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AEROSPACE INFORMATION REPORT

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Superseding AIR1336A

Ground Support Equipment Electrical Systems

RATIONALE

Revised to include updated information on alternator charging systems and electronic fuel injection systems.

TABLE OF CONTENTS

1. SCOPE

This SAE Aerospace Information Report (AIR) 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.

1.1 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. APPLICABLE DOCUMENTS

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

SAE J56 Road Vehicles - Alternators with Regulators - Test Methods and General Requirements

SAE J539 Voltages for Diesel Electrical Systems

SAE J1343 Information Relating to Duty Cycles and Average Power Requirements of Truck and Bus Engine Accessories

SAE J1908 Electrical Grounding Practice

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 ($Pb0_2$) in the positive plate immersed in an electrolyte of 36% sulfuric 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; three cells connected in series make up 6-volt batteries or six 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. More recent vehicles utilize maintenance free batteries which typically discharge at 2 to 3% per month.

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 amperes 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 Definition

The Cold Cranking Performance rating is the discharge load in amperes which a new fully charged battery at 0 °F (-17.8 °C) can continuously deliver for 30 seconds and maintain a terminal voltage equal to or higher than 1.20 volts per cell. Note: Some manufacturers publish ratings at 32 °F (0 °C). Comparison of battery specifications must always be at the same temperature rating.

3.1.3.2 Reserve Capacity Rating

This rating is the length of time one can travel with minimum electric load (lights and engine ignition) and no alternator 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 amperes 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 when battery carrying large load;

c. night or winter driving when electrical load exceeds generator/alternator capacity.

This deep cycling condition causes the positive plates to grow due to sulfation, then shrink as charging converts sulfate 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 alternator of proper capacity and voltage regulator should be adjusted to give a slight charge rate with normal lights and other load. Specify the alternator cold output required.

3.1.5.2 Battery overcharge occurs from an excessively high setting of the voltage regulator which produces an excessively high electrolyte temperature in the battery. High temperatures can also result if the battery in installed in close proximity to hot surfaces such as exhaust manifolds. A tell-tale sign of overcharging is excessive battery water consumption. Normal consumption is about 1 ounce/100 hours (29.6 cc/100 hours). 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. Alternators with internal voltage regulators can not be adjusted. The alternator must be replaced if overcharging. 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) An acid-resistant 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 voltage with a voltmeter with 0.01 volt divisions. If battery reads 11.7 volts or more - the battery is good. Readings less than 11.7 volts require the battery be recharged and retested with the above test. If it still fails to read 11.7 volts, replace the battery. Electric resistance load meters can also be employed for this type of test. Connect the meter and depress the switch to load the battery.

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 amperes 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 1 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 amperes 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

a. Visual inspection as in 3.1.6.1.1. Clean battery thoroughly using 1/2 to 3/4 pound (0.23 to 0.34 kg) of ordinary baking soda to a gallon of water.

b. Light load test as in 3.1.6.1.2 to determine if battery is good enough to recharge.

3.2 AC Charging System

3.2.1 Alternator

An alternator is a belt-driven AC (alternating current) generator that serves two functions in the charging system. It must generate enough electrical power to operate all of the electrical components and keep the battery charged. More recent vehicles employ the alternator to generate electrical energy. An alternator is 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 DC 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 AC voltages which are rectified by the diodes to a single DC voltage and DC 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.

3.2.1.1 Alternator Types

There are many different types and designs of AC 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 AC alternators, however, develop three-phase AC voltage which is then rectified to a single DC voltage available at the output terminals. This output occurs even at engine idle, the amount depending on the application.

3.2.1.1.1 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 DC generator.

b. Cold Output Rating: The output in amps at low (2000 revolutions per minute) and high (5000 revolutions per minute) 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.

3.2.1.1.2 Light-Duty

These are medium load range alternators with hot output ratings up to approximately 50 amperes. This alternator delivers 5 to 10 amperes 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 AC 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; three are in the end frame and three 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.

3.2.1.1.3 Heavy-Duty

These alternators usually use a 16-pole rotor with a “Y” connected stator and all six diodes assembled into two 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 amperes. Output at idle is approximately 25 amperes.

