



AEROSPACE INFORMATION REPORT

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VEHICLE ELECTRICAL SYSTEMS

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PREPARED BY

SAE COMMITTEE AGE-2C, VEHICLE MAINTENANCE
AND AIRCRAFT SERVICING

1. PURPOSE

Electrical Systems Engineering is the modern concept of integrating load requirements with generator/ alternator and battery capacity and regarding this electrical equipment as a complete system rather than a collection of independent units. The old adage "a chain is not stronger than its weakest link" is particularly valid for electrical circuits. So great care must be taken in selection of equipment and in considering the operating position and environment in which the equipment is expected to function.

2. SCOPE

This document considers the following major areas:

1. Major components and their ratings
2. Selection criteria for optimum design balance for electrical systems
3. Effects of operating conditions and environment on both maintenance and life of components
4. Trouble signals -- their diagnosis and cure

3. MAJOR COMPONENTS OF VEHICLE ELECTRICAL SYSTEMS

3.1 Batteries: An electrochemical device for converting chemical energy into electrical energy with electrical current being produced by chemical reaction between grids or plates containing, alternately, sponge lead (Pb) in the negative plate and lead peroxide (PbO_2) in the positive plate immersed in an electrolyte of 36% sulphuric acid and 64% water. A fully charged battery contains electrolyte with a specific gravity of 1.270 at 80°F. (26.7°C). The plates are grouped with PVC separators between positive and negative plates forming an element. Multiple elements of plate groups are placed in cells of a battery case with partitions separating the cells. Each cell has an approximate potential of 2 volts; 3 cells connected in series make up 6-volt batteries or 6 cells connected in series make up 12-volt batteries.

3.1.1 Wet-Charged Batteries: Those batteries fully charged and activated at the factory. When not in use, they will slowly "self discharge". High temperatures accelerate this condition -- at 100°F (37.8°C), a battery in a vehicle or in storage will completely discharge without use in 90 days. Storage in a cool place is mandatory.

3.1.2 Dry-Charged Batteries: Those batteries fully charged at the factory but the cells are dry of electrolyte. Electrolyte is normally supplied in a plastic bag in correct amount. Such batteries can be stored indefinitely in any environment with no periodic service or recharging necessary during storage. It is "factory fresh" when electrolyte is added and ready for immediate use. Proper activation consists of adding electrolyte of 1.265 specific gravity to each cell. After several minutes, check level again. Once the full electrolyte charge has been added, only add water thereafter. To insure best performance: Check voltage at terminals -- if less than 10 volts on 12-volt battery, it should be replaced. When temperature is 32° F (0° C) or when battery and electrolyte are not 60° F (15.6° C) or above, battery should be warmed by a boost charge of 15 amps for 10 minutes -- then check temperature of electrolyte. If not 60° F (15.6° C) or above, continue boost charge until above 60° F (15.6° C)

3.1.3 Battery Ratings:

- 3.1.3.1 20-Hour Rating at 80° F (26.7° C): The most common battery capacity rating and is expressed in ampere-hours. This rating indicates the lighting and accessory load capacity. It is a laboratory accomplished test, consisting of applying a constant discharge rate with 80° F (26.7° C) battery temperatures for 20 hours. At the end of that time the voltage at the terminals must be 10.5 volts or more for a 12-volt battery. A 5 ampere current supply from the battery x 20 hours = 100 ampere hour rating. When replacing a battery, the new battery should at least be of equal ampere hour rating of the original battery.
- 3.1.3.2 Cold Rating at 0° F (-17.8° C): Another method of battery rating and indicates the cranking load capacity. The rating is obtained by discharging a fully charged battery at 0° F (-17.8° C) in a laboratory at a constant 300 amperes for 10 seconds. The rating is indicated either by voltage reading obtained after 10 seconds or time in minutes to reach the end voltage of 5.0 volts. Thus a 12-volt battery having a 10-second voltage rating of 7.6 volts at 300 amperes will maintain 7.6 volts or higher for 10 seconds. Also, that same battery having a 2 minute rating will operate under the above conditions for 2 minutes before the output falls below 5.0 volts. The higher the Cold Rating in time or minutes, the greater will be the cranking capacity of the battery.
- 3.1.3.3 Reserve Capacity Rating: A newer consideration. This rating is the length of time one can travel at night with minimum electric load and no generator output. It is expressed at the time in minutes for a fully charged battery at 80° F (26.7° C), discharged at a constant 25 amperes, to reach a voltage of 1.75 volts/cell or 10.5 terminal volts.
- 3.1.4 Effect of Temperature On Capacity: The Cold Rating of a battery is its cranking power at 0° F (-17.8° C) normally expressed in watts. The wattage rating is determined in controlled laboratory tests and obtained by multiplying the voltage by the current. The example in Cold Rating capacity (3.1.3.2) shows 300 amps x 7.6 volts = 2180 watts. For heavy duty service a watt rating of 2500 or better is required. At 0° F (-17.8° C), the capacity of a battery at full charge is only 61% of its 80° F (26.7° C) normal full charge rating, at -20° F (-28.9° C) its capacity is only 45% of the normal 80° F (26.7° C) rating. At the same time, the load imposed on the battery by the cold engine increases due to the friction and lack of lubrication. At 0° F (-17.8° C) it is 250% greater, at -20° F (-28.9° C) it is 350% greater than the normal cranking load at 80° F (26.7° C). In other words, at low temperatures, the battery is much smaller, the engine is much larger. Both the battery ratings of 20-Hour Rating at 80° F (26.7° C) in ampere-hours and the Cold Rating at 0° F (-17.8° C) should be considered in battery selection to meet vehicle electrical demands.
- 3.1.5 Battery Failures: There are five major reasons why batteries wear out prematurely.
- (a) deep cycling (the most common cause)
 - (b) overcharging
 - (c) excessive vibration
 - (d) high temperature
 - (e) improper watering
- 3.1.5.1 Deep cycling occurs when a battery carries a large part of the electrical load frequently, then is recharged after each discharge period. This happens when:
- (a) drivers leave lights or radio/transmitter on during extended coffee breaks or rest periods.
 - (b) Low-speed, long-idle periods with battery carrying large load.
 - (c) Night or winter driving when electrical load exceeds generator/alternator capacity.

3.1.5.1 (Continued)

This deep cycling condition causes the positive plates to grow due to sulphation, then shrink as charging converts sulphate back to lead peroxide. This expansion and contraction cycle loosens plate material so it sheds to the bottom of the battery case. Gradual deterioration takes place until a particularly heavy load occurs, such as a first cold morning start. The engine won't crank. Sudden failures occur when the sediment from plates fills chambers at the bottom of the battery case and a short circuit between positive and negative plate bottoms causes a "dead" cell. This condition terminates the life of a battery.

Solution: (1) Use a higher ampere-hour rated battery with more plates and greater reserve for handling more deep cycles.

- (2) Select a charging system balanced to the electrical load at idle engine speed. The generator/alternator of proper capacity and voltage regulator should be adjusted to give a slight charge rate with normal lights and other load. Specify the generator cold output required.

- 3.1.5.2 Batter overcharge occurs from an excessively high setting of the voltage regulator or by an excessively high electro-temperature in the battery. A tell-tale sign of overcharging is excessive battery water consumption. Normal consumption is about 2 oz. per 2000 miles or 30 days. Check the electrolyte temperature with a service thermometer after extended operation--this should not exceed 125° F (51.7° C). Excessive temperatures result in rapid deterioration of the battery. Above 150° F (65.6° C) ambient temperature, the sealing compound softens and cell covers push up on the positive end. At this sign, severe damage has already been done.

Solution: (1) Reduce voltage regulator setting. Both transistor and vibrating contact type offer external adjustment. Keep track of water consumption and specific gravity reading carefully. The factory settings are usually too high for airline ground support operations.

- (2) Move battery to a cooler location. Equipment design often compromises the space for locating a battery. It is imperative to move or insulate the battery from "hot spots".

- 3.1.5.3 Vibration shortens battery life by speeding up shedding and causes plate and separator wear. The battery carrier should securely hold the case of the battery.

Solution: (1) Locate battery where it is subjected to minimum vibration forces.

- (2) A rubber pad 1/8 inch (3 mm) thick placed under the case in the battery carrier sill compensates for irregularities and minimizes localized stresses.

- (3) Check the carrier hold-down device.

- 3.1.5.4 High electrolyte temperature due to excessive charging or "hot spot" environment causes premature wear out. Temperatures over 125° F (51.7° C) in the electrolyte cause "boil out" of the electrolyte, corroding terminals, carrier case, and hold-downs.

Solution: (1) Check location in vehicle.

- (2) Check charging rate as above.

- 3.1.5.5 Overwatering causes electrolyte loss and poor performance. Too little acid remains in the electrolyte in each cell and the overflow causes corrosion of terminals and carrier case.

Solution: (1) Don't overwater.

