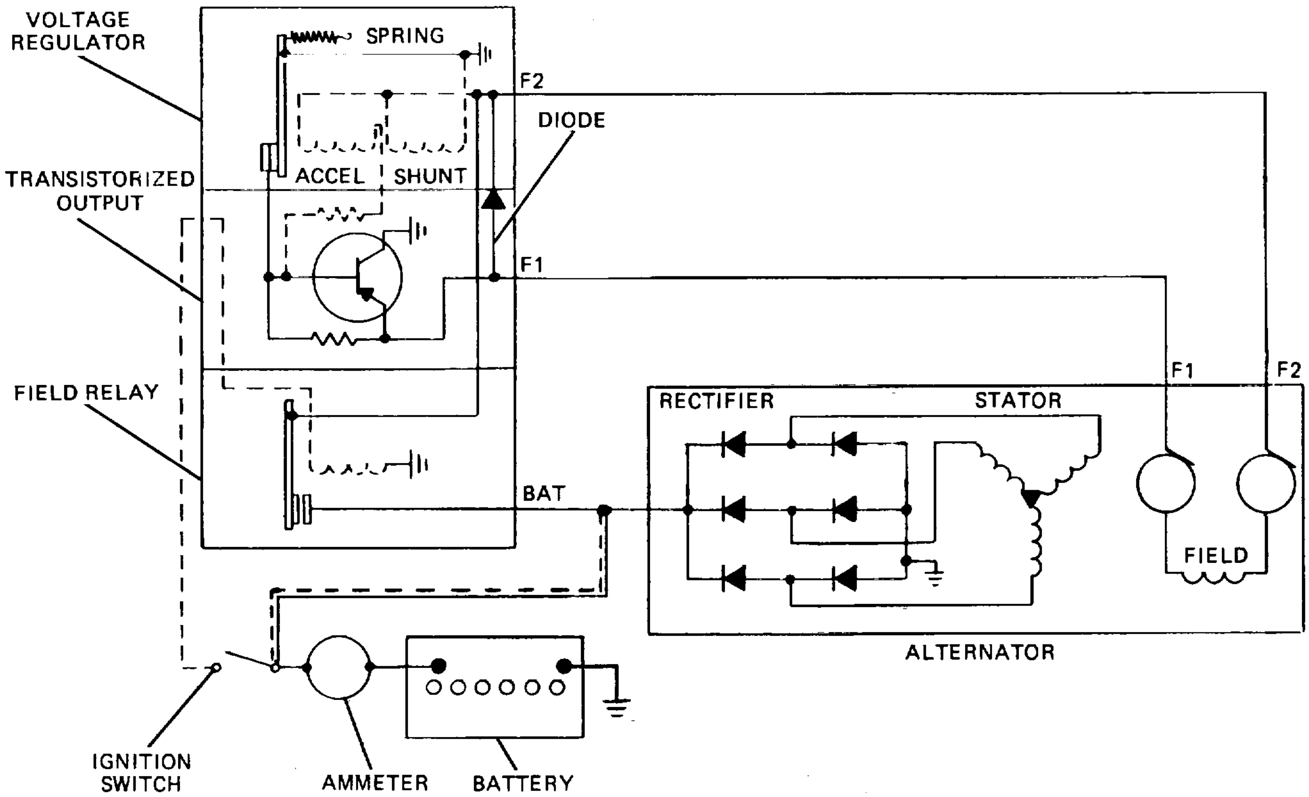

Figure 13-36. Transistorized Voltage Regulator

alternator output. The solid-state regulator virtually has replaced the mechanical units in all currently produced equipment due to the extreme reliability and low manufacturing costs of solid-state components. Another desirable feature of a solid-state regulator is that it can be made small enough to be built into the alternator.