3.2.1.1.4 High Output at Idle

If the application requires higher output at idle engine speed, these alternators supply approximately 40 amperes at engine speeds of 600 revolutions per minute or lower. Special models are available for heavier electrical loads supplying up to 125 amperes at idle and 175 amperes at engine speed of 1000 revolutions per minute. Applications using this alternator include fire trucks with radios or ground support vehicles with radios.

3.2.1.1.5 Special AC Alternators

A totally enclosed brushless model is available requiring oil and air cooling which is designed for very dirty environments.

3.2.1.2 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 to 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.

3.2.2 AC 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. Three types are in general use - the double-contact (vibrating) regulator, the external transistor regulator and the internal transistor regulator. External regulators, either double-contact or transistor, have been replaced in all but the oldest ground support equipment with internal regulators built into the alternator.

3.2.2.1 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.

As the AC 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 revolutions per minute with battery voltage of 12.0 volts and regulator spring setting on lower contacts of 13.8 volts, the voltage range (12.0 to 13.8) is not sufficient to pull the armature of the voltage regulator. So throughout the 0 to 1000 revolutions per minute speed range, the lower contacts remain closed. As the alternator speed goes from 1000 to 2000 revolutions per minute, 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 revolutions per minute.

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 revolutions per minute the voltage regulator will “float” so both contacts remain constantly open. So between 1000 and 3000 revolutions per minute, the contacts “vibrate” staying open progressively longer periods of time till at 3000 revolutions per minute, they are open all the time.

As the engine speed goes higher than 3000 revolutions per minute, 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 zero causing the spring to open the upper contacts. This “vibration” cycle is very rapid (up to 300 times per second at 8000 alternator revolutions per minute - the field current may be reduced to 0.1 ampere). 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.

3.2.2.1.1 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 amperes and the maximum output of the alternator is 40 amperes. With a fully charged battery (battery will then draw about 2 amperes 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 ampere charging rate at 13.8 volts. With the 30 ampere accessory load, the total current requirement is 50 amperes. But the alternator is capable of only 40 amperes, so the accessories will get 30 amperes, the battery 10 amperes 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.

3.2.2.1.2 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 overcharge 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)).

3.2.2.1.3 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.

3.2.2.1.4 Types of Double-Contact Regulators

a. Three unit regulator contains a double-contact type voltage regulator, a field relay, and 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.

3.2.2.1.5 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 trichloroethylene to remove residue.

3.2.2.2 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. 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.

3.2.2.2.1 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 abort 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 amperes maximum field current). With internal transistor regulators the entire circuitry has been reduced to an integrated circuit chip(s) located inside the alternator.

3.2.2.2.2 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. Alternators with internal regulators do not have any provision for voltage adjustment.

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 jump 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.

3.2.2.2.3 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 to 1500 revolutions per minute). The battery must be fully charged when setting the regulator adjustment and all electrical loads off.

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 AC charging system.

3.2.3 Wiring Circuit

The wiring circuit is just as important a part of the AC 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.

3.2.3.1 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.

3.2.3.2 Electrical Grounding Practice

Grounding of electrical circuits should be in accordance to SAE J1908.

3.2.4 Troubleshooting the AC Charging System

AC charging system circuits are completely different from DC charging system circuits. None of the troubleshooting checks outlined for DC systems can be used on AC systems. Before attempting to troubleshoot, 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 DC 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.

3.2.4.1 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 1 ounce/100 hours (29.6 cc/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 nor the wiring is the source of trouble, check the regulator. Place a voltmeter across the battery. Start the engine and run at 1500 to 1700 revolutions per minute. Note the voltmeter reading. If the reading is 16.0 volts or above, the voltage regulator setting is too high. Adjust an external regulator according to instructions below (for internal regulators replace the alternator):

   (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 to 15.0 volt range. If no adjustment is possible, replace regulator.

(2) If the voltage reading in 3.2.4.1(c) was less than 16.0 volts, the type of use by the engine or vehicle is probably always at high revolutions per minute and the regulator setting should be lowered. For this minor adjustment, allow the engine to run 15 min to stabilize the regulator setting. Then follow the same procedure as (1) above but adjust regulator voltage lower by 0.3 volt 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.