- 3.1.6 Battery Maintenance: Both shop maintenance and on-vehicle battery care are most important. Service records of each battery throughout its life are very necessary to check preventive maintenance and service.

3.1.6.1 On-vehicle Maintenance:

- 3.1.6.1.1 Visual Inspection: Check electrolyte level; clean corrosion off terminals; check tightness of battery cables; inspect for broken case or pushed up cell cover; check tightness of hold-down device.
- 3.1.6.1.2 Light Load Test: Place a load on the battery by holding the starter switch "on" for 3 seconds or until engine starts. If engine starts, turn off immediately. Next, turn lights "on". After 1 minute and with lights still "on", read the individual cell voltages with a voltmeter with .01 volt divisions. If all cells read 1.95 volts or more -- the battery is good. Readings less than 1.95 volts require the battery be recharged and retested with the above test. If it still fails to read 1.95 volts on all cells, replace the battery. Check full charge hydrometer readings. Each cell should be above 1.230 to 1.310 with variations of not more than .050 between cell readings.
- 3.1.6.1.3 Slow Charge and Boost Charge of Battery: Slow charge is the best method of recharging a discharged battery. A slow charge is at a rate of 5 amps for 24 hours or at a rate of 7% of ampere hour rating. Full charge of a battery is indicated when cell gravity readings do not increase when checked at three times at intervals one hour apart. (1.230 to 1.310)

A fast or boost charge is at a rate of 50 amperes for 20 minutes on light truck applications, or 60 amps for 30 minutes on heavier duty applications. The battery should be given the Light Load Test after recharge by either of the methods of 3.1.6.1.2. Then place battery on "ready status" after making appropriate entries on the battery record.

3.1.6.2 Out-of-vehicle Maintenance:

- (1) Visual inspection as in 3.1.6.1.1. Clean battery thoroughly using 1/2-3/4 lb. of ordinary baking soda to a gallon of water.
- (2) Light load test as in 3.1.6.1.2 to determine if battery is good enough to recharge.

3.2 D. C. Charging System:

- 3.2.1 D. C. Generator: A machine that converts mechanical energy, supplied by the engine drive, into electrical energy used for recharging the battery and for supplying power to the electrical systems. The DC generator output is speed sensitive; at idle speed the output is 0 and energy for ignition, lights, and accessories must be supplied by battery only. At medium speeds, both generator and battery supply the needed energy, while at high speed, the generator alone supplies energy to recharge the battery and to power the electrical system. A generator operates on the principle of electro-magnetic induction; voltage is generated when any conductor is moved at right angles through a magnetic field. Voltage produced causes current to flow in the system and will climb to any value necessary to overcome the resistance of the attached circuits providing the speed of armature rotation is sufficient. At higher speeds, driven by the engine, the generator output voltage would go so high it must be controlled by an external unit, such as the voltage regulator. The power output or wattage of the generator is the product of its rated current times its regulated voltage.

- 3.2.1.1 Rating of D. C. Generators: The voltage rating of a generator denotes the system voltage of the vehicle in which it is used; 12 or 24 volts are most common. Current flow is the result of voltage developed in the armature coils. The amount of current flow in the armature and in attached circuits depends on the voltage developed and the resistance in these circuits. To avoid excessive current flow which results in over-heating of the generator armature, an external unit called a current regulator (part of the voltage regulator unit) is employed to limit current flow in the generator. The current rating of a generator denotes the amount of current the generator can supply continuously without damage to its structure under normal operating conditions. The field current rating at 80° F (26.7° C) is normally 1.5-3 amps on a 12 volt system.

The speed of the generator is a critical factor. Applications in automotive engines may vary from 2 to 1 to 3 to 1 ratio of generator to engine speed. One may change the generator speed only if the application requires low-speed engine operation a great percentage of the time. Do not exceed 3 to 1 ratio. Higher speeds result in reduced life, but is an inexpensive way of utilizing a generator that doesn't match the application of the vehicle.

Generator ratings are usually given at cold output 80° F (26.7° C) with the volts at 14; amp ratings from 35-50, and the engine rpm at which this rating should occur. This rpm is the key to selection of the DC generator. For low-speed or extensive idle operations, the rpm should be between 1500 to 1900 at which speed the amp rating should be high (30-50). For extended high-speed operation, the rpm may be selected between 2500-3500 at which speed the amp rating should be low (15-25). This balances the generator output to the use of the vehicle with less wear and longer life to the contacts of the voltage regulator.

3.2.1.2 D. C. Generator Types:

- (a) Standard Duty Type: (with bronze bushing in commutator end, ball bearing on pulley end) These are 30-35 amp rated units using the standard 3-unit vibrating contact voltage regulator.
- (b) Standard Duty Type: (with ball bearings on both ends) This generator is rated at 35 amps and also requires the above 3-unit voltage regulator.
- (c) High Speed Extruded Frame Type: (with heavy duty ball bearings and provision for air blast tube to augment cooling) This generator is rated at 45 amps, but its output is limited by a 45 amp double contact voltage regulator. If the air blast cooling is not used, the output should be limited to 40 amps by the voltage regulator.

3.2.1.3 "A" and "B" Circuit Generators:

- (a) "A" circuit generators are identified by observing connections; if the field-coil is connected to the insulated brush inside the generator, it is an "A" circuit type.
- (b) "B" circuit generators are also checked by observing if the field coil is connected to the grounded brush inside the generator or to the generator frame.
- (c) Checking and adjusting procedures differ, so the "type of circuit" must be identified. The voltage regulator must be compatible with the generator type and is not interchangeable.

3.2.1.4 D. C. Generator Servicing (on vehicle):

- (a) The bronze bushing end bearing must be lubricated at each vehicle lubrication period with 50 drops of medium engine oil added to the hinge cap oiler.
- (b) The ball bearings of all DC generators should also be lubricated at each vehicle lubrication period with 8-10 drops of medium engine oil. Do not over-oil or you might wash out the grease packed in the bearings.

3.2.1.4 (Continued)

- (c) Generators without hinge cap oilers have permanently lubricated bearings good for 50,000 miles of maintenance-free operation.
- (d) Check fan belt tightness.
- (e) If noisy operation, remove belt and check end play of shaft for rough, worn bearings.
- (f) Check condition of brushes for wear and free movement. Half worn brushes should be replaced.
- (g) Inspect commutator. If burned in spots, remove and check for cause. If commutator is glazed, oxidized, or dirty, clean with No. 00 sandpaper or brush seating stone. Really bad cases may require turning down in a lathe. The mica between commutator bars should be undercut if refinish with a lathe is required.
- (h) Thrown solder indicates overheating; check for cause and damage.
- (i) After disconnecting and reconnecting the generator or regulator leads, or after installing a new unit, the generator must be polarized before starting the engine. This is done by momentarily connecting a jumper between GEN and BAT terminals. Failure to do this may result in damage to the cutout relay points in the voltage regulator.

3.2.2 D. C. Voltage Regulator: The three basic fundamentals that determine a D.C. generator's output are speed of rotation, number of armature conductors, and strength of the magnetic field. Any one of these could be used to control the generator voltage and current. The simplest method is used. The voltage regulator and current regulator are units in the external circuit used to sense either high voltage or high current supplied to the external loads. These two units automatically decrease the magnetic strength of the magnetic field of the generator and safety limit the voltage and current at all conditions of speed and load.

3.2.2.1 The Voltage Regulator Unit (Standard): If the resistance in the load circuit is high, the generator will build up a high voltage to overcome it. High generator voltage causes high current to flow in the field circuit which intensifies the magnetic field between the poles. Additional voltage is developed within the armature windings which is commuted to the field coils for even more current. When this happens, the danger of too-high voltage becomes evident. A set of contact points is placed in series with the field coils so that all field coil current passes through them. When the contacts open, the current travels through a resistance to ground reducing the field coil current which reduces the voltage developed in the D. C. generator.

To accomplish this automatically, a shunt coil is connected across the generator brushes. This coil generates a "magnetic pull" on the armature to which the points are attached. When voltage becomes high enough, the spring, which holds the points closed, is overcome by this magnetic pull and the points open. This shunt coil becomes the "sensing unit" that controls the operation of the points which reduces voltage generated. When the generator voltage drops as a result of inserting the resistance in the circuit, the spring recloses the points allowing the voltage to build up again and the points again open. Rapid opening and closing of the points creates the name "vibrating contact". The vibrating action is so rapid that a voltmeter will only register the average voltage developed. This describes the operation of the voltage regulator relay in the standard D. C. voltage regulator.

There are normally three units making up a D. C. voltage regulator: The voltage regulator, the current regulator relay, and the cutout relay.

