Li-ion Pouch Cell Designs; Performance and Issues for Crewed Vehicle Applications

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Li-ion Pouch Cells

Outline

• Purpose and Motivation
• Cell designs evaluate
• Cell lot uniformity, why that’s important
• Forward plans
  – High rate performance
  – Cycle life durability
  – Seals
  – Corrosion susceptibility
  – Manufacturing quality
• Conclusions
Purpose & Motivation

• Compelling Advantages
  – Li-ion pouch cell designs provide the highest specific energy (> 220 Wh/kg), energy density (> 450 Wh/L) of all commercially available designs
  – Many high power designs also exist with very impressive performance (> 2000 W/kg and > 4000 W/L)
  – Numerous designs are being produced worldwide in high volumes for the emerging EV/HEV/PHEV market
    • As such, calendar life, cycle life, and durability has been improved over the last 5 years
    • Many designs have extensive field testing and therefore, maturity
• Our purpose: Are there any performance show stoppers for spinning them into spacecraft applications?
  – Are the seals compatible with extended vacuum operations?
  – How uniformly and cleanly are they made?
  – How durable are they?
• Why now?
  – Electric vehicle market has driven significant improvements
  – Many of our applications (VASIMR, R2, etc) could benefit right now
  – We have access to several high volume cell suppliers which will soon have US production lines up and running
Maturity of Pouch Cell/Module Designs

- **Dow Kokam**
  - 15 high power cell designs offered
  - From 145 mAh to 200 Ah
  - Z-fold separator stacking method
  - PHEV battery module, liquid cooled, optimized for high energy, with 4 years, 1 million km of fleet testing
    - 98.4V, 7.1 kWh, 85 kg module

- **EIG**
  - 4 high power designs with good energy density
  - From 8 to 25Ah
  - Standard pack module is fan cooled for scooters, bikes, robots
    - 48V, 960Wh, 8.9 kg

- LG Chem is providing cells in high volume for Chevy Volt battery packs
- A123 Systems also preparing for high volume cell production in US
### Assessment of Cell Designs

<table>
<thead>
<tr>
<th>#</th>
<th>Vendor</th>
<th>P/N</th>
<th>Mass (g)</th>
<th>Rated Discharge Capacity (Ah)</th>
<th>Standard Charge Regime</th>
<th>Max Discharge</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A123</td>
<td>PHEV</td>
<td>480</td>
<td>20</td>
<td>3.6V at C/2 with C/50 taper current limit</td>
<td>80A to 2.0V</td>
</tr>
<tr>
<td>2</td>
<td>Dow Kokam</td>
<td>SLPB75106100</td>
<td>165</td>
<td>8</td>
<td>4.2V at C/2 with C/50 taper current limit</td>
<td>32A to 2.7V</td>
</tr>
<tr>
<td>3</td>
<td>EIG</td>
<td>C020</td>
<td>425</td>
<td>20</td>
<td>4.15V at C/2 with C/50 taper current limit</td>
<td>80A to 2.5V</td>
</tr>
<tr>
<td>4</td>
<td>LG Chem</td>
<td>P1</td>
<td>383</td>
<td>15</td>
<td>4.15V at C/2 with C/50 taper current limit</td>
<td>60A to 2.8V</td>
</tr>
</tbody>
</table>

- All 4 are mature cell designs, made in high volume production lines
- All 4 provide a blend of high power and energy density capability
From the Dow-Kokam Datasheet

- Specific Energy at 4C, RT → 158 Wh/kg
- Energy Density at 4C, RT → 278 Wh/L
- Thin tab termination
- Blend of high power (up to 5C continuous discharge rates) with high energy capability
Energy Innovation Group

Product General Specification

**Mechanical Characteristics**
- **Model**: C020
- **Length**: 216.0 ± 1 mm (excluding terminal)
- **Width**: 130.0 ± 1 mm
- **Thickness**: 7.2 ± 0.2 mm
- **Weight**: approx. 425 g

**Electrical Characteristics**
- **Nominal Voltage**: 3.65 V
- **Nominal Capacity**: 20 Ah
- **AC Impedance (1 KHz)**: < 3 mΩ
- **Specific Energy**: 175 Wh/Kg
- **Energy Density**: 370 Wh/L
- **Specific Power (DOD50%, 10sec)**: 2300 W/kg
- **Power Density (DOD50%, 10sec)**: 4600 W/L

