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
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AEA Bypass Switch Schematic

CBPD - EMPA Schematic

(Low Melting Point Alloy)

NOTE: Tested devices have 6 series diodes in charge path (not 4 as shown)

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AEA Cell-Bypass-Switch Spec

TRW spec for Aqua

90 grams

$I_{charge} \sim 75A$

$R \sim 500 \text{ microOhms}$

CBPD - Specification

- 75 grams
- $I_{charge} < 35A$
- $I_{discharge} < 235A$
- Triggering - see operation summary
- $R \sim 200 \text{ microOhms}$
- $I_{operation} < 400A$ - dependent on leads and mounting
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)

\[ R \approx 0.08 \text{m}\Omega \]
(4.3 inches of #2 awg wire + terminals)

\[ R \approx 0.17 \text{m}\Omega \]
(11 inches of #2 awg wire + terminals)
Test #1

Heatgun repositioned for second application

First application of heatgun
Test #1  Scope Traces
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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 \approx 0.08\text{m} \Omega \star \\
(4.3 \text{ inches of #2 awg wire} \\
+ \text{terminals}) \\

\[ R \approx 0.17\text{m} \Omega \\
(11 \text{ inches of #2 awg wire} \\
+ \text{terminals}) \\

\star \text{increased by } 50\text{m} \Omega \text{ for Test #5} \]
Test #2

Engineering Model CBPD after test

CBPD opened after test.

CHARGE side

DISCHARGE side (not activated)
Test #2 & 3 Scope Traces

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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)
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Test #4 Data

Oscilloscope Display

Cell current (35mS scan)

Diode supply ON

Diode current (~12A)

Diode supply OFF

Diode current reduced to maintain switch temperature

Switch(+) temp

Switch(-) temp

Cell temps

ELAPSED TIME (SECONDS)
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 #2 (EM01)

Test #3 (EM02)

Test #4 (F02)
# Test Summary

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