- 3.2.2.2 The Current Regulator Relay: Since current flow depends on the voltage or pressure causing it to flow, any reduction in voltage will result in a reduction in current. The current regulator relay employs a coil placed in series with the load. The magnetic pull tries to open the contact point. When sufficient load current passes through the coil to overcome spring tension holding the points closed, the points open. This places a resistance in series with the field coils of the generator, and generator voltage is decreased so less current is forced to flow. This regulation controls the current output of the generator. The series coil thus is the "sensing unit".

The current regulator relay and voltage regulator relay work together to give generator control. If the load resistance is large (all electrical appliances turned off and battery fully charged) the generator voltage is high and the voltage regulator relay will operate. If the load resistance is low as when many appliances are turned on and a battery is low in charge, the generator voltage will be low and a high current will flow so the current regulator relay will operate. Either the voltage unit or the current unit will operate, never both at the same time.

The current regulator relay vibrates to prevent the output current of the generator from exceeding the rating of the current of the generator. The air gap of the contact points is 0.075 inch (1.90mm).

- 3.2.2.3 "A" and "B" Type Regulators: The relay points of both the voltage regulator and current regulator are in the field circuit of the D. C. generator after the field coils. The field circuit, grounded outside the generator at the regulator, is attached to the insulated brush inside the generator. This type of field circuit is called an "A" type unit.

If the points of the voltage regulator and current regulator are placed before the field coils of the generator, this is called a "B" type unit. Regulation of current and voltage is accomplished in exactly the same manner, the difference is location of the points. The field circuit in the "B" type hook up is attached to the insulated brush outside the generator through the regulator and is grounded inside the generator at the generator ground brush.

"A" and "B" Type regulators require different procedures for checking and adjusting, so this must first be determined by inspection of connections at the brushes and fields. If the field coil lead is connected to the insulated brush, the circuit is "A" type. If the field coil lead is connected to the grounded brush or to the generator frame, the circuit is "B" type.

- 3.2.2.4 Cutout Relay: A magnetically-operated relay switch which connects and disconnects the generator to and from the battery at the correct time, determined by speed of rotation. When the generator voltage becomes high enough for charging, the cutout relay closes. It remains closed normally at all speeds other than engine idle. When the generator slows down and the voltage drops below the battery voltage, the cutout relay opens, protecting the battery from discharging through the generator. The point opening is 0.020 in. (0.51 mm) with a closing voltage range of 11.8 - 13.5 volts.
- 3.2.2.5 Double-Contact Regulator (D. C. System): The construction and operation of this type of voltage regulator relay is fully described later in 3.3.2.1 with D. C. charging systems. These are used for applications of high electrical load demand.

3.2.2.6 Applications of D. C. Voltage Regulators:

- (a) Standard Three Unit Regulators, "A" Circuit Type. These are common on all G. M. vehicles with D. C. charging systems (never on Ford vehicles).
- (b) Double-Contact Three Unit Regulators, "A" Circuit Type. These are used on vehicles that have high current demands, such as air conditioning or radio transmitters. This regulator type has an extra long life. It is identified by the words on the cover "Double-Contact Regulator -- Caution -- Do not ground F Terminal. To check generator, detach lead and ground it".
- (c) Standard Three Unit Regulator, "B" Circuit Type. This is used on all Ford products and some American Motors vehicles (never on G. M. vehicles).

3.2.2.7 Servicing the D.C. Voltage Regulator: No periodic service is required. Only when abnormal fluctuations of the charge indicator occur when in operation or if contacts appear oxidized, should service be required. This is usually a simple cleaning with a cloth with trichlorethylene or alcohol. Tests for point cleaning follow: For "A" and Double Contact Circuits:

1. With engine stopped, disconnect battery lead from terminal marked "BAT". Connect test ammeter leads to "BAT" terminal and battery lead.

2. Turn on head lights. Start engine and adjust engine speed until 5 amps is read on test ammeter.

3. Disconnect field lead from regulator "F" terminal and ground it. If ammeter reading increases more than 2 amps, the points of the regulator are oxidized.

4. For Double-Contact Regulator (Caution) Never use a jumper to ground the generator or regulator field terminal when these units are connected and operating together. This might burn the contacts of the voltage regulator.

For "B" Circuit only: Follow same steps as required for 1. and 2. above, then touch a jumper lead between "GEN" terminal and "F" terminal of regulator. If the test ammeter increases more than 2 amps, oxidized contact points are indicated.

3.2.2.7.1 Cleaning Methods: Because of some contacts being hard and some soft, care must be exercised. Soft contacts points are used to Double Contact Voltage Regulators and all Cutout Relays. These should be cleaned with #400 silicon carbide paper folded over and pulled back and forth between contacts, then wash the contacts with trichlorethylene or alcohol. On standard regulators, the large flat contact of the voltage regulator is made of hard material. This usually requires more attention than the soft mating contacts. Also the large flat contact of the current regulator is hard. Use a spoon or riffer file to remove any cavity. NEVER use emery cloth or sandpaper to clean contact points.

3.2.2.7.2 Tailoring the D.C. Voltage Regulator Settings: The desired setting of any Voltage Regulator is one which keeps the battery satisfactorily charged without causing excessive use of water. To obtain the correct setting:

1. When battery uses excessive water, the charging rate is high. Lower the setting and check for improved battery conditions. Lower the setting 0.2 volts at a time, then check.

2. When battery is consistantly undercharged, the charging rate is low. Increase the setting 0.2 volts at a time and check battery.

3. Warning. The setting of the current regulator relay must match the rated output of the D.C. generator.

3.2.3 Electrical Wiring Circuit: The wiring circuit is just as important a part of the charging circuit as the electrical components themselves. Undersize wire, loose connections between the regulator and battery, or poor ground connections between the battery and the generator will cause a lowering of the charge rate to the battery. High resistance resulting from loose or corroded connections in the charging system between the generator and regulator will result in a high voltage at the generator and cause premature failure of the regulator contacts.

- 3.2.3.1 Periodic Wiring Service: A visual inspection often reveals useful information about the condition of the charging system. All wiring should be inspected for frayed or damaged insulation. Faulty wiring should be replaced. All terminals should be checked for loose or corroded connections. All terminals should be cleaned and tightened. Excessive resistance causes voltage drops in the charging circuit which tends to keep the battery in an uncharged condition. If excessive voltage drop is suspected, follow the check procedures outlined in service instructions by the manufacturer for the "A" or "B" circuit as required.
- 3.2.4 Trouble Shooting the D. C. Charging System: To determine which unit of the D. C. charging system is at fault, follow the procedures outlined below. Note that trouble in the system is usually evidenced by an undercharged or overcharged battery.

3.2.4.1 Charge Too Low (Undercharged Battery):

On Double-Contact "A" and "B" Circuits.

- (a) Check for defective battery.
- (b) Check generator pulley and drive belt for slippage.
- (c) Connect a 0-20 range voltmeter between "A" terminal of generator and a good ground.
- (d) Start engine, run at 1000-1500 rpm.
- (e) Note voltmeter reading. A reading of 1 to 4 volts indicates an open field circuit or a field circuit with excessive resistance. The circuit is made up of the generator, wiring, and regulator so it will be necessary to determine which component is at fault.
 - (1) On "A" and "Double-Contact" systems, remove lead from regulator "F" terminal and momentarily touch to ground.
 - (2) On "B" circuit systems, remove lead from regulator "F" terminal and momentarily touch it to the "GEN" terminal.
 - (3) If the voltage reading rapidly increases to system voltage (12 volts), the regulator is at fault and should be repaired or replaced.
 - (4) If voltage remains low, remove the field lead at "F" terminal of the generator. On "A" and "Double-Contact" systems, momentarily touch the generator "F" terminals together on the generator.
 - (5) If the voltage reading rapidly increases to system voltage, the wiring is at fault and must be repaired or replaced.
 - (6) If the voltage remains low, the generator is at fault and must be repaired or replaced.
- (f) If the voltmeter reading is 0 volts, this indicates a grounded armature circuit. This circuit is made up of the generator, wiring, and regulator so it will be necessary to determine which component is at fault.

3.2.4.1 (Continued)

- (1) On "A" and "Double-Contact" systems, remove the lead from the regular "GEN" terminal.
- (2) On "B" circuit systems, remove lead from "GEN" terminal of the regulator and connect a jumper between "A" and "F" terminals.
- (3) If the voltage reading rapidly increases to system voltage, the regulator is at fault and should be repaired or replaced.
- (4) If the voltage remains at 0, remove the lead from the "A" terminal of the generator. (The jumper lead from "A" to "F" terminal of the generator should remain in place on the "B" circuit systems.)
- (5) If the voltage increases rapidly to system voltage, the wiring is at fault and must be repaired or replaced.
- (6) If the voltage remains at 0, the generator is at fault and must be repaired or replaced.
- (g) If the voltmeter reading is system voltage, this indicates an open charging circuit. The generator is operating normally.
- (h) Move voltmeter lead to "GEN" terminal of the regulator. If the voltage is 0 at this terminal, the lead between the regulator and generator is open and should be repaired or replaced. If the voltage is the same as it was at the generator, the trouble is in the regulator.
- (i) Now move the voltmeter to the "BAT" terminal of the regulator. If the reading is 1 or 2 volts lower at this terminal than it was at the "GEN" terminal, the problem is in the regulator, (the cutout relay may need adjustment) and it should be repaired or replaced.
- (j) A reading of system voltage could indicate high resistance somewhere in the charging circuit wiring. Check all connections.
- (k) A reading of system voltage at both the generator "A" terminal and battery insulated post accompanied by chronic discharged condition of battery on the same vehicle might be eliminated by raising the voltage regulator setting.

