Capacity Balance during Li-Ion Cell Life Testing

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Cell Balance during Lithium-Ion Battery Operation

• Cell state-of-charge imbalance can gradually accumulate due to differing self-discharge rates in cells
  – Results in cell voltage divergence
  – Can limit life if divergence becomes excessive

• Cell rebalancing electronics can compensate
  – Unless rate of divergence is too great
  – May depend on rebalancing electronics design

• Primarily a LEO issue
  – In GEO orbits there are substantial quiescent periods that allow rebalancing

• Matching of cell self-discharge rates should minimize divergence rates
  – If divergence rates correlate with BOL self-discharge rates
  – If self-discharge rates do not diverge significantly as cells age
Questions This Presentation Will Address

• Does cell voltage divergence during battery operation correlate with BOL cell self-discharge rates?

• Do cell self-discharge rates change as cells age during long term operation?

• How is cell divergence observed or controlled in different types of life tests?
  – Tests using individual cell control: imbalance compensated by each cell getting slightly differing Ah charge return as needed
  – Tests using pack level control: All cells get same Ah return, cell voltages diverge according to relative self-discharge losses

• What is the best way to run a life test?
Does Cycling Divergence Correlate with BOL Self-Discharge Rates?

Factors likely affecting divergence

- Self discharge
- Temperature variations
- Cell compression
- Case isolation
- Cell degradation

Answer: Yes, if cell self-discharge rates show sufficient variation

Good correlation between BOL self-discharge rate during charged stand and cycling divergence seen for packs that showed significant variation in cell self-discharge rates
Role of BOL Cell Matching

• Matching of BOL cell self-discharge rates can prevent rapid cell divergence during cycling

Typical statistics for self-discharge rates

• Matching cell self-discharge rates should be a key part of selecting cells

Standard deviation needed for desirable 10 mv/1,000 cycles divergence rate
Effects of Cell Age on Self-Discharge

- Aging tends to either not change relative self-discharge rate or cause differing self-discharge rates to converge.

Relative position of cells in group unchanged over nine years of LEO cycling

Relative position of cells in group has converged over nine years of HEO cycling
Cell Divergence in Pack-Level Life Tests

- Tends to increase during LEO cycling until rebalancing is performed
- Rebalancing should be often enough to keep cells reasonably matched
- If divergence is too rapid, rebalancing can become difficult

- Voltage divergence is typically nearly linear with time
- Indicates self-discharge rates do not change
Cell Divergence in Cell-Level Life Tests

- Ah return is sufficient to keep all cell charge voltages matched
- Cells with greater self-discharge get a higher Ah return
- Can be translated into voltage divergence rate, based on mv/Ah, if all cells received the same Ah return, as in pack level control

- Imbalance in Ah return indicates a pack that has more divergent cells
- Divergence is typically nearly linear with time, indicating a nearly constant self-discharge rate
Cell-Level Life Test Limitation for Divergence

• Typical accuracy of differential Ah return measurements is ±0.01%
• If cells all have similar self-discharge, the real differences in Ah return cannot be measured accurately enough to be meaningful

Difficult to detect differences in self-discharge of less than ~0.01 Ah/day from Ah return differences in cell-level life tests
**Merits of Pack-Level and Cell-Level Test Control**

- **Pack-level charge control is potentially more TLYF**
  - *Flight like thermal control, charge control, cell compression, and cell matching are required for Test as You Fly conditions*

- **Pack-level control does not allow individual cell capacity trends to be measured**
  - *Only the lowest cell capacity is measured by a full discharge*
  - *Capacity is influenced by time-varying cell voltage imbalance*

- **Cell-level control enables all cells procured to be tested**
  - *No extra cells needed for cell matching (significant cost savings)*
  - *All cells operated at more consistent charge voltages, allowing parametric degradation rates to be more easily trended*

- **Significant cell divergence rates can be detected from either type of test (voltage divergence or Ah return divergence)**
  - *Low cell divergence rates cannot be accurately measured in cell-level tests due to differential Ah return accuracy limitations*
Conclusions

• Cell matching based on BOL self-discharge rates can prevent significant cell divergence rates during operation

• As cells age in batteries, relative cell self-discharge rates tend to either remain similar to BOL, or converge

• Parametric life tests where limited test cell numbers are available should probably utilize cell-level charge control

• High-fidelity TLYF battery tests should utilize the same charge control approach planned for end-item battery operation

• High cell divergence rates that could threaten battery performance can be detected in either cell- or pack-level life tests

• Planned cell rebalancing protocol and capability defines how well cell self-discharge rates must be matched in a battery
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