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Ground Support Equipment Electrical Systems

RATIONALE

This report covers 12 volt electrical systems for gasoline and diesel powered GSE. It is longstanding stable technology not likely to change in the future.

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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 (PbO₂) 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 is 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.