3.2.4.2 Charge Too High (Overcharged Battery):

- (a) When light bulbs burn out or excessive loss of battery water.
- (b) Connect voltmeter (0-20 volts) between "A" terminal of generator and a good ground.
- (c) Start engine, run at 1000-1500 rpm.
- (d) Note voltmeter reading:
 - (1) Disconnect wire attached to "F" terminal of regulator. If reading drops to about 4 volts, the regulator is at fault and must be adjusted, repaired, or replaced.

3.2.4.2 (Continued)

(2) With the wire disconnected at the "F" terminal of the regulator, the voltage reading may remain high. If this is so, remove the lead at "F" terminal of the generator. If the voltage now falls to about 4 volts, the field lead is grounded on the "A" circuit system, or is touching the lead attached to the "A" terminal of the generator in some way on the "B" circuit system. The lead or leads must be repaired or replaced.

(3) With the wire disconnected at the "F" terminal of the generator, the voltmeter reading may remain high. If this is the case, the generator is at fault and must be repaired or replaced.

3.2.4.3 Adjusting The Voltage Regulator Setting: The desired setting is one which keeps the battery in satisfactory state of charge without causing excessive battery water usage. Normal consumption of water is 1 ounce per 100 hours of operation. Remember the normal factory adjustment is at 80° F (26.7° C). The regulator automatically compensates its setting with change of ambient temperature. The voltage setting is higher when the regulator is cold than when it is hot. This machines the charging requirements of the vehicle battery.

- (a) When the battery uses excessive water, the regulated voltage is above the normal range. Lower the setting to a value within the upper portion of the normal range and check for an improved battery condition over a reasonable service period.
- (b) When the battery uses excessive water and the regulated voltage is within the normal range, lower the setting 0.2 or 0.3 volt and check for an improved condition over a reasonable service period. Repeat until the battery remains charged and water usage is normal.
- (c) When the battery is consistently undercharged and the voltage regulator is below the normal range, increase the regulator setting to the lower portion of the normal range and check for an improved condition over a reasonable service period.
- (d) When the battery is consistently undercharged and the regulated voltage is within the normal range, increase the setting 0.2 or 0.3 and check for an improved condition over a reasonable service period. Repeat until the battery remains charged. Avoid regulated voltage above 14.8 volts @ 125° F (51.7° C) ambient as this may cause damage to lights or other voltage sensitive equipment.

3.2.4.4 Other D.C. Charging System Problems: Batteries which do not respond to voltage regulator adjustments might be failing because:

- (a) Vehicle engine is operated at low speeds over extended periods.
- (b) Battery might have been improperly activated.

(1) When engine is operated at low speed over extended periods, the battery may remain uncharged even with a regular setting of 14.8 volts. The generator output and charging time may be insufficient to offset electrical loads on the battery. Periodic recharging of the battery from an outside source or replacement of the original generator with a special extra-output d. c. generator will be required.

3.2.4.4 (Continued)

(2) Batteries suspected of having been improperly activated should be removed and completely checked. If the specific gravity at full charge is less than 1.230 in any cell, the battery is either worn out or has been improperly activated. If the specific gravity is above 1.310, the battery has been filled with too strong an electrolyte, or electrolyte has been added in place of water. Either situation will cause early battery failure.

3.3 A. C. Charging System.

3.3.1 Alternator: More recent vehicles employ the alternator to generate electrical energy. A small, light-weight component offering the advantage of an output at engine idle, a high output per pound of weight, and a minimum of periodic maintenance. It is superior to the D. C. generator offering very reliable service. Constructed essentially as a rotor on ball bearings in two end-frames; a stator assembly; six silicon diodes; this device develops A. C. voltages which are rectified by the diodes to a single D. C. voltage and D. C. current output. To obtain the highest output with a smoother voltage and current, a three-phase stator is connected to six diodes which together form a "three-phase full wave bridge rectifier". The alternator was developed to meet the higher loads of increasing electrical system demands and also to supply an output even at idle engine speeds. All alternators have a rotor mounted on ball or roller bearings, each having a supply of grease to last for years of service without attention. Current to the coil winding mounted on the rotor is supplied through brushes riding on smooth slip rings. All alternators are self-limiting in maximum output -- this occurs as the magnetic field produced by the current in the stator windings opposes in polarity and approaches in value the magnetic field provided by the rotor as the alternator output increases. This causes the alternator to limit its own output to a maximum value. So alternators do not require voltage regulators equipped with current limiting relays.

3.3.1.1 Alternator Types: There are many different types and designs of A. C. alternators. Some factors which determine design are type of mounting, vibration, belt loading, minimum and maximum rotor speeds, current output, service life required, and environmental factors such as dust, dirt, road splash, or explosive mixtures in the atmosphere. All A. C. alternators, however, develop three-phase A. C. voltage which is then rectified to a single D. C. voltage available at the output terminals. This output occurs even at engine idle, the amount depending on the application.

3.3.1.1.1 Factors Required In Specifying Alternators:

- (a) System polarity - battery polarity is mandatory for proper connection that will not destroy the diodes. "N" indicates a negative battery ground and "P" indicates positive battery ground. Caution: Do not polarize an alternator like a D. C. generator (3.2.1.41).
- (b) Cold output rating - the output in amps at low (2000 rpm) and high (5000 rpm) speeds and at the specified voltage (14 or 28 volts) when the alternator temperature is approximately 80° F (27° C).
- (c) Hot output rating - this is the maximum output at the specified voltage (14 or 28 volts) with the alternator temperature stabilized in a laboratory ambient temperature of 80° F (26.7° C). (Note: the alternator temperature will be higher than the 80° F (26.7° C) ambient when in use on a vehicle). If the ambient is higher than 80° F (26.7° C) the alternator temperature is respectively higher and the output will be correspondingly lower.

- 3.3.1.1.2 Light Duty: These are medium load range alternators with hot output ratings up to approximately 50 amps. This alternator delivers 5 to 10 amps at curb idle. The rotor assembly consists of two iron pole pieces with interlacing fingers mounted over many turns of wire wound over the rotor core mounted on the shaft. This rotor coil is connected electrically to the two slip rings, which are then connected to the battery through brushes and leads. This size rotor (in Light Duty) normally has 14 poles. The stator assembly is a "Y" connected 3-phase winding of copper wire mounted on a laminated frame. There is one coil for each pair of rotor poles. With seven coils in series, there will be seven voltages added together to provide the complete winding voltage. With a 14-pole rotor, seven complete cycles of A.C. voltage will be produced for each rotor revolution. The two other stator windings complete the 3-phase unit. The stator is connected to six press-in type diodes; 3 are in the end frame and 3 in an electrically insulated heat sink. The entire unit is cooled by a fan mounted at the pulley end of the shaft which draws air through the alternator.
- 3.3.1.1.3 Heavy Duty: These alternators usually use a 16-pole rotor with a "Y" connected stator and all 6 diodes assembled into 2 separate heat sinks. This type of alternator can be applied to heavy duty truck, marine, or industrial applications requiring current outputs of 60 to 100 amps. Output at idle is approximately 25 amps.
- 3.3.1.1.4 High Output at Idle: If the application requires higher output at idle engine speed, these alternators supply approximately 40 amps at engine speeds of 600 rpm or lower. Special models are available for heavier electrical loads supplying up to 125 amps at idle and 175 amps at engine speed of 1000 rpm. Applications using this alternator include fire trucks with radios or ground support vehicles with radios.
- 3.3.1.1.5 Special A.C. Alternators: A totally enclosed brushless model is available requiring oil and air cooling which is designed for very dirty environments.
- 3.3.1.2 Alternator Service: End bearing grease supply should be sufficient for life, however, at time of engine overhaul, the bearings should be checked for rough operation and excessive end play. The fan belt drive should be checked every 30-60 days for evidences of slipping or belt breakage. The brushes should never need service except if the vehicle has been used in a very dirty environment.
- 3.3.2 A.C. Voltage Regulator: The sole function of the voltage regulator in any charging circuit is to limit the alternator voltage to the proper safe value to charge the battery and operate the electrical accessories over the wide range of engine speeds required in an automotive vehicle. Two types are in general use -- the Double-Contact (Vibrating) Regulator and the Transistor Regulator.
- 3.3.2.1 Double-Contact Regulators: This unit gets its name from the dual set of contacts used on the voltage regulator relay and achieves voltage regulation by controlling the amount of alternator field current. Remembering that alternator voltage is proportional to field current, it is seen that for any given speed, decreasing field current will decrease voltage. By decreasing the field current as the alternator speed increases, a balancing effect is obtained resulting in a constant voltage limited by the voltage regulator unit. This voltage regulator consists of a magnetic coil that reacts on a moveable armature with upper and lower contacts with spring tension in one direction. The pull of the magnetic coil, which is controlled by field winding current, moves the armature contact back and forth or to "vibrate" to control the output voltage at a seemingly flat output. The higher the engine speed, the faster the points vibrate. Vibration frequency varies up to 300 cycles per second resulting in a good control of the voltage value. This voltage regulator is called a "vibrating contact" type.

