Long Term Performance Retention Test
Using High Power COTS NiCd and NiMH Cells

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by

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Presentation Objectives

• Introduction to Space-Flight High Power Applications

• Problem Description for Current Designs

• Test Plan for NiCd and NiMH

• Results and Analysis

• Conclusion
Introduction

• Space Flight electromechanical actuators will require short duration high power batteries

• X-38 Crew Return Vehicle electromechanical actuators
  • Qualified the first 270V, 5 Ah (8.4Ah Actual) NiCd battery module for single use application
  • Requires 41.5W/Cell @ 1.0V
  • NiCd and NiMH ~40-50Wh/kg for commercial SubC cells have demonstrated capability
  • Cell charging maintenance development is needed to meet the 3 year on-orbit CRV mission

• Orbital Space Plane OSP will also need to maintain battery performance readiness > 6 months requiring similar maintenance regime development
Problem Description for Current Designs

- NiCd designs demonstrate unfavorable power degradation after long periods of inactivity
  - Up to 35% and 45% reversible and irreversible capacity losses were experienced after 4 and 7 months of charged storage (monthly maintenance charge)
  - Up to 70 and 85 mV/cell of voltage depression (impedance growth) after 4 and 7 months (monthly maintenance charge)

- Although some of the decay is recoverable with cycling, this adds a heavy interface requirement thereby reducing battery readiness

- Charging development options are limited by contactor life (100,000 cycles) for X-38 270V Battery.
Test Plan Objective

- A 5-cell SubC stick test vehicle was chosen using NiCd (CP-2400SCR) vs NiMH (HR-SC2600) both by Sanyo

- Compare differences at different charge maintenance regimes for NiMH as an alternative to NiCd
  - Capacity to 1.0V
  - Voltage after 1.2Ah discharge
  - Resistance @ 100 ms
  - Available pulse power @ 1.0V

- Identify regimes that provide acceptable performance
## Continuous Charge Maintenance Test Plan

<table>
<thead>
<tr>
<th>Regime Type</th>
<th>Charge Method</th>
<th>Continuous Maintenance</th>
<th>Duration</th>
<th>Rest</th>
<th>Discharge</th>
<th>Pulse after 1.2Ah</th>
<th>Rest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily</td>
<td>@ 2.4A; Peak V-10 mV/cell (-5mV/cell for MH)</td>
<td>0.24A, 1 sec on, 10 sec off</td>
<td>Daily</td>
<td>1 hr</td>
<td>@ 3.5A to 1.0V</td>
<td>24A @ 0.1 sec / 2.4A @ 2 min</td>
<td>3 hr</td>
</tr>
<tr>
<td>Continuous Maintenance Groups (4)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weekly</td>
<td>@ 2.4A; Voltage Cutoff, -10 mV/cell (-5mV/cell for MH) less than peak</td>
<td>0.24A, 11 sec on, 10 sec off</td>
<td></td>
<td></td>
<td>@ 3.5A to 1.0V</td>
<td>24A @ 0.1 sec / 2.4A @ 2 min</td>
<td>3 hrs</td>
</tr>
<tr>
<td>Monthly</td>
<td></td>
<td></td>
<td>Week</td>
<td></td>
<td>Month</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 Month*</td>
<td></td>
<td></td>
<td>1 hr</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 Month*</td>
<td></td>
<td></td>
<td>3 Months</td>
<td></td>
<td>6 Months</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Note: Includes monthly check-out (0.5A for 3 min, 10A, 0.1 sec, recharge @ 2.4A to -dV)

- Discharge interval ladder with C/110 Charge
  - Daily cycle (Two 3-cell sticks)
  - Weekly, monthly, quarterly, semi-yearly cycle (4 groups; one 5-cell stick each)
Periodic Charge Maintenance Test Plan

<table>
<thead>
<tr>
<th>Regime Type</th>
<th>Charge Method</th>
<th>Rest</th>
<th>Topping Frequency</th>
<th>Discharge</th>
<th>Pulse after 1.2Ah</th>
<th>Rest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Periodic Charge Maintenance Groups (4)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No Topping</td>
<td>@ 2.4A; Voltage Cutoff, -10 mV/cell (-5mV/cell for MH) less than peak</td>
<td>1 month</td>
<td>None</td>
<td>@ 3.5A to 1.0V</td>
<td>24A @ 0.1 sec / 2.4A @ 2 min</td>
<td>3 hrs</td>
</tr>
<tr>
<td>Weekly Topping</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mid-month Topping</td>
<td>CC/CV @ 2.4A to 1.44V, 1.44V to 0.24A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant Voltage</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Intermittent maintenance interval ladder
  - None, weekly, mid-monthly maintenance groups (3 groups; one 5-cell stick each)
  - No maintenance with constant voltage charge @ 1.44V (1 group; one 5-cell stick)
Control for Continuous Charge Maintenance
Daily Charge, Capacity and On-Demand Power at 1.0V

