



SURFACE VEHICLE INFORMATION REPORT

SAE J2289 JUL2008

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Electric-Drive Battery Pack System: Functional Guidelines

RATIONALE

This document provides guidance in designing battery systems for electric vehicles and hybrid electric vehicles. The document is basically an extensive checklist of design considerations for battery packs: mounting, operation, environment, durability, safety, etc. These design considerations have not changed appreciably since the standard was issued in 2000.

This document should be revised only for corrections of minor typographical errors.

FOREWORD

The mission of this document is to provide guidance in designing vehicle level battery systems for Electric Vehicles and Hybrid Electric Vehicles using electrically rechargeable battery modules. Items addressed include battery system content, component and system safety and reliability, improving system performance of the battery, and optimizing battery life.

The term battery used throughout this document implies the complete energy storage system and its auxiliaries, which are used to deliver power and energy to an electric vehicle traction system.

Design of aqueous electrolyte battery modules and cells as to electrochemical performance and design are defined in SAE J1797, and referenced here. An electric drive battery system as described here may be designed to meet the safety and crash requirements of SAE J1766 and SAE J2344. The requirements outlined in this document are intended to guide the vehicle manufacturers in understanding the environmental conditions that a well designed battery pack should be able to withstand. It is at the manufacturer's discretion as to what tests and test limits to implement.

1. SCOPE

This SAE Information Report describes common practices for design of battery systems for vehicles that utilize a rechargeable battery to provide or recover all or some traction energy for an electric drive system. It includes product description, physical requirements, electrical requirements, environmental requirements, safety requirements, storage and shipment characteristics, and labeling requirements. It also covers termination, retention, venting system, thermal management, and other features. This document does describe guidelines in proper packaging of the battery to meet the crash performance criteria detailed in SAE J1766. Also described are the normal and abnormal conditions that may be encountered in operation of a battery pack system

1.1 Purpose

This document provides the guidelines for designing a battery system to package into manufacturer's electric drive vehicles. It lays the foundation for electric vehicle battery systems and provides information to assist in developing a robust battery system.

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1.2 Field of Application

This document applies to vehicles using electrically rechargeable storage traction batteries that provide energy and power to an electric drive system for propulsion, namely Electric Vehicles and some Hybrid Electric Vehicles.

This document does not fully address all guidelines for mechanically rechargeable battery systems. Users of mechanically recharged batteries should evaluate applicability of individual sections of this document.

1.3 Product Classification

The battery system is a vehicle subsystem that provides all or some of the traction power and energy for vehicles using electric drive systems.

This document does not apply to low voltage non-traction battery supply systems.

1.4 Product Description

A battery system is the complete set of assemblies required to supply traction power and energy to an electric vehicle drive system. A battery pack is a single assembly with batteries that is part of a Battery System. In some cases a single pack may comprise the complete Battery System.

Electric Drive vehicles may require an electrically rechargeable secondary battery to provide motive traction power and energy as well as power and energy for incidental loads like power steering, heating and air conditioning, FMVSS mandated exterior lighting, controls, customer convenience features, etc. The battery can also represent a significant physical load to the vehicle in terms of mass, volume, and controls complexity. Consequently, the battery exerts a significant factor in vehicle design.

2. REFERENCES

2.1 Applicable Publications

The following publications form a part of this specification to the extent specified herein. Unless otherwise specified, the latest issue of SAE publications shall apply.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 5096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

| | |
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| SAE J551 | Performance Levels of Methods of Measurement of Electromagnetic Radiation from Vehicles and Devices |
| SAE J1211 | Recommended Environmental Practices for Electronic Equipment Design |
| SAE J1555 | Recommended Practice for Optimizing Automotive Damagability |
| SAE J1654 | High Voltage Primary Cable |
| SAE J1673 | High Voltage Automotive Wiring Assembly Design |
| SAE J1715 | Electric Vehicle Terminology |