3.3.2.1 (Continued)

As the A. C. alternator begins to operate and the speed increases, the alternator voltage will increase in value above the battery voltage. The alternator is then charging the battery and supplying its own field current. At alternator idle speed of 1000 rpm with battery voltage of 12.0 volts and regulator spring setting on lower contacts of 13.8 volts, the voltage range (12.0 - 13.8) is not sufficient to pull the armature of the voltage regulator. So throughout the 0-1000 rpm speed range, the lower contacts remain closed. As the alternator speed goes from 1000 - 2000 rpm, the voltage increases and exceeds the 13.8 volt spring setting and the spring tension is overcome. When the lower contacts are opened the alternator field current is diverted through a resistor in series with the field winding. This reduces the field current and the alternator output voltage is correspondingly reduced. The spring then can reclose the lower contacts. This cycle repeats as often as 50 times per second to limit the alternator voltage to 13.8 volts at 2000 engine rpm.

As the speed goes higher, the field current must be further decreased to limit the voltage to 13.8 value. The voltage regulator unit will automatically lower the field current by changing the relationship between open and closed periods in a cycle. This "vibrating" contact is now open longer than the closed period. At 3000 rpm the voltage regulator will "float" so both contacts remain constantly open. So between 1000 and 3000 rpm, the contacts "vibrate" staying open progressively longer periods of time till at 3000 rpm, they are open all the time.

As the engine speed goes higher than 3000 rpm, the armature contact will close on the upper contact which is set at 14.0 volts. Current now flows directly to ground through a resistor. The field current then decreases to 0 causing the spring to open the upper contacts. This "vibration" cycle is very rapid (up to 300 times per second at 3000 alternator rpm -- the field current may be reduced to 0.1 amp). Note that the contact periods have reversed and are closed longer on the upper contact than they are open.

In summary, both the lower contacts and upper contacts operate automatically to provide the field current needed at various speeds to achieve voltage limitation.

3.3.2.1.1 Voltage Regulator Operation with Load Changes: Electrical load is determined by the state of charge of the battery plus the number of accessories in operation. As the battery charge decreases and more accessories are turned on, the current demand from the alternator increases. As the current demand increases, more field current is needed to develop the required voltage. For any given speed, the voltage regulator will change its closed and open periods to provide more field current as the alternator output increases.

Assume the electrical accessories draw 30 amps and the maximum output of the alternator is 40 amps. With a fully charged battery (battery will then draw about 2 amps holding current) the total output is 32 amperes and the voltage regulator will operate to limit voltage to 13.8 volts.

Now assume a discharged battery so that it would accept 20 amps charging rate at 13.8 volts. With the 30 amp accessory load, the total current requirement is 50 amps. But the alternator is capable of only 40 amps, so the accessories will get 30 amps, the battery 10 amps for charging rate at a voltage of some value less than 13.8 volts. The setting of the lower contact being at 13.8 volts, this means that the lower contact remains closed even though the alternator is operating at high speed. The voltage regulator unit does not necessarily "vibrate" at all times through the 1000 to high speed range if the battery is in discharged condition. If battery is charged and load is low, the voltage regulator will vibrate.

3.3.2.1.2 Temperature Compensation: Since a battery is subjected to a wide range of operating temperatures and requires high voltage to charge a cold battery, low voltage to prevent over charge of a hot battery, the voltage regulator contains three temperature compensation devices. All three operate together to give a lower setting when hot, a high setting when cold (14.0 volts at 60° F (15.6° C) 13.0 volts at 180° F (82.2° C).

3.3.2.1.3 The Field Relay Unit: This is a simple magnetic switch that is made to close when the field relay coil winding is energized. The contacts are spring loaded to separate when the coil is de-energized. The primary function of the field relay is to provide a low-resistance connection between the battery and the voltage regulator unit coil and also to disconnect the alternator field from the battery when the ignition switch is turned off. When the ignition switch is turned on, the field relay closes.

Some voltage regulators have no field-relay. In these, a special ignition switch having a separate set of contacts for the field current circuit eliminates the need for the field relay.

3.3.2.1.4 Types of Double-Contact Regulators:

- (a) Three unit regulator contains a double-contact type voltage regulator, a field relay, an indicator lamp relay. These are used in charging systems utilizing either an indicator lamp or ammeter.
- (b) Two unit regulator contains a double-contact type voltage regulator and a field relay.
- (c) Single unit regulator contains only a double-contact type voltage regulator with charging systems using an ammeter only. A special ignition switch is used to energize the field circuit.

3.3.2.1.5 Double-Contact Regulator Service: The voltage regulator is always covered and sealed to prevent entrance of abrasive materials. It is shock mounted to prevent effects of vibration from affecting operation. Normally no periodic service is required.

If erratic operation occurs, the points should be cleaned. Erratic voltage readings on a voltmeter is a sign that service is required. Check for loose connections. Then clean the contact points using a strip of #400 silicon carbide paper folded over and pulled back and forth between the contacts. After cleaning, the contacts should be washed with alcohol or trichlorethylene to remove residue.

3.3.2.2 Transistor Voltage Regulator: This is a completely static unit containing no moving parts. Consisting of resistors, capacitors, diodes, and transistors mounted on a printed circuit board. It limits the alternator voltage to a safe value. Resistors and capacitors are not new in the electrical field, but the operating principles of the diode and transistor were first discovered in 1948. Now this "Transistor Voltage Regulator" is in widespread use.

The transistor regulator performance is superior in many ways to the voltage regulator having vibrating contacts. With no moving parts, a maintenance-free service life of long duration results. This regulator is quite stable since the voltage setting is not affected by length of service, mounting position, or alternator output and speed. Higher field currents can be withstood than can be handled by the double-contact voltage regulator.

3.3.2.2.1 Operating Principle: All models of the transistor regulator contain the same basic internal circuitry. It operates electronically to alternately "turn off" and "turn on" the voltage across the field winding. This switching action between open-close-open can occur at a rate as low as 10 times per second or as high as 7000 times per second. A voltage sensitive or zener diode is used to detect voltage changes in the system. When the voltage rises to a predetermined limit, the zener completes the driver transistor base circuit. This turns the driver transistor on which allows a power transistor to turn off and open the field circuit of the alternator. When the voltage drops, the zener opens the driver base circuit, turning the driver off and allowing the power transistor to turn on and close the field circuit. This repeats itself very rapidly while the regulator is operating. The zener derives its operating voltage from an adjustable resistance which allows the voltage to be set at various set points.

The circuitry is built up with transistors and resistors, diodes in combination to achieve the regulation. Full protection for the circuitry is given by suppression diodes which short out any damaging currents. A thermistor which increases or decreases its resistance with temperature automatically compensates the output to a lower setting during hot weather and a higher setting during cold weather. A filter capacitor smoothes out the system voltage variations and gives very stable voltage control. This all solid-state regulator has no moving parts. All components are attached to a printed circuit board mounted in a finned aluminum case and requires no service, and is sealed at the factory. Transistor regulators are designed for use with self-current-limiting alternators (3 amp maximum field current).

The power transistor is of the germanium type, the driver transistor and other semiconductor components are silicon. The regulator will operate in a maximum temperature of 180° F (82.2° C).

3.3.2.2.2 Installation and Adjustments: The aluminum regulator case is not used as a ground. All connections are brought to external terminals making the regulator suitable for positive or negative ground installations. On positive ground systems, the regulator operates between the field and the ground (A circuit). On negative ground systems, it operates between the field and positive output (B circuit). Be sure the application circuitry wiring is checked.

Voltage is easily adjusted by removing the plug in the regulator case to expose the adjusting screw. Turning this screw, the operating voltage may be raised or lowered as desired.

The transistor regulator being all solid-state, will operate in any position. Care must be taken to see that any water, which may find its way into the case, will drain out through the drain holes provided. The reliability of any regulator depends on the wiring at installation. Be sure wire is adequate size and attached to terminals tightly.

Caution: Never attempt to ground or jumper the field terminal. Any attempt will permanently damage a transistor regulator.

Caution: Be sure the regulator is wired for the correct ground polarity. Do not charge or boost the battery or install it backwards.