**Operating Conditions**

**Charge Conditions**
- Recommended Charge Method: CC/CV
- Maximum Charge Voltage: 4.15 V
- Recommended Charge Current: 0.5 C Current

**Discharge Conditions**
- Recommended Voltage Limit for Discharge: 3.0 V
- Lower Voltage Limit for Discharge: 2.5 V
- Maximum Discharge Current [Continuous]: up to 5 C Current
- Maximum Discharge Current [Peak < 10 sec]: 10 C Current

**Operating Temperature**
- Recommended Charge Temperature: 0°C / +40°C
- Storage Temperature: -30°C / +50°C

**Cycle Life**
- Cycle Life at 25°C: 1000 Cycles to 80% Nominal Capacity

**Technology**
- Lithium Ion Polymer Battery
- Li(NiCoMn)O2-based Cathode
- Graphite-based Anode
- High Energy Density
- Optimized for PHEV, EV
Energy Innovation Group

- From their datasheet
  - 148 Wh/kg
  - 311 Wh/L
- Max continuous discharge rate is 5C, capable of 10C pulses
- Beefy tabs

20Ah cell design
LG Chem 15Ah Cell Design

- From their datasheet
  - 150 Wh/kg
  - 300 Wh/L
  - At 4°C, RT

- Capable of >10C continuous discharge
  - Thick and wide tabs
A123 Systems

- LiFePO$_4$ cathode
  - More thermally stable
  - Flat discharge curve
- Very high power, but lower energy according to their datasheet
  - 120 Wh/kg
  - 219 Wh/L
Test Plan for Assessment of Cell Designs

- **Acceptance Testing**
  - Visual, OCV, AC Impedance, mass, dimensional
  - Pouch isolation resistance
  - Soft short (OCV bounce back after deep discharge)

- **Capacity performance**
  - Capacity/Energy vs rate
    - at ambient T, C/5, C/2, C, 2C, 4C with 3 cells per design,
    - all charging at manufacturer’s recom rate

- **Cycling performance**
  - Capacity/Energy vs cycle number
    - 4C discharge, C/2 charge at ambient T for >100 cycles
    - Testing one 3S string per cell design and cycling condition (4 strings total) with cells under compression as per manufacturer’s recommendation

- **Evaluate cell design and manufacturing quality**
  - Seal leak rate and compare to 18650 crimp seal rates
    - Seal cells in Al laminate bag
    - Then thermally cycling (vs not) for 3 weeks
    - Sample container gas for electrolyte to determine leak rate and/or measure mass lost
  - Corrosion susceptibility
  - Destructive Physical Analysis (Tear down)
Examples of Pouch Corrosion

- Defective inner isolation layer of the laminate pouch results in corrosion of the Al layer
- Polarizing the Al layer to the (-) terminal is a quick test method
Soft Short (Small 18650 Cell)

14-day OCV bounce back after deep discharge (constant voltage to 3.0V)

Very uniform OCV bounce back performance
14-day OCV bounce back after deep discharge (constant voltage to 3.0V)

4 cells out of 20 had declining OCV between days 10 and 14
What to look for in DPAs?

• Consistent mechanical alignment
  – Anode overlapping cathode
  – absence burrs
  – No separator tears or wrinkles
• Lack of contamination
  – Heat effective zone halos
  – No foreign or native delamination debris
• No Li deposits or plating
• Consistent active material coating with smooth edges
• Solid weld connections without splatter

Photos courtesy of Exponent
Preliminary Conclusions

• Current Li-ion pouch cells designs for electric vehicle market are offering
  – Over 150 Wh/kg and 300 Wh/L at 15 minute (4C) discharge rates
    • Based on 2 manufacturer’s data sheets (to be verified)
    – High maturity with numerous units fielded
    – Manufactured in high production lines
• Planned testing will determine their readiness for the demands of crewed spacecraft
  – Manufacturing quality
  – Effectiveness of the seals
  – Durability of performance
• Results will be available by August of 2011