Battery & Electrical Systems Session

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Electrical Regulations and Battery Protection
5.7 STORAGE BATTERIES

5.7. A Weight Limits

- 125 kg of sealed Lead Acid
- 100 kg of NiCad
- 70 kg of NiMH
- 30 kg of Li-Ion or Li-Polymer

Manufacturer’s Weight is the “Official Weight”
5.7.B Protection Circuitry

- 5.7.B.1 Definitions
  
  - **5.7.B.1.a Cell**  The smallest available source of energy in your battery pack that you purchase from a manufacturer. A single electrochemical cell.
  
  - **5.7.B.1.b Module**  The smallest easily removable group in your battery pack.
  
  - **5.7.B.1.c String**  The series group of cells needed in your battery pack that provide the required voltage.
  
  - **5.7.B.1.d Protection Limit**  The measured level that your team decides is adequate to protect from an event.
  
  - **5.7.B.1.e Active**  Active means constantly monitored measurements where action can be taken immediately without operator intervention.
5.7.B.2 Li-Ion

- Electrical Isolation is required from the pack when,
  - Over-Voltage
  - Over-Current
  - Under-Voltage
  - Over-Temperature

  is exceeded at the module level as a minimum.

  The need for cell level may be required based on manufacturer.

  - Fuses are not acceptable for Over-Current protection, but are required for 5.9

5.7.B.2.a Isolation

- MOSFETs or other solid state switches are not acceptable for isolating Li-ion battery packs
5.7.B.3 Ni-MH / NiCd

Active measurement is required for:
- Over-Voltage
- Over-Temperature

At the pack level, if unavailable, isolation is recommended

• 5.7.B.4 Pb-Acid

Active measurement required for:
- Over-Voltage

At the pack level, if unavailable, isolation is recommended
5.7.C Hybrid Battery Packs
- Based on weight allowances for type of module used
- Total weight may not exceed 100%

5.7.D Supplemental Batteries
- Replaceable batteries can power the following accessories:
  - Radios
  - Electronic panel meters
  - Driver ventilation
  - Main disconnect relay
  - Horn
  - Telemetry
- **Not battery ventilation, battery controller, electronic mirror or vehicle controls.**
5.7.E Other Storage Techniques

- Must be shown to contain NO energy before the start of each Day of the Rayce.

5.8 Battery Enclosures

- Must be:
  - Electrically isolated from the vehicle > 1Mohm
  - Securely attached
  - Labeled with 10mm high “Caution – Chemical Hazard” and “High Voltage” and “Battery Technology”
  - No more than two enclosures for Li-Ion, up to 4 for all other types
5.8.A Battery Removal
- Pack removal required each Rayce Day for Impound per 7.22
- Box required to safely/securely store pack

5.8.B Battery Stacking
- Non-conductive enclosure
- Meets same requirements as Enclosure

5.8.C Battery Ventilation
- Must operate whenever pack connected electrically to incoming or outgoing power
- Must deliver 280 LPM to the exterior of the vehicle
- Must be powered by the pack, not supplemental battery
COMPLETED BATTERY APPROVAL FORMS BY MARCH 15, 2008, but no earlier than December 1, 2007
- Manufacturer’s published data for Cells
- MSDS
- Configuration description
- Protection System, don’t confuse with control
  • Schematic
  • High level description
  • Things that it is to protect & Set points

For SCRUTINEERING
- Electrical schematic of vehicle, power and control
- Manufacturer’s datasheets for FUSE and POWER SWITCH(ES)

Open Battery Approval Form
• Supporting information
  – Battery Selection

  Pb-Acid

  • Is most robust to solar raycing applications
  • Need to understand voltage discharge curves
  • Need to get balance among cells/modules at start
  • Use Peukert plots to assess rated capacity
  • Still gasses if over-voltaged, thus fan operation
  • Emits hydrogen as gas - flammable, can explode
Battery Pack Cycling
52 ah cells-7 days

Amp-hrs

Start Cycle one (42 out 40 in) Cycle two (35 out 37 in) Cycle three (43 out 40 in) Cycle four (35 out 37 in) Cycle five (39 out 40 in) Cycle six (13 out 14 in) Cycle seven (36 out 0 in)
Battery Pack Cycling
Lithium Technology

Start Cycle one Cycle two Cycle three Dendritic Growth Begins Cycle four Cycle five Cycle six Cycle seven Cell Catches on Fire
Cell Voltage

Battery Pack Cycling
Lithium Technology

S. McMullen 6-5-03
Pb-Acid cont.

- Usually terminated with lugs
- Must be properly torqued and inspected frequently
- Utilize entire surface area of battery terminal
- Looseness results in high resistance connections, resulting in localized heating, losses, and loss of battery
- Corrosion will negatively effect electrical conductivity
- Elyte spillage must be neutralized – baking soda
- Hold-downs are to be used, otherwise entire surface area should be in contact with restraint mechanism.
NiMH & NiCd

- Still requires balance among modules
- Nickel based internal resistance increase as SOC increases
- Sensitive to over-temperature when recharging
- Electrolyte is caustic
- Requires mild acid as neutralizer – Boric Acid powder
- Typically more specific energy than pb-acid
- Provides larger capacity per cell than most lithium
- Typically have longer deep cycle life than pb-acid
- Utilize entire surface area of battery terminal
Lithium Technology Cells

