Safety Requirements for Low Voltage Systems

Jeff Kessen
June 16, 2016
Targeted to improve power at extreme cold, UltraPhosphate was developed for low voltage batteries.

A123 now offers parity with lead-acid cold cranking performance at -30°C, erasing the performance barriers to the mass market.
Moving to the Mainstream

Low voltage Li-ion batteries will reach millions of units

- Driven by global clean air legislation, low voltage hybrids are a key part of most OEM product strategies globally
- A123 is ramping up to support volumes indicative of mainstream technology
- Total annual volume sourced to A123 expected to be >1M units by 2020
Low Voltage Li-ion Battery Safety

• Lithium-ion technology has been used for decades in other applications, but is relatively new to low voltage automotive applications causing uncertainty around how to approach battery safety

Global OEM survey results:
Pass criteria for 12V LiSB crash incident

- 43%: Battery is safely venting non-toxic gas
- 24%: Battery has some cell deformation and is functional
- 19%: Battery has no cell deformation and is functional
- 14%: Unsure

• What happens when these batteries are crushed?
• What happens when these batteries are inadvertently overcharged?
Low Voltage Li-ion Battery Packaging

Location influences battery safety requirements

**Under Hood Risks**
- High temperature effect on battery life
- Crush zone implications

**Passenger Cabin / Open Cargo Area Risks**
- Electrolyte fumes from inadvertent leakage
- Gassing caused by inadvertent overcharge

**Trunk Risks**
- Crush zone implications
- Electrolyte fumes from inadvertent leakage
- Gassing caused by inadvertent overcharge
High Voltage Battery Crush Requirements

Industry Norms

- Propulsion batteries are not typically packaged in crush zones, with some exceptions
- There is general industry tolerance to accept battery cells safely venting when damaged (EUCAR 4)

<table>
<thead>
<tr>
<th>Test cases</th>
<th>Pass criteria</th>
<th>EUCAR equivalent</th>
</tr>
</thead>
<tbody>
<tr>
<td>UN 38.3 (cell level)</td>
<td>Plate crush until 13kN or voltage drop or 50% deformation</td>
<td>&lt;170’C and no fire</td>
</tr>
<tr>
<td>GB/T 31467.3 (pack level)</td>
<td>Pole crush 200kN or 30% deformation</td>
<td>No fire, no explosion</td>
</tr>
<tr>
<td>OEM pack example out of crush zone</td>
<td>250kN or 50% deformation</td>
<td>EUCAR 4 or better</td>
</tr>
<tr>
<td>OEM pack example in crush zone</td>
<td>Textured platen crush to 60mm of deformation</td>
<td>No explosion, no fire, no visible gas</td>
</tr>
</tbody>
</table>
## Low Voltage Battery Crush Requirements

### Uncharted Territory

- Packaged in and out of crush zones
- Pass criteria currently varied across industry

<table>
<thead>
<tr>
<th>Test case</th>
<th>Pass criteria</th>
<th>EUCAR equivalent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Starter battery 5 German OEM spec</td>
<td>Left to discretion of OEM</td>
<td></td>
</tr>
<tr>
<td>Starter battery customer example</td>
<td>Pole crush to 250kN with full backplane support</td>
<td>4 or better</td>
</tr>
<tr>
<td></td>
<td>No fire, no rupture, no explosion</td>
<td></td>
</tr>
<tr>
<td>Starter battery customer example</td>
<td>Pole crush to 250kN with edge support only</td>
<td>3 or better</td>
</tr>
<tr>
<td></td>
<td>No fire, no venting, no leakage</td>
<td></td>
</tr>
<tr>
<td>Starter battery customer example</td>
<td>Cube crush to 120kN</td>
<td>3 or better</td>
</tr>
<tr>
<td></td>
<td>No explosion, no fire, no venting, no enclosure cracks &gt;12mm</td>
<td></td>
</tr>
<tr>
<td>48V battery customer example</td>
<td>Pole crush 200kN or 30% deformation</td>
<td>3 or better</td>
</tr>
<tr>
<td></td>
<td>No venting</td>
<td></td>
</tr>
<tr>
<td>Starter battery customer example</td>
<td>Pole crush to 150kN</td>
<td>3 or better</td>
</tr>
<tr>
<td></td>
<td>No explosion, no fire, no venting, no enclosure cracks &gt;12mm</td>
<td></td>
</tr>
<tr>
<td>Starter battery customer example</td>
<td>Pole crush to 150kN</td>
<td>1 or better</td>
</tr>
<tr>
<td></td>
<td>No permanent cell deformation</td>
<td></td>
</tr>
</tbody>
</table>