3.2.4.2 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 as 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 (external regulator systems only). Reconnect battery ground strap, turn lights on high beam and heater blower motor on high speed. Operate engine at 1500 to 2000 revolutions per minute 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 to 1700 revolutions per minute. Turn on lights to add a 15 to 25 ampere loading. Note the voltmeter reading. If reading is below 13.1 volts, adjust as described in 3.2.4.1(c1) by turning adjusting screw clockwise to increase voltage to 14.5 to 15.0 volt range (external regulators only). Remove voltmeter and check battery for improved charging performance over a reasonable service period.

3.3 Ignition System (Gasoline Engine Installation)

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.

3.3.1 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.

3.3.1.1 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.

3.3.1.2 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 through 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.

3.3.1.3 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 degrees 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.

3.3.1.4 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.

3.3.1.4.1 Distributors with 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 through 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.

(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 through 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 under load, this could indicate the contact points need replacement.

3.3.1.4.2 Magnetic pulse distributors superseded contact point distributers in the 1980s. These distributors replace the contact points with a magnetic pickup coil. A rotating pole piece on the distributor shaft triggers an electrical pulse which signals a transistorized pulse amplifier. The pulse amplifier then switches the ignition coil primary winding. This results in prolonged spark plug life and higher current in the primary circuit because there is no arcing at the contact points which allows a stronger magnetic field to be developed in the ignition coil.

3.3.1.4.3 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.

3.3.1.4.4 Distributor Cap

Inspect the cap each time an engine tune-up is performed. 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.

3.3.1.4.5 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.

3.3.1.4.6 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 lightweight 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 distributor's 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.

3.3.2 Ignition Coil

This is a pulse transformer that steps up the lower battery or generator voltage to the high voltage necessary to ignite the air-fuel mixture at the gaps of the spark plugs. It contains three 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.

3.3.2.1 How the Ignition Coil Works

When the distributor contact points are closed or the pulse amplifier completes it's output circuit, the primary coil circuit is energized and a magnetic field is built up around both coils. When the points are opened or the pulse amplifier turns off it's output circuit, the primary coil 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.

3.3.2.2 Ignition Coil Service

Ignition coils normally require no service. At time of engine tune-up, 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.

3.3.3 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. Some systems employ an ignition coil with the resistor built into the coil.

3.3.4 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.

3.3.5 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.

3.3.5.1 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 (0.112 cm). 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.

3.3.5.2 "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.

3.3.5.2.1 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.

3.3.6 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.

3.3.6.1 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 suppresser 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.

3.3.6.2 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.

3.4 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.

3.4.1 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 through series coils also flows through the armature windings, but current through 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.

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.

3.4.2 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 degrees (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.

3.4.3 Motor Drives

The motor drive mechanism is assembled onto 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.

3.4.3.1 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 counterweight 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.

3.4.3.2 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 de-energizing the solenoid moving the shift lever.

3.4.3.3 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 four 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 four 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.

3.4.3.4 Sprag Clutch Drive

This is similar to the roll clutch drive except that a series of sprags, usually 30 in number, replace the four rolls between the shell and the sleeve. These sprags are held against the shell and sleeve surfaces by a garter spring. The shell and sleeve assembly is splined to the armature shaft, and the pinion is spiral splined to the sleeve with a stop collar on the end. As the shift lever moves by solenoid action against the collar, it causes the entire clutch assembly to move along the splined shaft engaging the pinion in the engine ring gear. When the switch energizes the cranking motor, torque is transmitted from the shell to the sleeve and pinion through the sprags which tilt slightly and are wedged between the shell and sleeve. When the engine starts, the pinion and sleeve run faster than the armature and the sprags tilt in the opposite direction to allow the pinion and sleeve to overrun the shell and armature. Like all lever actuated drives, this is used only on larger cranking motors.

3.4.4 Magnetic Switches and Solenoids

A magnetic switch operates electromagnetically to open and close the circuit between the battery and the cranking motor. A solenoid performs two functions in the cranking circuit; it closes the circuit between the battery and motor, and also the solenoid plunger shifts the motor drive mechanism into mesh with the engine ring gear.

