Effects of AEA Cell-Bypass-Switch Closure on Charged EOS-Aqua NiH₂ Cell

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Objectives

- Verify the Performance of AEA Cell Bypass Protection Device (CBPD) under simulated EOS- Aqua/Aura flight hardware configuration
- Assess the Safety of the hardware under an inadvertent firing of CBPD switch, as well as the closing of CBPD switch under simulated high cell impedance
- Confirm that the mode of operation of CBPD switch is the formation of a continuous low impedance path (a homogeneous low melting point alloy)
EOS-Aqua Flight Hardware

• Battery Cells:
  – Eagle-Picher 160 Ah NiH$_2$ (RNH 160-3)
  – Size:  ~ 12cm Diameter
     ~ 32cm overall Height
  – Weight:  ~ 4.3kg

• Cell-Bypass-Switch:
  – AEA Technology
    Cell Bypass Protection Device (CBPD)
AEA Hardware Tested

- A total of five (5) CBPDs were tested using the charged EOS Cell
  - Three FLIGHT devices
    (F01, F02 and F03)
  - Two ENGINEERING MODEL devices
    (EM01 & EM02)

- The two types of CBPDs are basically the same, with a change in separator and minor outer dimension changes
AEAA Bypass Switch Schematic

CBPD - LMPA Schematic
(Low Melting Point Alloy)

NOTE: Tested devices have 6 series diodes in charge path (not 4 as shown)
AEA Cell-Bypass-Switch Spec

CBPD - Specification

- 75 grams
- I charge < 35 A
- I discharge < 235 A
- Triggering - see operation summary
- R ~ 200 microOhms
- I operation < 400 A - dependent on leads and mounting

TRW spec for Aqua

90 grams
I charge ~ 75 A
R ~ 500 microOhms
Tests Performed

• Test#1: CBPD F01
  Activated with heatgun
  Switch-axis ~45° from Horizontal

• Tests #2 & 3: CBPD EM01 & EM02
  Activated through charge diodes
  Switch-axis Vertical

• Test#4: CBPD F02
  Activated through charge diodes
  Switch-axis Horizontal (launch orientation)

• Test#5: CBPD F03
  same as Test#4, with added 50 mΩ resistance in current path
Test #1 setup
(switch activated with heatgun)

R ≈ 0.08mΩ
(4.3 inches of #2 awg wire + terminals)

R ≈ 0.17mΩ
(11 inches of #2 awg wire + terminals)
Test #1 Scope Traces
Effects of AEA Cell-Bypass-Switch Closure on Charged EOS-Aqua NiH2 Cell

Test #1 Data

Oscilloscope Display

Cell current (35mS scan)

Cell current (1000mS scan) - Hi and Lo legs

Switch(+) temp

Switch(-) temp

Cell temps

ELAPSED TIME (SECONDS)
Test #2 thru 5 setup
(switch activated through diodes)

R ≈ 0.08mΩ*
(4.3 inches of #2 awg wire + terminals)

R ≈ 0.17mΩ
(11 inches of #2 awg wire + terminals)

*increased by 50mΩ for Test #5
Test #2

Engineering Model CBPD after test

CBPD opened after test.
Test #2 & 3 Scope Traces

Cell Voltage (0.5V/div)
- 2400A
- 1800A
- 1200A
- 600A
- 0A

Cell Current (600A/div)

Time (1ms/div)
Test #4

Charge diode string connection

CBPD in launch orientation.
Test #4  Scope Trace

Cell Voltage
(0.5V/div)

Cell Current
(600A/div)

Time (1ms/div)
Test #4 Data
Test #5

50 mΩ resistance added to positive current path
Test #5 Data (with added 50mΩ)
Scope traces for Tests #1 thru 4

Test #1 (F01)  Test #1 (F01)  Test #1 (F01)

Test #2 (EM01)  Test #3 (EM02)  Test #4 (F02)
## Test Summary

<table>
<thead>
<tr>
<th>Test #</th>
<th>CBPD #</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>F01</td>
<td>- Seven distinct current bursts were recorded&lt;br&gt;- Switch failed to provide continuous short even after heating to near 300°C&lt;br&gt;- It is expected that both charge and discharge switches were activated by the high temperature</td>
</tr>
<tr>
<td>2</td>
<td>EM01</td>
<td>- One distinct current burst was recorded&lt;br&gt;- Switch failed to provide continuous short</td>
</tr>
<tr>
<td>3</td>
<td>EM02</td>
<td>- One distinct current burst was recorded&lt;br&gt;- Switch failed to provide continuous short</td>
</tr>
<tr>
<td>4</td>
<td>F02</td>
<td>- One distinct current burst was recorded&lt;br&gt;- Switch temperature was maintained over three minutes past the event, and switch still failed to provide continuous short</td>
</tr>
<tr>
<td>5</td>
<td>F03</td>
<td>- With 50 milliohms added to the current path, switch closed as expected, and maintained low impedance after diode current was removed and switch cooled</td>
</tr>
</tbody>
</table>
Conclusions

- The nominal performance of AEA CBPD under simulated EOS-Aqua/Aura flight hardware configuration has been demonstrated.

- There is no evidence of cell rupture or excessive heat production during or after CBPD switch activation under simulated high cell impedance (open-circuit cell failure mode).

- Inadvertent CBPD switch activation with a charged cell (low impedance path) intermittently closes and opens up the switch, therefore the device may or may not provide protection against future open-circuit cell failure. Further testing with switches F01 and F02 may provide clarification.

- The formation of a continuous low impedance path (a homogeneous low melting point alloy), has been confirmed - which is the expected mode of operation.
Further Work

- DPA of F03 (the only device to operate and carry continuous current) is in progress to confirm the formation of a stable, low impedance path
- Retest of F01 and F02 using added 50mΩ resistance is planned, with DPAs to follow
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