3.3.2.2.3 Service of Transistor Regulators: Set the voltage adjustment between 13.8 and 14.2 volts as indicated on the voltmeter across the battery terminals. The engine should be running at a fast idle (1000-1500 rpm). The battery must be fully charged when setting the regulator adjustment and all electrical loads off.

3.3.2.2.3 (Continued)

To check the regulator itself, disconnect the field wire from the regulator and connect it to the negative regulator terminal while operating at fast idle. If output is now obtained, the regulator is faulty and should be replaced. Do not run at this condition any longer than necessary as a high voltage may develop which could damage the regulator.

If the charging rate is excessive and cannot be lowered, remove the field wire from the regulator. If output drops, the regulator should be replaced. This applies to both positive and negative ground systems.

Connection diagrams come with all transistor regulators. Be sure to follow the correct diagram for either ammeter or charge light circuits. Certain types of diesel powered equipment may not use an ignition or "run" switch. On these units, an oil pressure switch may be used to energize the A. C. charging system.

3.3.3 Wiring Circuit: The wiring circuit is just as important a part of the A. C. charging circuit as the electrical units themselves. Undersize wire or loose connections between the regulator and the junction block will cause a high charge rate to the battery. High resistance resulting from loose or corroded connections between the junction block and battery will cause a lowering of the charging rate to the battery.

3.3.3.1 Periodic Wiring Servicing: A visual inspection often reveals useful information about the condition of the charging system. All wiring should be periodically inspected for damage and loose or corroded terminals should be tightened and cleaned.

3.3.4 Trouble Shooting the A. C. Charging System: A. C. charging system circuit are completely different from D. C. charging system circuits. None of the trouble shooting checks outlines for D. C. systems can be used on A. C. systems. Before attempting to trouble shoot, the precautions below must be observed. Failure to do so can result in burned out alternator diodes and vehicle wiring.

- (a) When installing a battery, always make sure the battery polarity and ground polarity of the alternator are the same. If a battery polarity is wrong or if the battery is reversed when installing it, the battery is directly shorted through the diodes. The diodes and vehicle wiring are endangered by high current flow and may burn "open".
- (b) When connecting a booster or slave battery, make certain to connect the negative battery posts together and the positive battery posts together or the same damage as above may result.
- (c) When connecting a charger to the battery, connect the positive lead to the battery positive post and the negative lead to the battery negative post or the same damage as above may result.
- (d) Never operate the alternator on open circuit. With no battery or electrical load in the circuit, the alternator can build up high voltage which may damage the diodes and be extremely dangerous to anyone who might accidentally touch the alternator "Battery" terminal.
- (e) Do not short across or ground any of the terminals on the alternator or voltage regulator. Any grounding on purpose or shorting can cause serious electrical malfunction and endanger components of the electrical system.
- (f) Do not attempt to "polarize" the alternator. Unlike the D. C. generator, its polarity cannot be lost. An attempt to "polarize" can be of no value and might cause damage to the diodes or wiring. If there is any doubt as to the polarity of an alternator, refer to its specifications or connect a battery to the field circuit only, rotate the rotor slowly in either direction, and note the polarity of the voltage as measured by a voltmeter between the alternator insulated terminal and the alternator ground terminal.

3.3.4.1 Charge Too High (Overcharged Battery): Overcharge is indicated by excessive water usage. In extreme overcharge, the water level may drop far below the top of the plates. Since only the portion of the plates covered with electrolyte is useful in developing voltage, the battery may not have sufficient capacity to crank the engine. Normal water consumption is one ounce per 100 hours of operation. Also hot weather operation might slightly increase the water consumption. A high system voltage may damage voltage sensitive accessories such as light bulbs. To correct a high system voltage and overcharged battery, which shortens battery life, the system voltage must be lowered by adjustment of the voltage regulator.

- (a) Check the battery condition -- fill to proper level with water. Then apply the light load test (3.1.6.1.2) to determine if there is a shorted cell. Batteries with internal short circuits will accept a high charge rate and use water excessively. If a cell is shorted, replace with a good battery. Check for improved charging performance (decreased battery water usage) over a reasonable service period.
- (b) If battery was not the source of trouble, check the condition of the wiring. Visually inspect for damage or loose connections. Then check for improved battery charging performance (decreased battery water usage) over a reasonable service period after making repair of wiring system.
- (c) If neither the battery or the wiring is the source of trouble, check the regulator. Place a voltmeter across the battery. Start the engine and run at 1500-1700 rpm. Note the voltmeter reading. If the reading is 16.0 volts or above, the voltage regulator setting is too high. Adjust regulator according to instructions below:

(1) Remove lead from "V" terminal of the three-unit regulators (note this lead is "hot" from the battery, do not permit it to touch ground), or remove wiring connector body from one-unit or two-unit regulators. Remove regulator cover. Reconnect wire or wiring connector to regulator and note voltmeter reading. This reading will differ from that first noted with regular cover on. Adjust regulator by turning adjusting screw counterclockwise to decrease voltage setting. Reduce voltage to 14.5-15.0 volt range. If no adjustment is possible, replace regulator.

(2) If the voltage reading in 3.3.4.1 (c) was less than 16.0 volts, the type of use by the engine or vehicle is probably always at high rpm and the regulator setting should be lowered. For this minor adjustment, allow the engine to run 15 minutes to stabilize the regulator setting. Then follow the same procedure as (1) above but adjust regulator voltage lower by 0.3 volts only. This should bring the regulator within the 13.1 to 15.0 volt range.

(3) After regulator setting has been adjusted, remove the lead from "V" terminal. Replace regulator cover. Reconnect wiring to regulator and note voltmeter reading. (Should be between 13.1 to 15.0 volts.)

(4) Remove test voltmeter and check battery for improved charging performance (decrease water usage) over a reasonable service period. Repeat adjustment (2) above if necessary to lower regulator adjustment further.

3.3.4.2 Charge Too Low (Undercharged Battery): Undercharge is indicated by discharged or "run down" battery condition.

- (a) Check fan belt condition and tension: Tighten, if required, according to manufacturer's recommendation.
- (b) Check battery condition. A chronic undercharged battery should be checked with the light load test (3.1.6.1.2) to determine if battery is at fault. Replace with a good battery if required and check for improved performance over a reasonable service period.
- (c) Many discharged batteries are caused by a vehicle operator leaving the accessories "on" for an extended period without chance for recharge. This is not the fault of the battery or the charging system.
- (d) If none of the above are found to be at fault, check charging system wiring. Visually inspect wiring. Clean and tighten connections. Repair or replace as needed.
- (e) Check alternator output. First disconnect the battery ground strap. Then connect a service ammeter in the circuit at the "BAT" terminal of the alternator and a voltmeter from "BAT" terminal of the alternator to ground. Connect a jumper from "F" terminal to "BAT" terminal. Reconnect battery ground strap, turn lights on high beam and heater blower motor on high speed. Operate engine at 1500-2000 rpm as required to obtain maximum current output. If ampere output is within 10% of rated output on nameplate, the alternator is good. Turn lights and heater blower off, stop engine, remove jumper lead and remove instrumentation.
- (f) Check the voltage regulator setting. Place a voltmeter across the battery. Start the engine and run at 1500-1700 rpm. Turn on lights to add a 15 to 25 amp loading. Note the voltmeter reading. If reading is below 13.1 volts, adjust as described in (3.3.4.1(c1)) by turning adjusting screw clockwise to increase voltage to 14.5 to 15.0 volt range. Remove voltmeter and check battery for improved charging performance over a reasonable service period.

3.4 Ignition System: This system includes the distributor, ignition resistor, ignition switch, spark plugs, wiring, and battery. These units work together as a team to ignite the air-fuel mixture within the cylinders at the proper time. The components of the ignition system function together in two electrical circuits, the primary and secondary circuits.

3.4.1 Distributor: The distributor has a dual role in the ignition system. It must control the primary circuit by opening and closing it at the proper time and it must also distribute the high voltage in the secondary circuit to the proper spark plug.

3.4.1.1 Primary Circuit: The battery, coil, contact points, condenser, switch, and wiring make up the primary circuit. The distributor cam, contact points, condenser, and wiring work together in opening and closing the primary circuit. This supplies the electric impulse to the ignition coil which produces a high voltage surge to meet the spark requirements. Since the distributor is mechanically driven by the engine, the position of the distributor in the engine determines the initial timing of the spark. After the coil produces the high voltage surge, the ignition system distributes the voltage to the correct plug at the correct instant. The correct instant depends on engine speed and intake manifold conditions.

3.4.1.2 Secondary Circuit: The coil, distributor cap and rotor, spark plugs, and wiring make up the high voltage side or secondary circuit. The high voltage surge developed in the coil is applied thru a wire to the center tower of the distributor cap, it is then impressed on the rotor where it is distributed to each of the towers connected to the spark plug leads. Each plug is fired once during each revolution of the distributor.