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| SAE J1718 | Measurement of Hydrogen Gas Emission from Battery-Powered Passenger Cars and Light Trucks During Battery Charging |
| SAE J1742 | Connections for High Voltage On-Board Road Vehicle Electrical Wiring Harnesses—Test Methods and General Performance Requirements |
| SAE J1766 | Recommended Practice for Electric and Hybrid Electric Vehicle Battery Systems Crash Integrity Testing |
| SAE J1772 | SAE Electric Vehicle Conductive Charge Coupler |
| SAE J1773 | SAE Electric Vehicle Inductively Coupled Charging |
| SAE J1797 | Recommended Practice for Packaging of Electric Vehicle Battery Modules |
| SAE J1798 | Recommended Practice for Performance Rating of Electric Vehicle Battery Modules |
| SAE J1850 | Class B Data Communications Network Interface |
| SAE J2184 | Vehicle Lift Points for Service Garage Lifting |
| SAE J2288 | Life Cycle Testing of Electric Vehicle Battery Modules |
| SAE J2293-2 | Energy Transfer System for Electric Vehicles—Part 2: Communication Requirements and Network Architecture |
| SAE J2344 | Guidelines for Electric Vehicle Safety |
| SAE J2380 | Vibration Testing of Electric Vehicle Batteries |

2.1.2 Battery Council International (BCI) Publication

Available from Battery Council International, 401 North Michigan Avenue, 24th Floor, Chicago, IL 60611-4267, Tel: 312-644-6610, www.batterycouncil.org.

UL 1244 UL Standard for Safety Electrical and Electronic Measuring and Testing Equipment

2.1.3 NHTSA Publication

Available from NHTSA, 1200 New Jersey Avenue, SW, Washington, DC 20590, Tel: 1-888-327-4236, www.nhtsa.gov.

NHTSA FMVSS 305 Electric-powered Vehicle: electrolyte spillage and electrical shock protection

2.1.4 National Electric Code

Available from National Fire Protection Agency, 1 Batterymarch Park, Quincy, MA 02169-7471, Tel: 617-770-3000, www.nfpa.org.

National Electric Code 625

2.2 Related Publications

The following publications are for information purposes only and are not a required part of this document.

2.2.1 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 J2223-1 Connections for On-Board Road Vehicle Electrical Wiring Harnesses—Part 1: Single-Pole Connectors—Flat Blade Terminals—Dimensional Characteristics and Specific Requirements

SAE J2284 High Speed CAN (HSC) for Passenger Vehicle Applications

SAE J2464 Electric Vehicle Battery Abuse Testing

2.2.2 Battery Council International (BCI) Publication

Available from Battery Council International, 401 North Michigan Avenue, 24th Floor, Chicago, IL 60611-4267, Tel: 312-644-6610, www.batterycouncil.org.

Battery Council International Data Book

3. DEFINITIONS

Reference SAE J1715

4. SYMBOLS

Not used.

5. PHYSICAL REQUIREMENTS

5.1 Mechanical Retention

A retention system to attach components and the battery system to the vehicle should provide for retention in the three mutually perpendicular axes. The restraint need not contact the entire surface in the axis being restrained, i.e., small areas of contact are satisfactory as long as no damage is done to the components.

5.1.1 Physical/Mechanical Performance Requirements

- a. Any restraining system used shall not inhibit the normal electrical operation or ventilation of the module(s) through either physical or electrical obstructions. If an air draft system is used for thermal management or hydrogen gas emissions, the retention system should not hinder airflow around the module(s) needed for proper thermal management or venting of the entire battery system.
- b. The restraints should retain the orientation and position of the modules during vehicle operations. Crash performance as described in SAE J1766, is recommended to ensure that the retention system remains intact. It should also not directly damage modules, which could result in electrolyte leakage.
- c. Any retention system should maintain electrical isolation during a crash as referenced in SAE J1766. The retention system should prevent current leakage and should be protected against electrolyte corrosion. The retention system should not allow damage to sensor wiring, vent tubes, thermal management components, or primary traction wiring leads under all but extreme conditions.

5.1.2 Retention of Components in a Battery Pack System

It is recognized that there are a multitude of methods by which to restrain both single modules and multiple modules connected together in a system. Although electrical cables and connections may seem to provide some form of retention and restraint of modules in relation with one another, this is not considered to be a part of an acceptable retention system that provides restraint in normal and some safety critical situations.