13-30. Accessory Items.

a. Fuel Pressure Field Switch (Fig. 13-38). The fuel pressure field switch is a device that is used on high output alternators to prevent the alternator from placing a load on the engine until it is running by opening the alternator field circuit until the fuel pressure reaches the normal operational range.

b. Field Relay. The field relay is used in two basic applications:

(1) It can be used to isolate the field circuit from the battery whenever the ignition switch is turned off (fig. 13-39). In this application, the magnetic coil is energized with the ignition switch. The contact points then pull together, completing the field circuit.

(2) It also can be used to operate an alternator no-charge warning light (fig. 13-39). In this application, the magnetic coil is energized by one of the stator windings. This will cause the contact points to be pulled together whenever the alternator produces sufficient current to sustain operational voltage. When the contact points are open (alternator not operating), the field circuit receives current from a lead that passes in series through an indicator lamp that is in parallel with a resistor. The field current will cause the lamp to light. As the alternator begins to produce, the field relay contact points will close, shunting the field circuit directly to battery voltage, causing the indicator lamp to go out.

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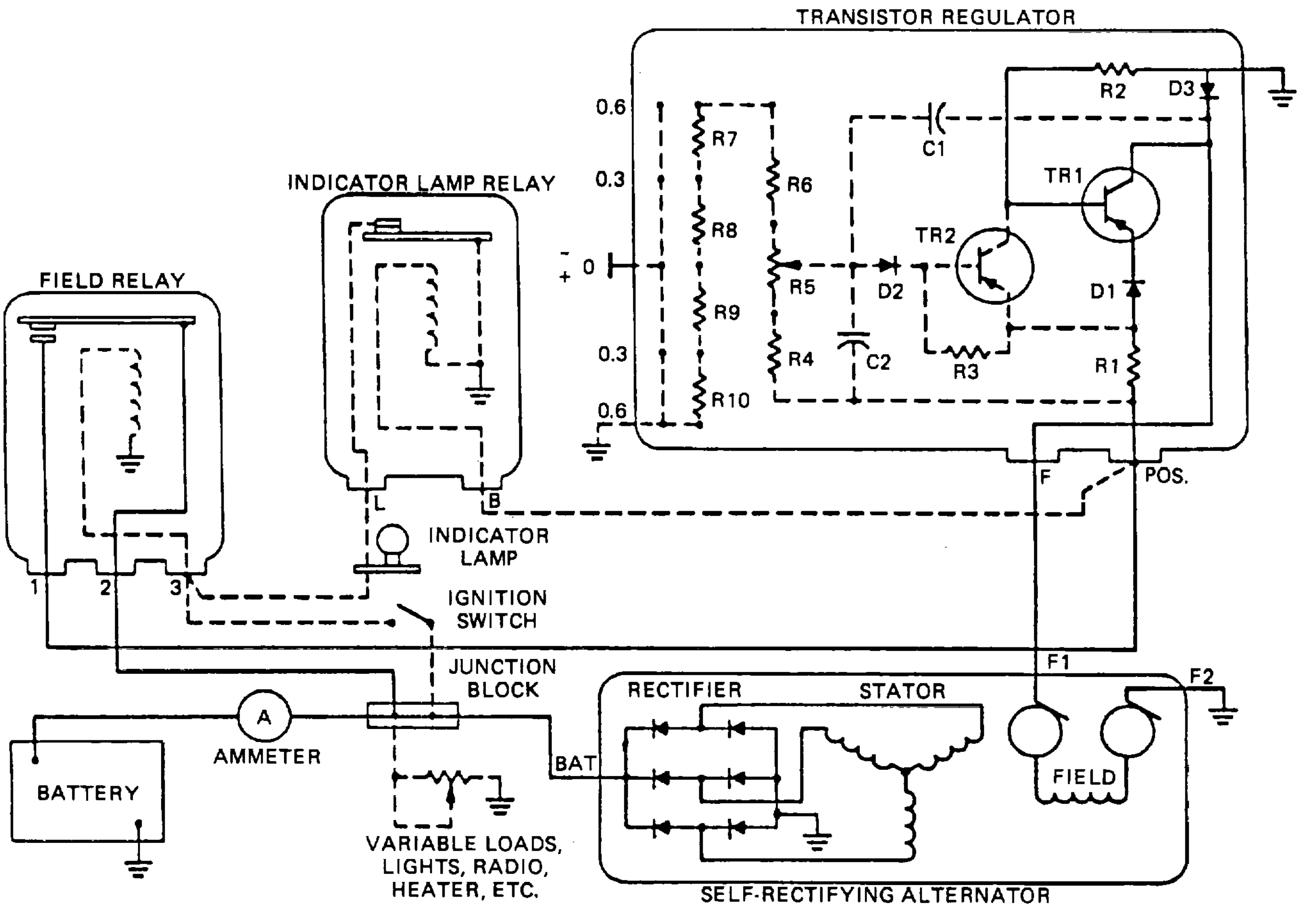