3.4.4.1 Magnetic Switches

These consist basically of a wire winding mounted in a hollow cylinder containing a moveable core or plunger with a contact disc assembled on the plunger. When the winding is energized, plunger movement causes the contact disc to be held tightly against two main switch terminals and closing the circuit between the two terminals. When the winding is de-energized, a return spring causes the plunger to return to its original position.

3.4.4.2 Solenoid Switches

These consist basically of two windings mounted around a hollow cylinder containing a moveable core or plunger. A shift lever is connected to the plunger and a pushrod with contact disc is assembled in line with the plunger but completely separate. When the windings are energized, the plunger core pulls the shift lever and engages the motor drive with the ring gear. The contact disc is pushed into firm contact with the solenoid battery and motor terminals to start cranking. The two windings in the solenoid are called “hold-in” and “pull-in” windings. The “hold-in” winding contains many turns of fine wire and the “pull-in” winding contains the same number of turns of larger wire. When the start switch is closed, current flows to both windings simultaneously. The magnetism created by each winding adds together to form a strong magnetic field that attracts the plunger into the core to shift the motor drive. Once the shift movement is completed, much less magnetism is needed to hold the plunger. With the contact disc contacting both the solenoid battery and motor terminals, the “pull-in” winding is shorted and current stops flowing through it. This design reduces the current draw on the battery and reduces the amount of heat created in the solenoid switch. When the start switch is opened, current flows, for a brief instant through the contact disc to the solenoid motor terminal through the “pull-in” winding in reverse direction, and then through the “hold-in” winding in a normal direction. The opposing magnetisms created by each opposing winding cancel each other, and the return spring moves the shift mechanism back to the “at rest” position. All solenoid switches operate on the above basic principal.

Another feature on some models adds a contact finger which touches the contact disc in the cranking mode. This contact finger makes contact directly to the ignition coil, bypassing the ignition resistor, and provides more available ignition voltage during cranking.

3.4.5 Basic Circuits

There are two basic types of cranking motor circuits. The first involves a motor with Bendix drive that relies on inertia to move the pinion into mesh with the ring gear. The second uses a motor with drive mechanisms requiring a shift lever to move the pinion. A magnetic switch is used with the Bendix drive motor to provide a circuit of short length and low resistance between the battery and motor because the motor may draw over 100 amperes during operation. This takes heavy, short length cables to reduce the voltage drop. The magnetic switch then is in close proximity to the battery and motor, and small longer leads connect the coil to the start switch.

The second basic circuit is with the solenoid switch to shift the pinion as well as operate the cranking motor so this switch is always located right on the motor body, but the size of lead between battery and motor must be as short as possible.

A neutral safety switch is generally used to close only when the transmission shift lever is in the proper “neutral” or “park” position thereby preventing cranking of the engine with the shift lever in a gear.

3.4.6 Series-Parallel Circuits

The function of the series-parallel switch is to connect two 12-volt batteries in series for 24-volt cranking, and to connect the same 12-volt batteries in parallel where it is desirable to have 12-volt charging and electrical accessories. A typical series parallel switch might also incorporate a magnetic switch for Bendix drive motors. Although series-parallel system has been widely used, it is being replaced by 12-volt motors having essentially the greater power of a 24-volt motor when the same total battery capacity is used with the new 12-volt motors.

3.4.7 Cranking Motor Maintenance

Cranking motors have only one function; that is to crank engines or turbines at a speed sufficient for starting. There are many sizes and designs to meet the requirements of each engine. Other factors to consider are whether the load is disconnected from engine and also, its high and low environmental temperatures. All designs of cranking motors support the armature shaft with bushings at the ends. Lubrication is provided by wicks and hinge cap oil reservoirs or grease cups. A few models use oilless bushings. Larger motors feature a center bearing that supports the armature shaft during cranking.

The cranking motor is designed for intermittent duty only. It should never be operated more than 30 seconds at a time without pausing for at least 2 minutes to allow it to cool. It is designed for great overload for short periods and it provides a high horsepower output for its small size. It is important that the battery be maintained fully charged. If sluggish cranking is encountered, the condition of the battery should be checked. The size and performance of the battery should be as specified by engine manufacturer. Battery voltage rating should be the same as the rating of the motor.