3.4.1.3 Distributor Timing: At engine idle, the spark is timed to fire the plug just before the piston reaches its top dead-center position. Burning time of the air-fuel mixture is approximately 0.003 second. Burning must take place before the piston travels 10 to 20 deg past top dead-center in order to obtain full power from the explosion. Since the burn time is fixed and the position of the piston at completion of burn is fixed, it is necessary to fire the plug earlier as the engine speed increases. To obtain this spark advance as required by engine speed, most distributors have a centrifugal advance mechanism. This consists of two weights which throw out against spring tension to advance the breaker cam as the engine speed increases. The timing, consequently, varies from no spark advance at idle to full advance at high engine speed at which time the weights of the centrifugal advance mechanism reach the full extent of their travel.

Under part throttle operation, a high vacuum is created in the intake manifold. Accordingly, the air-fuel mixture taken into the cylinder is not so highly compressed as during full throttle and so burns at a slower rate. When this condition exists, an additional spark advance will increase fuel economy. So, on many applications where part throttle operation predominates, a vacuum advance mechanism is used in conjunction with centrifugal advance. This provides additional spark advance required for increased economy.

3.4.1.4 Distributor Service: There are a number of components which require periodic service. Although, there are many types of distributors, they are all the same in basic parts and servicing requirements.

3.4.1.4.1 Distributor contact points normally provide many hundred hours of service. Points will develop a rough surface of transfer of material. Rough contact points become grayish in color and often provide a greater contact area than new contacts and will function until most of the tungsten is worn off. "Pitted contacts" is a normal condition and points should not be replaced unless the transfer has exceeded 0.020 inch. Burned contact points should be replaced.

(1) Clean the points with a few strokes of a clean, oil-free, fine cut "contact" file. Don't remove all roughness, merely remove scale and dirt. Never use emery cloth or sand paper. The abrasive particles will embed in the contact point surface and cause rapid burning. Contact point burning will result from high voltage, presence of oil or other foreign material, a defective condenser, or improper point adjustment.

(2) High voltage causes a very high current flow thru the contact points which produces sufficient heat to burn them. High voltage can result from an improperly adjusted voltage regulator or inoperative regulator or from a shorted bypass resistor.

(3) Oil or crankcase vapors which work up through the distributor and deposit on the point surfaces will result in rapid point burning. It is easy to detect, since oil produces a smudgy line under contact points. Check for a clogged engine breather pipe which builds crankcase pressure to force oil vapors into the distributor. Over oiling the distributor will also produce this condition.

3.4.1.4.1 (Continued)

(4) If the contact point opening is too small, the points will burn because they are closed too long a part of the operating time. Average current flow thru the points will be too high causing rapid burning. Also excessive arcing will occur between the points causing low secondary voltage and engine miss.

(5) A high series resistance in the condenser will cause the contact points to arc and burn rapidly. This resistance could be a loose condenser mounting or lead connection, or by a defect in the condenser.

(6) There are many engine applications and environments, so it is impossible to suggest a length of point life. If the engine lacks power, or misses during acceleration or underload, this could indicate the contact points need replacement.

3.4.1.4.2 Distributor Condenser: A condenser can be tested for (a) insulation breakdown test; (b) series resistance; (c) capacity (MFD) on a reliable tester. Normally a check by test or replacement of the inexpensive condenser at time of contact point replacement is recommended.

3.4.1.4.3 Distributor Cap: Inspect the cap each time the contact points are changed or inspected. Always wipe the cap with a clean cloth, then inspect for chips, cracks, or carbonized paths which indicate high voltage leakage to ground. Loose leads in the cap towers cause gaps and high resistance; the resulting heat and arcing cause erosion which is an easy path for leakage. The tower inserts should be clean and free of corrosion. The rotor button should be checked for excessive wear. Any defect as mentioned above requires replacement of the cap.

3.4.1.4.4 Distributor Rotor: Wipe rotor with a clean cloth whenever distributor is inspected. Check for chips, cracks, etc. The metal rotor tip should be checked for burning. Scrape it clean. Check the spring on the rotor for sufficient tension.

3.4.1.4.5 Distributor Lubrication: Many distributors have permanently lubricated bushings which need no attention until major engine overhaul. Distributors with oil reservoir tubes should be filled with light weight engine oil. Add oil until oil stands in bottom of reservoir. For distributors with grease cup fittings, the cup should be filled with No. 2 1/2 grease then replaced and tightened one or two turns. Do not over lubricate distributors bushings.

Whenever new contact points are installed, place a few drops of light oil on wick in the shaft under the rotor, if a wick is present. Also breaker plates, vacuum pivot arm posts, and contact point pivot arm require a few drops of light oil to insure free movement. Do not over oil. The breaker cam should be lightly wiped with a film of high temperature grease.

3.4.2 Ignition Coil: Pulse transformer that steps up the low battery or generator voltage to the high voltage necessary to ignite the air-fuel mixture at the gaps of the spark plugs. It contains 3 basic parts; (a) a primary winding consisting of a few hundred turns of heavy wire; (b) a secondary winding consisting of many thousand turns of very fine wire; (c) a laminated soft iron core which serves to concentrate the magnetic field. The primary winding is outside of the secondary winding, the laminated iron provides both a core and outside shell around both windings. These three parts are placed in a coil case and immersed in oil. The coil cap, with its attachments to the windings, completes the entire coil.

- 3.4.2.1 How The Ignition Coil Works: When the distributor contact points are closed, the circuit is energized and a magnetic field is built up around both coils. When the points are opened, the circuit is de-energized and the magnetic field collapses about the coils and induces a voltage in both. The voltage developed in the primary winding (about 250 volts) is absorbed and dissipated by the distributor condenser. The voltage developed in the secondary winding (about 25,000 volts) is distributed to the spark plugs for igniting the air-fuel mixture within the cylinders.
- 3.4.2.2 Ignition Coil Service: Ignition coils normally require no service. At time the distributor contact points are replaced, the coil should be inspected:
- (1) Check top for cracks or carbon tracks which indicate current leakage. Clean with solvent or a clean rag.
 - (2) Check the wire in the tower to be sure it is tight and rubber boot is effectively keeping out moisture and dirt. The small wires of the primary circuit should be clean and tight.
 - (3) The primary terminals of the coil must be connected properly. With a negative grounded electrical system, the distributor primary lead should be connected to the (-) ignition coil terminal. With a positive grounded system, the distributor primary lead should be connected to the positive (+) ignition coil terminal.
- 3.4.3 Ignition Resistor: This is electrically part of the coil design and permits maximum life of contact points and coil. It is connected in series with the primary circuit between the battery and coil. Most ignition resistors are an integral part of wiring (the resistance of the wire is "built in" and calibrated to a predetermined value). Some are wire wound in a ceramic block with terminals at both ends for connection. To obtain greatly improved starting performance at low temperatures, the resistance is bypassed during cranking. This connects the ignition coil directly to the battery, making full battery voltage available to the coil which keeps ignition voltage as high as possible during cranking, when the battery voltage decreases under the load of cranking. There is no service necessary to the ignition resistor.
- 3.4.4 Ignition Switch: The ignition switch connects or disconnects the ignition circuit from the battery or generator. It is in series with the primary circuit. Any resistance on switch terminals or within the switch will adversely affect the ignition system. No periodic service is necessary.
- 3.4.5 Spark Plugs: A spark plug consists of two electrodes separated from each other by a specific gap. The side electrode is part of the threaded shell grounded to the engine block, the center electrode is completely insulated from the shell by ceramic. The high voltage from the ignition coil causes a spark to jump the gap to the side electrode. This spark, inside the cylinder, ignites the air-fuel mixture for combustion in the cylinder.
- 3.4.5.1 Spark Plug Gap Spacing: The gap between electrodes is critical. Each engine manufacturer specifies the correct gap for efficient operation in that engine. The gap varies between 0.022 to 0.044 inch. The correct spacing affects the entire range of performance of the engine - starting, idling, accelerating, power, and top speed. Uniform spark plug gap is essential for a smooth running engine.
- 3.4.5.2 "Hot" and "Cold" Spark Plugs: Spark plugs must operate in a certain temperature range to give top performance. The ability of a spark plug to conduct heat away from the center electrode and its insulating material is controlled by the design of the shell and insulator. Heat must escape through the insulating material, shell, gasket, and threads to the cylinder head and engine coolant. Manufacturers can vary the construction of the insulator and vary the heat dissipating characteristics. There are a number of plugs in any size to permit selecting one with the correct heat range characteristics for the engine operating conditions. Charts from spark plug manufacturers show the plugs recommended for each engine.

- 3.4.5.2.1 Spark Plug Service: Examination of a used spark plug usually reveals if the correct heat range is used for the type of engine operation. If the plug is too "hot", the insulator will blister or crack and the electrodes will burn rapidly. If the plug is too "cold", soot and carbon will deposit on the insulator causing fouling and missing.