Fasteners, used to mount components to the structure should consider the strength over time and corrosion due to the emission (leakage or spillage) of electrolyte, or other contaminants that may enter the battery system.

Use of high stress clamping retention should be evaluated in the light of not exceeding the force required to damage thermal welds of plastic structures or stress the electrical isolation of metal cans or to cause deformation of the module/cell surface.

5.1.3 Retention of Battery Pack to Vehicle

Sufficient structural strength is required to withstand severe contact loads from FMVSS Crash conditions and rollover without ejecting modules or while providing clearance to the vehicle body. Retention should be sufficient to prevent damage to the batteries by repetitive motion contact. In addition it is necessary to provide retention to protect the battery and the vehicle from damage or affect overall pack reliability.

5.2 Installation/Removal for Service

Battery pack design should consider installation and removal by service personnel. One consideration is structural support of the battery tray during installation and removal after it has been disconnected from the vehicle. During this time, some additional structure (pallet or other) may be needed to support the battery pack to preclude damage and enable movement by fork lift trucks or cranes to move a battery pack from the service bay to a transport truck in instances of swapping or offsite servicing of a battery pack.

Clearances on the vehicle that are adequate to enable easy installation or removal of a battery pack should be verified during vehicle design to simplify service operations. SAE J1555 and SAE J2184 may need to be evaluated to prevent interference's with the battery systems.

The vehicle manufacturer should offer detailed service information and training to service personnel. It should include safety procedures due to high voltage potentials in battery systems.

5.3 Clearance

5.3.1 Ground Clearance

Ensuring adequate ground clearance may be required to protect the structural integrity and durability of some battery systems mounted under the vehicles' structure. This is to verify that departure angles for a vehicle's beginning or ending grade climbs or passing over bumps or other obstacles is not compromised. The amount of ground clearance is left to the discretion of the vehicle manufacturer based on vehicle mission and image.

5.3.2 Body Clearance

Body clearance spacing may be required to provide adequate protection of the battery system components movement to preclude contact of the battery pack or components to the vehicle. These limits are specified as part of the manufacturers design for manufacture/assembly/service guidelines to assist in developing a robust design. Battery packs should be located to reduce probability of damage. Locating battery packs in susceptible locations should consider use of additional crash structure to protect the battery.

5.3.3 NVH Compatibility (noise vibration harshness)

Battery packs should have sufficient retention to provide structural rigidity and separation from the body. Retention should also be sufficient to prevent vibrations/low frequency noises that may reduce structural reliability or be objectionable to passengers. Some designs may also include isolation mounts to reduce NVH.

5.4 Durability Requirements

5.4.1 Mechanical Shock

Battery systems and components should withstand automotive shock effects. This includes shock induced by shipping and handling, component installation, in-use operation, and crash. Battery modules may have additional shock limitations as described by the battery manufacturer. Section 4.8 of SAE J1211 may be an acceptable standard. Also reference SAE J1555. Battery packs may be exposed to the underside of the vehicle, which could result in ground contact or other impacts such as road debris.

5.4.2 Vibration

The battery pack assembly should be capable of surviving the durability of extended vibration due to road conditions and normal operations. Battery systems should meet SAE J2380 or the vehicle manufacturers preferred vibration test.

5.4.3 Corrosion

The completed battery pack should be capable of surviving to the manufacturer's durability requirements, which could include: Battery electrolyte or other fluids for electrochemical system used, Salt water, Salt spray, Salt Mist atmosphere, and Mud bath. Reference SAE J1211.

5.4.4 Abrasion/Road Hazards

Battery packs installed under a vehicle may expose battery modules to road debris such as stones, 4x4 wood studs, pothole material, etc. may impact on the battery structure. This can affect the performance or durability of the battery system. These events could result in electrolyte loss, insulation loss, and pressure containment loss or in damage to the structure either of which could cause premature mortality of a battery module(s). Design for durability to withstand this road debris impacting the battery support structure should be considered, to preclude premature structural failure or perforation of battery cell casings, which will result in cell mortality.