All circuit connections should be maintained in a clean and tight condition. Since the solenoid initially may draw 100 amperes and large motors several hundred amps throughout the cranking cycle, tight connections avoid excessive voltage drop and lines must be large enough to handle the current.

Most motors are now totally enclosed minimizing service to brushes and component wear from dirt. The proper weight of engine oil in the engine crankcase is also important. An oil heavier than recommended lowers cranking speed drastically at low temperatures and could prevent engine starting.

If the battery, wiring, and engine are in good condition, the cranking motor should be removed for testing if it fails to start the engine. Check for mechanical restrictions to freedom of operation. Wear is usually not the reason for failure.

3.5 Electronic Ignition System

Modern engines are equipped with a solid state electronic ignition system. It is capable of controlling the spark timing more accurately and with fewer misfires than the mechanical, breaker-point type systems. The electronic ignition system will increase the maintenance intervals and result in more consistent engine performance.

3.5.1 Components

The Ford Duraspark II ignition system is a second generation pulse amplifier system which consists of primary and secondary circuits. The primary circuit consists of the following items: battery, ignition switch, ballast resistor - start bypass, ignition coil primary windings, ignition module, and distributor stator assembly. The secondary circuit includes: ignition coil secondary winding, distributor rotor, distributor cap, ignition wires, and spark plugs. Duraspark II systems were widely used in ground support applications.

3.5.2 Operation Description

The ignition module controls the primary coil charging and discharging. The distributor supplies a signal to the module based on camshaft position, engine speed, and manifold vacuum.

The distributor provides an electric signal to the ignition module. The signal is generated by an armature passing by a stator - generating an electric voltage sensed by the module. The armature is connected to the main distributor shaft. Centrifugal weights vary the position of the armature relative to the shaft as engine speed changes. This results in changing the armature signal to the ignition module and advances timing as engine speed increases. The stator is mounted on a plate that is rotated by the vacuum diaphragm. Manifold vacuum is supplied to the diaphragm assembly that causes the stator plate to move. This advances the signal timing as manifold vacuum increases in mid and low engine loads.

The ignition module performs the function of turning off the current flow through the ignition coil in response to a control signal. The remainder of the ignition system functions identically to the breaker point style system described in 3.3.

3.5.3 Routine Maintenance

When the engine undergoes a routine maintenance check the ignition system should be inspected and the timing verified. The rotor cap should be removed and it and the exposed distributor assemblies cleaned and inspected for any mechanical failures such as chips or excessively worn contacts in the rotor. Any failed parts should be replaced per the engine service manual instructions. The coil should also be checked for chips, cracks, or leakage and replaced if necessary. Any frayed wiring should be replaced to prevent possible electrical shorts.

The spark plugs must be removed, cleaned, inspected, and re-gapped with new plugs used as needed or as recommended in the owner's guide. The ignition timing should be checked and adjusted if needed. The engine service manual should be consulted and followed exactly - failure to do so may result in pre-detonation problems and premature engine failures. Note that timing requirements may change from model year to model year so always ensure that the timing instructions used coincide with the year of the engine.

4. ELECTRONIC FUEL INJECTION SYSTEMS

4.1 Purpose and Description

Since approximately 2008 ground support equipment has been manufactured or retrofitted with throttle body fuel injection systems. These systems replace the standard carburetor with a throttle body injection unit controlled by a modern ECM computer which permits precise fuel control. The latest generation systems introduced in 2010 are available in a fully exhaust emissions certified version that meets both federal EPA Tier II and C.A.R.B Level 3a retrofit standards. This certification is made possible with a catalytic converter specifically designed for ground support equipment application.

4.2 Added Engine Protection

These systems incorporate engine protection items as well:

a. standard OBDII on-board diagnostics

b. low fuel shutdown which prevents starting the engine until refueled

c. low oil pressure shutdown

d. high coolant temperature shutdown

e. electric engine fan control

f. engine revolution per minute governor.