(1) Spark plug electrodes will erode eventually. Fuel additives tend to form rusty brown oxide deposits on the insulator and center electrode tip. Plugs should be cleaned regularly every 300 hours of engine operation. File the center electrode to renew sharp corners and reset gap to specifications. Replace spark plugs when electrodes are worn to where it is impossible to re-adjust proper gap and still maintain a "square relationship" between electrodes. Use a new gasket seat each time a plug is installed. The spark plug should be screwed into cylinder head only sufficiently tight to compress gasket. Torque specifications are issued by all plug manufacturers.

- 3.4.6 Ignition System Wiring: The wiring circuits are just as important as the electrical units themselves. Loose connections, frayed wire, or bad insulation can cause poor or no ignition performance. High resistance in the primary wiring can cause low voltage in the secondary (High Voltage) system. Poor insulation on the high voltage secondary circuit can permit current loss and prevent spark plug firing.
- 3.4.6.1 Radio Suppression: Ignition systems, during normal operation, produce high frequency electric signals that could interfere with the vehicle radio or nearby television reception. Practically all ignition systems now incorporate some form of resistance or suppression to eliminate this undesirable interference. One of the most common methods of suppression is the use of secondary "ignition suppressor cable" called TVRS cable. This type cable requires understanding and use of good service procedures so as not to damage the cable and create high resistance between the cable and its terminal connections.
- 3.4.6.2 Protection of Wiring Circuit: Wiring systems (except the secondary circuit) are protected from short circuit failure by adequate protection devices, i.e. fuses or insulating materials that will insure that a failure will be confined to the affected circuit and not cause a failure in adjacent circuits.
- 3.5 Cranking Motor: A cranking motor consists chiefly of an armature, a field frame, a drive mechanism, and in some cases a solenoid. It is designed and built to provide long periods of service in gasoline, diesel, and turbine engine applications.
- 3.5.1 Frame and Field Assembly: This consists of field coil windings assembled over iron pole pieces which are attached to the inside of a heavy iron frame. The iron frame and pole shoes not only provide a place where the field coils can be mounted but provide a low resistance path for the magnetic flux produced by the field coil windings. The polarity around the field frame alternates - North, South, North, South.

There are two types of field coils used in cranking motors; series and shunt. The current that flows thru series coils also flows thru the armature windings, but current thru a shunt coil bypasses the armature and flows directly back to the battery. The shunt coil can be easily identified by its direct connection to ground. The series coils contain several turns of heavy copper ribbon conductor while shunt coils contain comparatively more turns of smaller wire.

3.5.1 (Continued)

In cranking motor with series coils (all field coils in series with the armature) the speed of the armature is inversely proportional to the magnetic flux. In other words, the lower the magnetic flux, the higher the speed. So when a battery is connected to a series motor that is allowed to free speed (no load connected to the armature), the increasing speed of the armature causes the magnetic flux to decrease which in turn causes the armature speed to increase even further. Finally a maximum free speed is reached which may be high enough to cause the armature windings to be thrown from their slots. So some means must be provided to protect the armature of a series cranking motor. A shunt coil (field windings bypass the armature and flow current directly to ground) has a constant value of magnetic flux as determined by battery voltage always present in the motor, and the maximum free speed is accordingly limited.

- 3.5.2 Armature Assembly: This assembly consists of a stack of iron laminations located over a steel shaft, a commutator assembly, and the armature windings. The windings are heavy copper ribbons that are assembled into slots in the iron laminations. The winding ends are soldered or welded to the commutator bars which are electrically insulated from each other and from the iron shaft. There are two major types of armature windings; lap and wave. The lap winding has as many paths as poles, and the wave winding always has only two paths. A lap winding is normally used where a low resistance armature is needed.

In the lap winding (used in a 2-pole motor), the lead ends of a winding element, or complete turn of a conductor, are connected to adjacent commutator bars. With a battery connected to the brushes, the direction of current flow under the north pole is the same in all conductors, and the direction of current flow under the south pole is the same in all conductors. This arrangement provides maximum torque.

In the wave winding (used on a 4-pole motor), the lead ends are connected to commutator bars that are approximately 180 deg (3.14 rad) apart. As in the lap winding, the current flow directions in conductors under the same pole are the same to provide maximum torque.

The armature is supported on the shaft ends by bushings in end frames that are assembled onto the frame and field assembly. With brushes that are supported on the frame and field assembly riding on the commutator bars, the cranking motor assembly is formed.

Many cranking motors have a long pole shoe tip which is assembled in the direction of armature rotation. This feature permits the retention of brushes in the same location for motors of clockwise or counterclockwise rotation.

- 3.5.3 Motor Drives: The motor drive mechanism is assembled on to the armature shaft. This is the means of transmitting power from the rotating armature to the engine during the starting cycle. All drives, regardless of type, contain a pinion which is made to move along the shaft and engage the engine ring gear for cranking purposes. A gear reduction, usually 15 to 1, is provided between pinion and ring gear. The electrical design of the motor is selected to utilize this ratio to turn the engine at speeds sufficient for starting purposes. After the engine has started, the ring gear would drive the armature at excessive speeds, so all drive mechanisms are designed to disengage the pinion or to provide an overrun feature to protect the armature from damaging speeds.

- 3.5.3.1 Bendix Drive: These operate on the principle of inertia to cause the pinion to engage the engine ring gear when the cranking motor is energized. The drive pinion is unbalanced by a counter-weight on one side, and has screw threads cut in its inner bore. These screw threads match threads in the outer surface of the Bendix sleeve which fits loosely over the armature shaft. The pinion/sleeve assembly is connected to the drive head by a drive spring. When the armature starts to revolve, the rotation is transmitted through the drive head and spring to the sleeve. The pinion, being unbalanced and fitting loosely on the shaft, does not increase in speed with the armature due to its inertia. The result is that the spiral splined sleeve rotates within the pinion and the pinion moves endwise along the shaft to engage the ring gear. When the pinion reaches its stop on the sleeve, the teeth are engaged in the ring gear of the engine with the initial shock being taken up by the spring.

When the engine starts, the pinion is driven faster than the armature which causes the pinion to rotate in the same direction as the sleeve but at higher speed and the pinion is driven back out of mesh with the ring gear teeth. As long as the operator keeps the cranking motor energized with the engine running, the motor free speeds, so the starter switch should be released immediately. If a tooth abutment should occur during engagement, the spring compresses to allow the pinion to engage the next ring gear tooth.

A folo-thru Bendix drive contains a pinion and barrel assembly shrouding a spring-loaded detent pin that moves into a notch cut in the spiral spline which serves to lock the pinion in the cranking position. This feature prevents unwanted disengagement during false starts. When the engine starts, centrifugal force causes the detent pin to move out of the notch, and the pinion then is driven out of mesh with the ring gear. A second feature of the folo-thru drive is a sleeve or screwshaft having two pieces that are connected by a dentil clutch, or mating ratchet teeth. This prevents the armature from being driven at excessive speeds by the engine by allowing the pinion and the mating sleeve to overrun the ratchet teeth until the detent pin has disengaged the notch.

Another Bendix drive is the friction-clutch type used on larger cranking motors. This drive uses, instead of the drive spring, a series of flat spring-loaded clutch plates inside a housing that slip momentarily during engagement to relieve shock. A "meshing spring" is located inside the drive to allow the pinion to clear a tooth abutment condition. Otherwise this drive operates in the same manner as the other Bendix drives.

- 3.5.3.2 Dyer Drive: In this motor drive, the pinion is moved into mesh with the engine ring gear by a shift lever that is solenoid operated. This type of drive is used on large cranking motors for very large engines and features positive engagement of the pinion with the ring gear before the switch can be closed between the battery and motor. This avoids spinning meshing which might be damaging on high horsepower cranking motors with rapid armature acceleration.

A small pinion spring allows easy engagement with the ring gear. Then as the armature rotates, the shift sleeve backs up to the "at rest" position. As the engine starts, the pinion overcomes the light pinion spring pressure and the pinion backs out of the ring gear. Another cranking cycle cannot be started without first deenergizing the solenoid moving the shift lever.

- 3.5.3.3 Roll Clutch Drive: This device is also moved by a solenoid, but has a shell and sleeve assembly that is splined to match splines on the armature shaft. The pinion is located on the inside of the shell along with spring-loaded rollers that are wedged against the pinion and a taper cut inside the shell. When the shift lever is operated to push the pinion into mesh and to close the switch to start armature rotation, cranking begins with torque being transmitted from the splined shell to the pinion by the 4 rolls which become wedged tightly between the pinion and the taper cut into the shell. When the engine starts, it drives the pinion faster than armature rotation and the 4 rolls are moved away from the taper allowing the pinion to overrun the shell. Releasing the start switch moves the shift lever back by return spring action.