• Packaged in and out of crush zones
• Pass criteria currently varied across industry
Crash Simulation of 12V Starter Battery

A case study

- Vehicle OEM case: 12V Li-ion starter battery mounted under seat
- In a government crash test, the car is propelled sideways at 32km/h against a pole to determine vehicle ability to protect passenger’s head
  - Bench test proxy: 150kN pole crush test
- Higher speed crashes will result in stronger forces and translations
  - Bench test proxy: 250kN pole crush test
150kN Pole Crush Test

Temperature monitoring is uneventful

Exterior pole damage resulted in no permanent battery cell deformation

EUCAR 1 ACHIEVED
250kN Pole Crush Test

Temperature monitoring is uneventful

Exterior pole damage resulted in no permanent battery cell deformation even on the higher speed crash test proxy

EUCAR 1 ACHIEVED, REQUIREMENT EXCEEDED
Low Voltage Battery Crush Conclusions

- A123 has substantially strengthened the battery housing to survive simulated crash conditions

- Cells are fully protected but further consideration is needed to balance protection requirements vs. cost / weight
  - Standardization of crush requirements could optimize this balance

- Industry should consider adopting test criteria similar to traction batteries; low voltage batteries contain less energy and generally pose lower safety risks
  - Suzuki Wagon R with low voltage Li-ion battery has >1M units in service; battery packaged under the seat
What can cause low voltage battery overcharge?

• Battery overcharge is the most commonly discussed hazard for which low voltage battery electronics provide protection

• Most common failure modes
  + Alternator runaway
  + Double jump start
  + Connection to mismatched / oversized battery charger
  + Other inadvertent system failures

• A123 has worked with OEM partners to analyze possible failure modes and design failsafe to address them
Overcharge of Cabin Mounted 48V Battery

A case study

- Battery modules overcharged under deliberately exaggerated conditions (far beyond worst case)
  - Multiple layers of design protection disabled for test
- Captured vented gas from individual cells which were comparably overcharged and analyzed gas volume and composition
- Combined these results to determine extreme worst case exposure of vent gas diluted in cabin air
- Tests were designed to determine the appropriate ASIL rating for overcharge condition of a cabin mounted battery
Vented Gas Collection & Analysis

- Single cells were overcharged to 5.5V until vent, and gas was collected and analyzed for volume and composition.
- Worst case cabin composition and exposure were analyzed:
  - Assumed several cells in pack vented simultaneously according to overcharge hazard analysis and test results.
  - Assumed air-tight cabin of smallest volume produced by partner OEM.
  - Assumed 8 hours of exposure.
- Even under these extreme conditions, vented gas constituents were below the recommended exposure limits imposed by the National Institute for Occupational Safety & Health (NIOSH).

ASIL B rating for overcharge has been validated.
Vehicle energy management system (specified by OEM) is programmed to respect battery voltage limits

Battery management system has software limits which prevent overcharge (disconnect switch is driven open if limits are violated)

Battery management system hardware provides redundant protection (disconnect switch is driven open if limits are violated)

When applicable, vent tube attached to route vented gas outside of cabin

The concentration of constituents in vented gas does not present a safety risk

Protection path for overcharged low voltage battery
Summary & Conclusions

• Since satisfying the market’s performance requirements for low voltage systems, A123 has earned business with numerous vehicle manufacturers.

• The additional programs have introduced more application diversity in terms of packaging locations, duty cycles and safety requirements.

• Different customers have introduced the most stringent requirements on system behavior during crush and overcharge conditions.

  + The case studies provided today are examples of current safety requirements.

• Diversity of safety requirements is driving excess cost into products designed to serve multiple customers.

  + A123 can meet all existing safety requirements, but at incremental cost.

  + Standardization of safety requirements could lead to robust and cost-efficient product designs.
CHARGED FOR THE FUTURE
LEADING TECHNOLOGY FOR TRUSTED BRANDS
SOLUTIONS TO POWER INNOVATION