Sanyo HR-SC 2400 NiCd Control

Sanyo HR-SC 2600 NiMH Control
Results of Control

- For capacity to 1.0V after 6 months of daily cycling NiMH is favored over NiCd

- For available pulse power at 1.0V after 6 months of daily cycling NiCd is favored over NiMH

- Rapid power fade with daily cycles for NiMH is attributed to increase of internal resistance
Continuous Charge Maintenance
Capacity and On-Demand Power at 1.0V

Sanyo CP-2400SCR NiCd Charged Maintenance

Sanyo HR-SC 2600 NiMH Charged Maintenance

--- weekly dsch Capacity
△ monthly dsch Capacity
◊ 3-mo dsch Capacity
● weekly dsch Power
△ monthly dsch Power
◊ 3-mo dsch Power
□ 6-mo dsch Capacity
□ 6-mo dsch Power
Results of Continuous Charge Maintenance

- For capacity to 1.0V after 6 months for all continuous maintenance groups NiMH is favored over NiCd

- Capacity and power trends after 6 months appear stable for both chemistries

- For available pulse power at 1.0V after 6 months of continuous maintenance NiMH is slightly favored over NiCd
Periodic Charge Maintenance
Capacity and On-Demand Power at 1.0V

Sanyo CP-2400SCR NiCd Periodic Maintenance

Sanyo HR-SC 2600 NiMH Charged Maintenance Tests

- weekly top chg Capacity
- no top chg Capacity
- Daily top chg Capacity
- semi-monthly top chg Capacity
- cc/cv, no top Capacity
- weekly top chg Power
- semi-monthly top chg Power
- Daily top chg Power
- cc/cv, no top chg Power
Results of Periodic Charge Maintenance

• For capacity to 1.0V and available power at 1.0V after 6 months, NiMH is strongly favored over NiCd
  
  – Capacity and power trends in all groups are decreasing for NiCd and stabilizing for NiMH
  
  – Power fade in periodic charge maintenance groups is predominantly attributed to decrease of capacity and voltage

• NiCd groups with no maintenance including the constant voltage charge failed to deliver 1.2 Ah after 4 months
Available Power and Capacity vs Regime
@ 6 months, Power at 1.0V/Cell

- NiMH Capacity
- NiCd Capacity
- X-38 Specification
- NiMH Power
- NiCd Power

<table>
<thead>
<tr>
<th>Available Power W @ 1.0 Volts</th>
<th>100</th>
<th>90</th>
<th>80</th>
<th>70</th>
<th>60</th>
<th>50</th>
<th>40</th>
<th>30</th>
<th>20</th>
<th>10</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity Ah to 1.0 Volts</td>
<td>3.0</td>
<td>2.5</td>
<td>2.0</td>
<td>1.5</td>
<td>1.0</td>
<td>0.5</td>
<td>0.0</td>
<td>1.0</td>
<td>1.5</td>
<td>2.0</td>
<td>2.5</td>
</tr>
</tbody>
</table>

- Daily Average
- Week
- Month
- 3 Mos.
- 6 Mos.
- Week Top Chrg
- Sem Mos. Chrg
- No Top Charge
- CC/CV with No Top Chrg

- Control
- Continuous Maintainance
- Monthly Maintainance
Conclusions

• Continuous Charge Maintenance @ C/110 after 6 months
  – For daily discharge intervals only NiCd delivered greater than 41.5W
  – For weekly monthly, quarterly and semiannual discharge intervals both NiMH and NiCd delivered greater than 41.5W
  – Continuous duty cycle regimes impractical due to contactor design

• Periodic Charge Maintenance after 6 months
  – Only the weekly topping for NiMH performed greater than 41.5W
  – All NiCd periodic groups failed to deliver needed power
  – No-topping group experienced one high impedance short in a NiCd 5-cell stick, raising concerns over charge regime stability
Acknowledgements

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