5.4.5 Exposure to Water and Other Chemical Fluids

SAE J1211, 4.4 identifies potential liquids that the battery system may be exposed to. It also recommends tests to perform to verify resistance to splash and immersion.

Components of battery pack systems should be specified and tested for resistance to normal automotive fluids. Among these are: gasoline, diesel fuel, antifreeze, transmission fluids, brake fluid, windshield fluid, battery electrolyte, salt water, and carwash soap. A battery system may be exposed to water which raises concern for: electrical tracking, water intrusion, seal performance, mud build-up which could result in obstruction to air cooling orifices or hydrogen buildup during charging. Corrosion of a battery pack structure due to water should meet or exceed the vehicle manufacturer's durability requirements.

5.4.6 Sand and Dust

The abrasive effects on a battery system can include: abrasion of the external structure leading to long term corrosion of the support, damage or abrasion of the interconnect insulation which can lead to hazardous voltage exposure.

5.4.7 UV Exposure

Exposed battery pack cases should provide adequate protection against ultraviolet light (UV) exposure that may cause loss of structural or insulating properties. Manufactures may want to also consider cosmetic appearance and durability for expected life of the vehicle.

6. ELECTRICAL REQUIREMENTS

6.1 Operational Modes

The vehicle may be operated in the following modes and has associated electrical modes of operation:

Key on Discharge
 Charge including end of charge while plugged in
 Regeneration

Key off Charge including end of charge while plugged in
 Parked - off charging plug
 Operational
 Storage

A battery pack will also have an additional mode for storage in an unpowered state while not connected to a vehicle or control system. This mode may have several operational states depending on battery technology.

6.1.1 Key-On Discharge

6.1.1.1 Normal Operation

Individual components such as battery modules, electrical interconnects should be matched to the vehicle system demand. The system should have excess current carrying capability over the range planned to be used by the vehicle electrical propulsion and auxiliary equipment. The system should limit occurrence and amount of over-discharge of individual battery cells. Most batteries can be damaged by over-discharge.

6.1.1.2 Abnormal Operation

Devices like fusing or rapid response contactors should be considered to provide isolation for ground faults, and overcurrent protection. Possible causes of overcurrent conditions are: Crash resulting in internal and external faults or ground faults to the vehicle, parallel string faults, etc.

6.1.2 Regen Operation

Electrical regeneration or Regen is recovery of energy in lieu of or in parallel with braking action using the motor. Refer to SAE J2344 for safety effects of regen operation. During regen operation the battery voltage should not be allowed to exceed the voltage limits of the drive electronic components or the drive motor.

6.1.2.1 Regen at High States of Charge (Charge Acceptance)

The battery supplier should recommend profiles for regen recovery and discharge current and voltage at high states of charge to protect the battery from venting, overtemperature or other damage that may be caused by operation under these conditions.

6.1.3 Charge

For battery systems using external charging, individual components such as battery modules, electrical interconnects should be matched to the vehicle system charge acceptance capability. Charge control is the responsibility of the battery system. It may perform charge management internally to the battery pack, or may reside on other vehicle electronics.

The charge algorithm provided to the battery pack should be developed with consultation of the battery manufacturer. At the completion of charge, the vehicle may continue to use charger power to operate vehicle systems as described below.

6.1.4 Key-Off

6.1.4.1 Key-Off Parked Off Plug—Operating

This operational mode can exist for an extended period, energy drain should be managed to limit discharge and self discharge. Examples of this operational mode are: headlight usage, continued operation of clock, anti-theft system, remote entry, cellular telephone, pre-heat or pre-cool thermal management timing and control systems.

6.1.4.2 Parked Off Plug—IDLE/Storage Operation

Consideration should be made that the vehicle system or operator/service technician should be able to disconnect the battery circuit when placed in this operational mode.

This mode may be used while waiting for service operations or shipping as a safety consideration.

6.1.4.2.1 Extended Storage

Extended storage can occur with the batteries mounted in or stored off the vehicle due to extended non-use or crash repair. Self-discharge will occur for most battery types. The manufacturer may need to provide charge capability to boost the battery system to prevent permanent capacity loss as a routine maintenance program.

