Super NiCd Open-Circuit Storage and Low Earth Orbit (LEO) Life Test Evaluation

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Jean Marie Baer, Warren C. Hwang and Valerie J. Ang
Energy Technology Department
The Aerospace Corporation

Jeff Hayden
Eagle-Picher Technologies, Colorado Springs

Gopalakrishna Rao
NASA Goddard Space Flight Center
Background

- Super NiCd cells studied as potential replacement for existing conventional NiCd designs in Air Force programs
  - Lack of Air Force test data on larger cell sizes
  - Handling and storage required active charging
- 50 Ah cells manufactured by Eagle-Picher/Colorado Springs
  - Advanced cell design with improved separator material and electrode making processes
  - Used in several NASA and commercial programs
    - Handling and storage required active charging
  - Three 5-cell packs on test with variations in temperature
    - Initial open-circuit periods to simulate worst case handling
    - Life tests follow characterization and charged
Background (Cont’d)

- open-circuit storage
- NASA funded testing at Crane/NSWC (as part of a joint NASA/Air Force program)

• Purpose of testing
  - To evaluate the impact of various periods of charged, open-circuit storage on the initial and cycle life performance
  - To evaluate the life capabilities for generic cell qualification in Air Force programs
Test Plan

- Initial characterization tests: $10^\circ$C, $20^\circ$C and $30^\circ$C capacity; $0^\circ$C overcharge; and $20^\circ$C impedance, charge retention, charge efficiency and 24 hour voltage recovery
- Charged, open-circuit storage tests:
  - Pack 1 (Lot 3) stored at 1, 2 and 3 months at $20^\circ$C
  - Pack 2 (Lot 3) stored at 1, 2 and 3 months at $0^\circ$C
  - Pack 3 (Lot 2) stored at 1, 2, 3 and 6 months at $0^\circ$C
  - $20^\circ$C and $0^\circ$C capacities measured prior to first storage period and after each storage period
- Post storage characterization tests (same as initial)
- Accelerated LEO life tests at 40% DoD
  - Pack 1 at $20^\circ$C
  - Packs 2 and 3 at $0^\circ$C
Initial Characterization Tests

- The average cell values - pre storage tests:
  (in Ah, unless otherwise noted)

<table>
<thead>
<tr>
<th></th>
<th>10°C</th>
<th>20°C</th>
<th>30°C</th>
<th>0°C Ovch.</th>
<th>20°C Imp.</th>
<th>20°C Ch Ret</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pack 1</td>
<td>55.6</td>
<td>52.5</td>
<td>52.3</td>
<td>57.7</td>
<td>52.0</td>
<td>91.2%</td>
</tr>
<tr>
<td>Pack 2</td>
<td>54.9</td>
<td>52.0</td>
<td>51.2</td>
<td>56.5</td>
<td>51.6</td>
<td>90.2%</td>
</tr>
<tr>
<td>Pack 3</td>
<td>48.3</td>
<td>49.1</td>
<td>49.7</td>
<td>48.2</td>
<td>49.2</td>
<td>88.2%</td>
</tr>
</tbody>
</table>
Open-Circuit Storage Tests

- Comparison of capacities after charged, open-circuit stand to their pre-30-day open-circuit values:
  - Pack 1 at 20°C: 80.7% after 30-day-period to 72.1% after 90-day-period
  - Pack 2 at 0°C: 88.9% after 30-day-period to 85.4% after 90-day-period
  - Pack 3 at 0°C: 85.6% after 30-day-period to 70.9% after 180-day-period
  - Ave capacity at 0°C: 87.3% after 30-day-period to 70.9% after 180-day-period
Open-Circuit Storage Tests

- Comparison of capacities after charged, open-circuit stand to their pre-30-day open-circuit values:
  - Pack 1 at 20°C: 80.7% after 30-day-period to 72.1% after 90-day period
  - Pack 2 at 0°C: 88.9% after 30-day-period to 85.4% after 90-day period
  - Pack 3 at 0°C: 85.6% after 30-day-period to 83.0% after 90-day period to 70.9% after 180-day period
  - Ave capacity at 0°C: 87.3% after 30-day-period to 84.2% after 90-day period to 70.9% after 180-day period
Capacitance after Charged, Open-Circuit Periods

- Capacitance, 20 Deg. C
- Aver Capacit, 0 Deg. C
Open-Circuit Storage Tests (Cont’d)

- 0°C and 20°C capacities post open-circuit storage:
  - There is generally a small decrease in capacities post 20°C open-circuit storage (Pack 1)
    - Within 3 Ahrs of pre-30-day storage values
  - Generally, there is a slight increase in capacities post 0°C open-circuit storage (Pack 2)
    - Within 1.5 Ahrs of pre-30-day storage values
  - There is a small increase in capacities post 0°C open-circuit storage (Pack 3)
    - Within 3 Ahrs of pre-30-day storage values
- Long term impacts need to be assessed
0°C and 20°C Pack Capacities

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Change in Post Storage Capacity at 0°C With Reference to Pre-30-Day Storage Capacities

Open-Circuit Time (Days)
Change in Post Storage Capacity at 20°C With Reference to Pre-30-Day Storage Capacities
Post Storage Characterization Tests

