DEVELOPMENT OF A 10 Ah, PRISMATIC, LITHIUM-ION CELL FOR NASA/GSFC

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# Li-Ion Battery Technology Has Become a Promising Alternative to the Currently Used Ni-Cd and Ni-H₂ Battery Technologies

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Cell Chemistry</th>
<th>Li-Ion</th>
<th>Ni-Cd</th>
<th>Ni-H₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Energy (Wh/kg)</td>
<td></td>
<td>130</td>
<td>30</td>
<td>45</td>
</tr>
<tr>
<td>Energy Density (Wh/L)</td>
<td></td>
<td>200</td>
<td>85</td>
<td>100</td>
</tr>
<tr>
<td>Voltage (V)</td>
<td></td>
<td>3.6</td>
<td>1.2</td>
<td>1.25</td>
</tr>
<tr>
<td># Cells for a 28 V Battery</td>
<td></td>
<td>8</td>
<td>22</td>
<td>22</td>
</tr>
<tr>
<td>Charge Retention</td>
<td></td>
<td>good</td>
<td>fair</td>
<td>yes</td>
</tr>
<tr>
<td>Gas Generation</td>
<td></td>
<td>no</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Environmentally Friendly</td>
<td></td>
<td>yes</td>
<td>no</td>
<td>yes</td>
</tr>
</tbody>
</table>
Cell Design

- Prismatic, Stacked Electrode Design, Footprint of 7 Ah Ni-Cd Cell (height & width)
- Hermetically Sealed Type 316L Stainless Steel Hardware
- Ziegler Compression Seals With Copper & Aluminum Terminal Posts
- Rupture Disk With 175 psid Burst Pressure Rating
Electrochemical Design

- **Positive Electrode**
  - Lithiated Cobalt Dioxide, Pure 20 µm Al Foil Collector

- **Negative Electrode**
  - MCMB Carbon, Pure 18 µm Cu Foil Collector
  - Larger than Positive Electrode, All Around

- **Electrolyte**
  - LiPF₆ Salt in Mixed Organic Carbonate Solvents

- **Separator**
  - Celgard® 2300 Microporous Flat Sheet Tri-Layer Membrane

- **Capacity Ratings**
  - Design - 10 Ah, Nameplate

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Mechanical Design

- Equal Tab Length for All Electrodes
- Four Electrode Substacks With 22 Pairs Each
- Substacks Are Joined With Ultrasonically Welded Interconnect Tabs
- Tabs Are Ultrasonically Welded to Tab Adapters
- Tab Adapters Are Bolted to Terminal Posts (To Be Converted to a Welded Joint)

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## Weight & Volume Analysis

- Design Can Be Improved in Highlighted Areas

<table>
<thead>
<tr>
<th></th>
<th>Weight %</th>
<th>Volume %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardware</td>
<td>30</td>
<td>10</td>
</tr>
<tr>
<td>Positive Electrodes</td>
<td>27</td>
<td>17</td>
</tr>
<tr>
<td>Negative Electrodes</td>
<td>21</td>
<td>16</td>
</tr>
<tr>
<td>Electrolyte</td>
<td>16</td>
<td>34</td>
</tr>
<tr>
<td>Misc.</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>Free Volume</td>
<td>0</td>
<td>11</td>
</tr>
<tr>
<td>Total Units</td>
<td>464 g</td>
<td>183 mL</td>
</tr>
</tbody>
</table>
Void & Electrolyte Volume Analysis

- Electrolyte & Free Volume Can Be Optimized For Performance

- Separator: 7%
- Positive Electrodes: 15%
- Free Volume: 23%
- Negative Electrodes: 23%
- Free Electrolyte: 32%
Stabilization Cycles

18 Cells Exhibited Excellent Consistency

- C/5, 100% DOD Between 4.1 and 3.0 Volts

Discharge Efficiency (%)
Capacity at Different Discharge Rates and Temperatures

- Cells Deliver > 10 Ah Between -10 °C & 40 °C

100% DOD Between 4.1 and 3.0 Volts

Discharge Rate (C)

Capacity (Ah)
Charge Efficiency

Data Indicates Excellent Performance up to \(-10\, ^\circ\text{C}\)

Charge @ C/10, Discharge @ C/2, 100% DOD Between 4.1 and 3.0 Volts

- Discharge Capacity
- Coulombic Efficiency
- Energy Efficiency

Number of Cells = 4

Discharge Efficiency (%) vs. Cycling Temperature (°C)

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Self Discharge

Less Than 8% Capacity Loss After 3 Months

Storage Even at 35°C

Calculated Activation Energy for the Self-Discharge

Reaction: $E_a = 4.85$ kcal/mol

Charge @ C/10, Discharge @ C/5
Pulse Testing

Data Exhibits High Stability and Acceptable End-of-Discharge Voltages

Red = 24 °C  Blue = -5 °C  Number of Cells = 4

<table>
<thead>
<tr>
<th>Voltage (V)</th>
<th>Partially Charged</th>
<th>Fully Charged</th>
</tr>
</thead>
<tbody>
<tr>
<td>1C, 15 min</td>
<td>3.5</td>
<td>3.7</td>
</tr>
<tr>
<td>2C, 5 min</td>
<td>3.0</td>
<td>3.4</td>
</tr>
<tr>
<td>3C, 60 s</td>
<td>2.5</td>
<td>2.9</td>
</tr>
<tr>
<td>4C, 1 s</td>
<td>2.0</td>
<td>2.4</td>
</tr>
</tbody>
</table>

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Vibration Testing

➢ Resonance Search
  • Acceleration Level of 1 g Peak
  • 5 - 2000 Hz, 4 Octaves/min.
  • Y = none; X = 1,717 Hz; Z = 1,479 Hz

➢ Sine Dwell
  • Acceleration Level of 12 g Peak @ 1/3 Fundamental Frequency for 3 min.
  • Tested With Cell Under C/2 Load

➢ Sine Sweep
  • 1.5 Octaves/min., 5 - 50 Hz, ±3 g max.
  • Tested With Cell Under C/2 Load

➢ Random
  • 14.1 g rms, 20 - 2000 Hz, 2 Minutes Each Axis
  • Tested With Cell Under C/2 Load
Vibration Testing

- Vibration Had No Effect on Load Voltage
- A Destructive Physical Analysis Revealed No Damage to the Electrode Stack or Tabs
LEO Cycling Data

- Technology Developments Continue to Improve Performance

40% DOD Between 4.1 & 3.0 Volts

End of Discharge Potential (V)

- 50 Ah (late 2000)
- 10 Ah (early 2000)
- 50 Ah Prototype (1999)

Cycle

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Safety Testing

Tests in Progress:

- Short Circuit
- Overcharge

(the data will be available prior to the meeting)
Conclusions

- MSA’s 10 Ah Li-Ion Cell Is a Rugged Design Suitable for the Stringent Requirements of Aerospace Applications

- 18 Cells Demonstrate Consistent Cycling Performance Over a Wide Range of Rates & Temperatures

- The Cell Passes Qualification Requirements for Vibration Survivability

- Technology Improvements at MSA Continue to Enhance Cell Performance

- (Based on Safety Test data)
Acknowledgements

- NASA/GSFC for Funding
- George Methlie for his technical advice and Encouragement