When in storage it may be desirable for a battery pack to be attached to a monitoring tool, to enable diagnostics or to external controls to provide off vehicle charge, data recording or thermal systems management.

6.2 Electrical Ratings

Performance ratings of a battery pack system are established by the vehicle manufacturer and the support of subsystem or component manufacturer for measuring net performance ratings of individual components and the system. For example: battery modules, high voltage wiring, monitoring and control equipment, fuses, etc.

6.2.1 Battery Modules

Battery module packaging and performance of aqueous electrolyte batteries is defined in SAE J1797. Performance ratings of battery modules are defined in SAE J1798. Battery module life ratings are defined in SAE J2288.

6.2.2 Traction Wiring and Connectors

Traction wiring within a battery pack system is high current, high voltage wiring and interconnects between battery modules. It also includes wiring to a battery pack connector for attachment to the vehicles' high voltage wiring system. Battery Traction wiring should be compatible with traction wiring outside the battery systems as described in SAE J1654, SAE J1673 and SAE J1742.

6.2.3 Sensor Wiring

Sensor wiring within a battery pack system should be in separate wire harnesses according to voltage range. High voltage sensor leads should be bundled separately and routed apart from low voltage wiring harnesses. Utility wiring connectors between the battery pack and the rest of the vehicle should consider separating high and low voltage signals into different connectors with appropriate voltage range markings. This aids in reducing the possibility of stray high voltage leakage from damaging control and information/diagnostic signals needed to manage the battery pack system or in determining the extent or cause of damage. Reference SAE J1673 for high voltage wiring standards.

6.2.4 Contactors/Disconnects

Contactors or disconnects are recommended to switch the battery circuit. They should de-energize exposed external terminals. They should be located close to or be part of a battery pack. Contactors or disconnects may be packaged external to battery pack systems. In this case, some means should be taken to de-energize exposed terminals or wires. The manufacturer may provide an interlock mechanism that disconnects the battery circuit when the battery is disconnected from the vehicle or the battery tray is opened to allow service.

6.2.4.1 Contactors

A contactor is an electrically controlled device used to switch high current. Precharge contactors are also included in this category. Contactor operation should be under the control of the vehicle electric drive control system and also may include deactivation by crash sensors or isolation fault detection to provide isolation protection in crash or isolation breakdown.

6.2.4.2 Disconnects

Disconnects are used to switch high voltage circuits. They may be used for added safety during service or by first responders during accidents. They also may be used for extended storage to minimize parasitic discharge. Reference SAE J2344 for use and implementation of these disconnects.

6.2.5 Fusing

Battery fusing should be compatible with SAE J2294.

6.3 EMI/RFC Emissions and Susceptibility

The manufacturer should implement their corporate standards for meeting applicable and useful EMC and transient emissions and susceptibility performance. Reference SAE J551.

6.4 High Power Connection Requirements

Both battery and vehicle manufacturer should agree upon the type of fastener that is used to connect the high power leads to the terminal. Vibration, creep, thermal environment, number of times fastener removed and reinstalled, should be considered in system design. The connector used to mate with the terminal land area and cable or bussbar shall be adequate to carry maximum expected current without heat generation that would cause damage to battery modules or interconnects. Terminal torque affects current carrying capability, and is affected by vibration and creep.

6.5 Electrical Isolation

Electrical isolation of the battery pack from the vehicle chassis, and both external and internal to the pack should be provided regardless of operating mode including exceptional circumstances. Service procedures may temporarily negate this requirement, but are not discussed under the scope of this document. Electrical isolation also reduces inadvertent battery discharge. SAE J1766 describes a means of measuring the amount of isolation present. Avoiding moisture condensation within the battery pack should be considered. Some key considerations are:

- a. Avoidance of leaks in liquid systems.
- b. Contaminants that would cause the loss of electrical isolation.