- The average cell values - post storage tests:
  (in Ah, unless otherwise noted)

<table>
<thead>
<tr>
<th></th>
<th>10°C</th>
<th>20°C</th>
<th>30°C</th>
<th>0°C Ovch.</th>
<th>20°C Imp.</th>
<th>20°C Ch Ret</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pack 1</td>
<td>51.1</td>
<td>51.6</td>
<td>52.3</td>
<td>50.1</td>
<td>51.3</td>
<td>88.8%</td>
</tr>
<tr>
<td>Pack 2</td>
<td>53.5</td>
<td>51.5</td>
<td>51.5</td>
<td>53.4</td>
<td>51.1</td>
<td>92.7%</td>
</tr>
<tr>
<td>Pack 3</td>
<td>51.6</td>
<td>51.4</td>
<td>51.9</td>
<td>50.9</td>
<td>51.1</td>
<td>89.6%</td>
</tr>
</tbody>
</table>
Post-Storage Accelerated LEO Life Tests

- For each of the three 5-cell packs, a life cycle simulates a 90-minute orbit
  - Discharge at 40 A for 0.5 hr, 40% DoD
  - Per initial test plan, failure defined as < 1.0 V/cell
  - Charge at a high-rate current of 40 A, followed by a taper charge for an hour of total duration.
  - Temperature-compensated V/T levels
- Pack 1 consists of five lot 3 cells
  - 20°C test started on 8/11/97
  - Initial V/T = 1.414 V/cell. Incrementally increased to current value of 1.454 V/cell during cycle 24088
  - Low EODVs
Post-Storage Accelerated LEO Life Tests (Cont’d)

- As of 2/8/02, 24900 cycles have been completed.
  - Average EOCV = 1.454 V
  - EOC cell voltage differential = 7.5 mV
  - C/D = 1.005
  - Average EODV = 1.050 V
  - EOD cell voltage differential = 19.2 mV
(Pre-life Storage @ 20°C: 1, 2, 3 Mos.)

Pack 1: Average Voltage and C/D
Pack 1: EOCV and EODV
(Pre-Life Storage @ 20°C: 1, 2, 3 Mos.)
Post-Storage Accelerated LEO Life Tests
(Cont’d)

- Pack 2 consists of five lot 3 cells
  - 0°C test started on 8/11/97
  - Initial V/T = 1.444 V/cell, which remains the current limit
  - As of 2/7/02, 24800 cycles have been completed.
    - Average EOCV = 1.443 V
    - EOC cell voltage differential = 2.0 mV
    - C/D = 1.003
    - Average EODV = 1.076 V
    - EOD cell voltage differential = 33.2 mV
(Pre-Lite Storage @ 0°C: 1, 2, 3 MOS.)

Pack 2: EOCV and EODV
Post-Storage Accelerated LEO Life Tests
(Cont’d)

- Pack 3 consists of five lot 2 cells
  - 0°C test started on 2/17/98
  - Initial V/T = 1.444 V/cell. Increased to present value of 1.450 V/cell during cycle 81
    - Recharge close to, but less than, 100%
  - As of 2/9/02, 21900 cycles have been completed.
    - Average EOCV = 1.449 V
    - EOC cell voltage differential = 3.2 mV
    - C/D = 1.002
    - Average EODV = 1.115 V
    - EOD cell voltage differential = 28.0 mV
(Pre-Life Storage @ 0°C: 1, 2, 3, 6 Mos.)

Pack 3: Average Voltage and C/D
Cycle No.

0.0000 0.0005 0.0010 0.0015 0.0020 0.0025 0.0030 0.0035 0.0040 0.0045 0.0050 0.0055 0.0060 0.0065 0.0070 0.0075 0.0080 0.0085 0.0090 0.0095 0.0100 0.0105 0.0110 0.0115 0.0120 0.0125 0.0130 0.0135 0.0140 0.0145 0.0150

C/D Ratio

0.00 0.05 0.10 0.15 0.20 0.25 0.30 0.35 0.40 0.45 0.50 0.55 0.60 0.65 0.70 0.75 0.80 0.85 0.90 0.95 1.00 1.05 1.10 1.15 1.20 1.25 1.30 1.35 1.40 1.45 1.50

Average Voltage (V)

(O) EOC Voltage • EOD Voltage • C/D Ratio

Pre-Lite Storage @ 0 Deg. C: 1, 2, 3, 5, 6 Mos.

Pack 3: Average Voltage and C/D
Cycle No.

0 4000 8000 12000 16000 20000 24000

Cell Voltage (V)

0 0.50 1.00 1.10 1.20 1.30 1.40 1.50

EODV

EOCV

(PRE-LIFE STORAGE @ 0 DEG. C: 1', 2', 3', 6 MOS)
PACK 3: EOCV AND EODV
Summary

- Cycle-life capability supports generic Air Force qualification
  - Conventional LEO mission goal up to 5-year duration
  - Conventional GEO mission goal up to 10-year duration
- Handling and storage may not require active charging
  - Cell manufacturer now provides option of up to 180 days of open-circuit storage with top-off charging every 14 days or less
  - Programs have more flexibility
- Launch site
  - Could eliminate requirement for continuous trickle charge
  - Can result in battery processing cost and time reduction