- **Delicate**, must be handled carefully
- Mounting and restraining are a challenge
- Vibration isolation for cell, but more so for termination is important
- Great Solar Battery, Efficiency is in the **99%** range
  (charge in to charge out)
- Desired, High specific energy – Whrs/kg
- State of Voltage is good indicator of SOC
- Understand effects of welding/soldering terminals to cell operation,
  heat affects the cell seal and may ultimately shorten the life of the cell.
Lithium Technology Cells

- Constant monitoring is necessary to optimize a lithium pack.
- Use manufacturer as advisor on all other facets.
- Lithium cells have narrow voltage window to operate
- Lithium cell control is the enabler to success with lithium technology
- Lithium control is independent of Protection System
- Three known vehicle events with lithium thus far, all do to inadequate control and or protection systems
Typical “safe” range of Lithium cell operation
Lithium Technology Cells cont.

- Some issues to Lithium Cell monitoring.
  - Should provide redundant sensing compared to the required protection system (backs up sense, improves reliability)…..
  - Since telemetry can be run on Aux Pack, this allows monitoring to continue after Protection System disconnects
  - Pack Monitoring should not be an afterthought
  - Fusing is required on any leads exiting pack

The Environment

- Rain does Happen - Prepare Accordingly
- Vibration is extreme - Design Appropriately
Lithium Safety (why **Protection System** is **Required**)

- Electrolyte (elyte) is flammable and moisture sensitive
- Elyte exposure to moisture in air results in hydrofluoric acid which can irritate and burn skin.
- Overcharging cell causes the elyte to decompose with the formation of gas that may result in cell leakage and flame
- Over current causes elyte to decompose & boil in the cell.
- Under-voltage causes internal copper corrosion resulting in dendritic growth of copper on recharge leading to shorts and ultimate failure.
- Over-temperature leads to expansion of elyte and potential for leakage, shorts, resulting in flammable gas emissions, swelling.
Lithium Safety Concerns cont.

- Pierced/leaky cells should be removed from operation and sealed in poly bag till properly disposed
- Mounting is a sensitive issue, must isolate vibration to terminals yet retain cells
- Be careful not to destroy cells by tension on the terminals
- Pack imbalance will lead to protection system operation.
- Sense leads must be individually fused if exiting pack
- Consider a two level control scheme; where team is alerted of impending shutdown and can act prior to Protection System engagement
- May consider solid state devices to control/monitor cells independent of Protection System.
- **Control** of cells is necessary for optimum performance and efficiency
5.9 Main Fuse
- Separate fuse is series with the Battery System rated ≤ 200% of max current draw, first in series on positive lead
- Any low voltage taps exiting the main or auxiliary battery must be fused

5.10 Power Switch
- Capable of interrupting voltage and full load current
- Easy reach of driver and emergency personnel
- Relay must be normally open and may be powered from aux battery

5.10.A External Power Cut off Switch
- Switch actuation must also be present on the exterior of vehicle, either mechanically or electrically
- Must be marked according to 5.10.A
5.11 Cable Sizing

- All cables must be sized to expected currents
- Cables should be restrained to prevent chaffing
- Cables should be marked to alleviate delay during emergencies
- Terminations should utilize entire surface of lug, terminal or spade.

5.12 Electrical Shock Hazards

- Exposes connections, terminations and junction boxes greater than 32 volts must be labeled with “High Voltage”
- Enclosures are preferred
5.16 Accelerator
   – Free Moving, returns to zero upon brake activation and starts from zero when re-engaged

5.17 Control
   – Vehicle is to be sole control of the driver
Pack

– Dress all leads for neatness, and chaffing
– Optimize distribution cables – err on side of larger cables
– Test, test, test, understanding the voltage and current relationship on each cell or paralleled cell group (module) is very important
– Once understood, balancing is required for modules wired in series, all must operate with same energy profile.
– **Weakest cell will limit the pack**
– Lithium, with its large quantity of cells paralleled and then series’d is highest battery risk.
– AVOID Shorting, will cause failure of cell(s)
Impound

- Daily – expect to remove pack and place in lockable box
- Design pack to safely isolate potential shorts for impound
- Battery Protection System should be included if necessary for safe storage overnight
- Watertight container if water can hurt your battery pack
- Be creative, every minute wasted during pack removal is one less minute of charging
- May be useful for over the road transport protection as well.
Safety

- High voltage > 48 volts – respect it – it can **Kill You**
- Electrolyte Spillage – appropriate neutralizer – proper ventilation
- Explosion – uncontrolled thermal event
- Melt down – loose terminal
- Fire – appropriate fire suppression material
- ABC for all, Sand for Lithium in addition, Class D (copper powder) if Lithium alone, (no electronics)
- For contact with Lithium electrolyte (HF), flush with copious amounts of water and apply Calcium Gluconate skin cream for the resulting irritation.
Safety cont.

- **Plan** for all these activities and **know ahead** what to do
- Assign team member to have **authority** to drive safety
- **Plan** for everything to be electrically “HOT”
- Rubber Gloves – rated for voltage
- Break pack wiring into safer voltage elements
- Develop procedures to safe shut down
- Develop start-up procedures for initial start-up as debugging begins
ASC 2008 Workshop

Good Luck!