6.5.1 Isolation—Exposure to Conductive Liquids

A vehicle will travel in conditions where the underside and underhood will be exposed to significant amounts of water mixed with conductive fluids like electrolyte residue, snow/road salt, sea water, mud, oil, other suspensions in water/snow. Gas venting may produce electrolyte droplets that may result in tracking to occur. Conductive surfaces may be electrically exposed for some time period as specified by the manufacturer. Measures should be taken to provide isolation under these conditions to reduce self-discharge, tracking and arcing potential. Action may be taken in terminal, interconnect, or exterior packaging design to promote isolation of hazardous voltages. Electrical isolation impedance of the pack shall meet the requirements of SAE J1766.

6.5.2 Isolation—Tracking and Dielectric Insulation

Battery module terminals may be exposed to conductive materials like electrolyte or other conductive fluids. This can result in hazardous voltage exposure or produce leakage currents during vehicle operation, including crash, service. The battery module should be encased in a sufficiently high dielectric material as to not allow electrical punch through during highest module voltage spikes of regenerative braking instances or during charge.

6.5.3 Isolation—Ground Fault

During the life of the vehicle the pack should meet the pre-test ground fault isolation requirements of SAE J1766 in operation.

6.6 Monitoring/Control Interfaces

A battery system health and life can be improved by integrating a monitoring and control system to protect the battery from abuse, optimize the charging of the battery and enable correct diagnosis of faulty components of the battery system. The vehicle manufacturer should enable the battery controls to communicate with the remainder of the appropriate vehicle controls to promote limit management and diagnostics.

6.6.1 Discharge Management—Performance Limits

The monitoring/management system should protect for overtemperature, under-temperature, over-current/exceeding peak power, and under-voltage operation.

The thermal and electrical balance of the pack should be considered or assured so as to protect individual modules from effects of over-charge or over-discharge. During discharge, the monitoring system should detect under-voltage, which could result in cells being reversed. This condition can be hazardous to the life, performance, and possibly safety of the battery or individual cells. Exceeding the design current limit may cause temperature extremes within individual cells or interconnects that can cause damage to the battery.

The battery manufacturer should recommend algorithms to estimate state of charge, and propose performance limits of the battery to extend life.

6.6.2 Charge Management

Proper charging or regen recovery of the battery is necessary to promote optimum life of the battery by reducing time spent of overvoltage, gassing, or overtemperature. It should be noted that undercharge can contribute to loss of life, and performance which can be permanent.

The charge control algorithms may be contained within the battery controller and can communicate with Level I, Level II or Level III chargers as per SAE J1772, SAE J1773, and SAE J2293.

6.6.3 Regen Management

Regen management at high states of charge can require high performance monitoring of voltage and current to protect the battery and high voltage bus electronics from overvoltage and or overcurrent. This may result in battery damage caused by over temperature or excessive gassing.

Regen consistent with hybrid battery use generally results in a battery state of charge range that does not produce overvoltage or overcurrent conditions, however the system design and state of charge range should consider the protection methods to ensure the battery is not excessively overcharged to protect it from damage.

6.6.4 Interfaces

It is the responsibility of the battery module manufacturer to recommend the proper thermal performance limits and heat rejection/absorption rates of the battery. The thermal system may be unique and proprietary to the vehicle manufacturer. The battery manufacturer should provide guidelines to follow. Some of the key areas for the vehicle manufacturer to consider are: Operating thermal range of the battery modules including minimizing thermal differences caused by cooling performance, and heat transfer rates matching the operating environment or thermal management system.

6.6.5 Heating and Cooling

The method used for heating and cooling battery modules should be selected by the vehicle manufacturer to meet the temperature limits suggested by the battery manufacturer.

Areas of particular concern are:

- a. Attachment of heating and cooling devices/systems.
- b. Reliability of connections.
- c. Breach of high voltage system.
- d. Rate of heat transfer to not deform the battery case material or adversely affect electrochemical functioning or shorten life.
- e. Insulation surrounding the battery.

6.7 Diagnostics and Service

6.7.1 End of Line Manufacturing Diagnostics

Consideration should be given to having built in diagnostics to verify the battery pack is correctly assembled prior to installation to the vehicle or before the vehicle is completed prior to shipment.