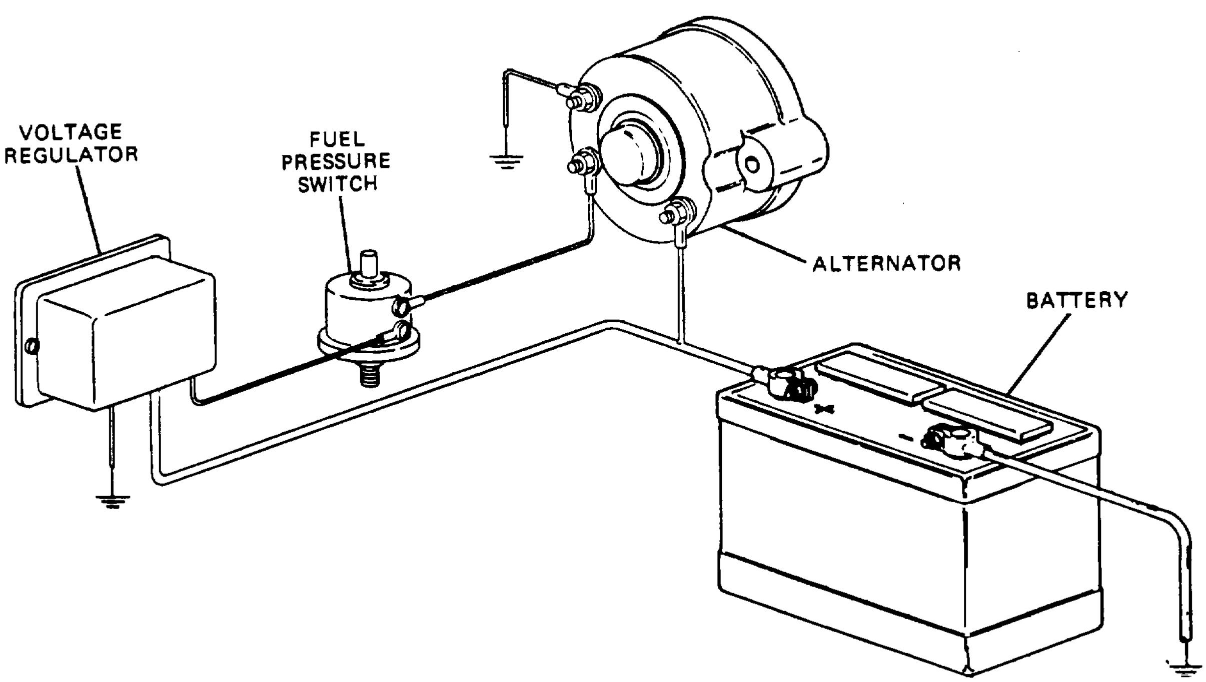

Figure 13-37. & Figure 13-38. Fuel Pressure Field Switch Circuit

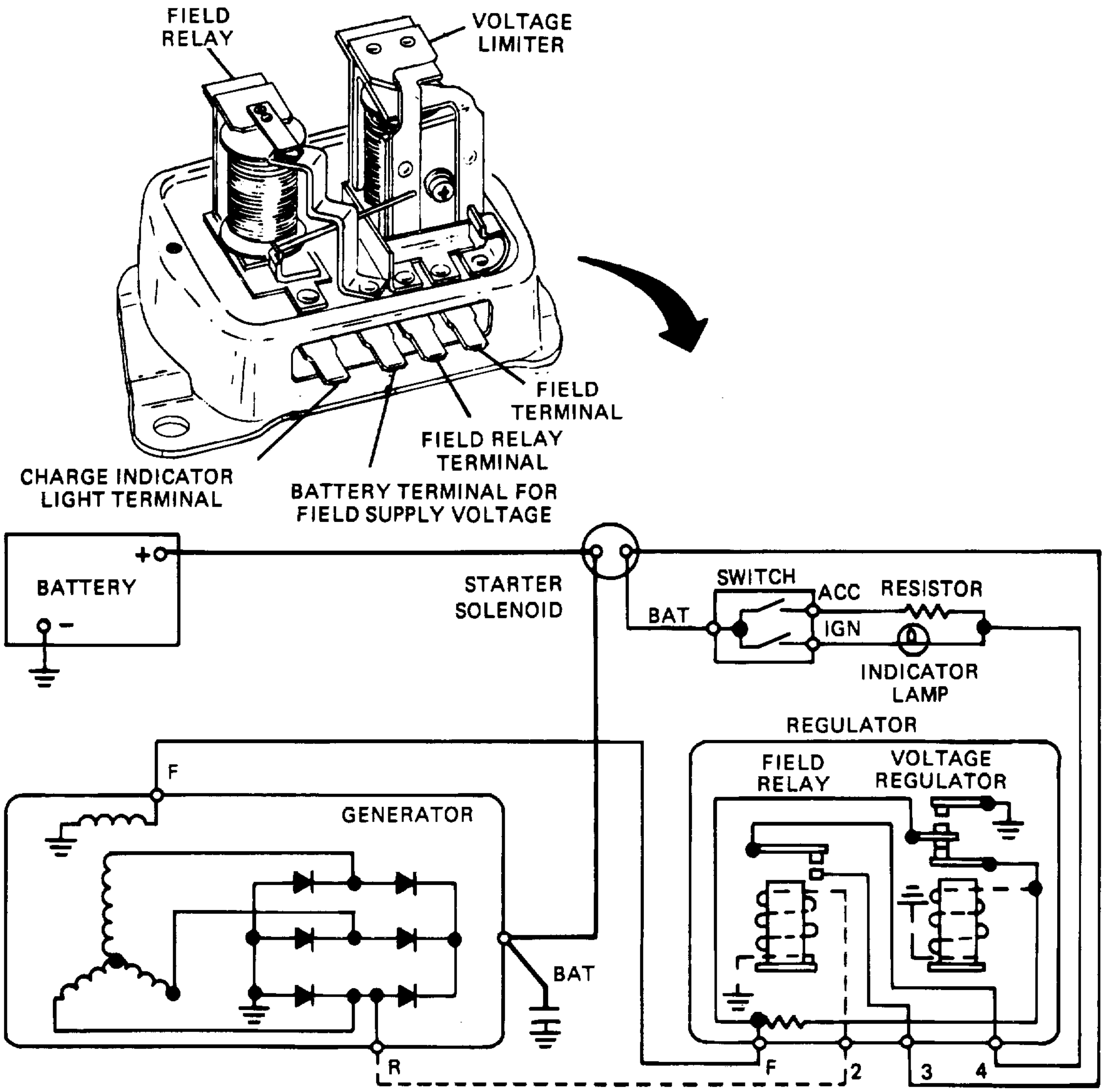

Figure 13-39. Field Relay and Warning Light Circuit.

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