Capacity Balance during Li-Ion Cell Life Testing

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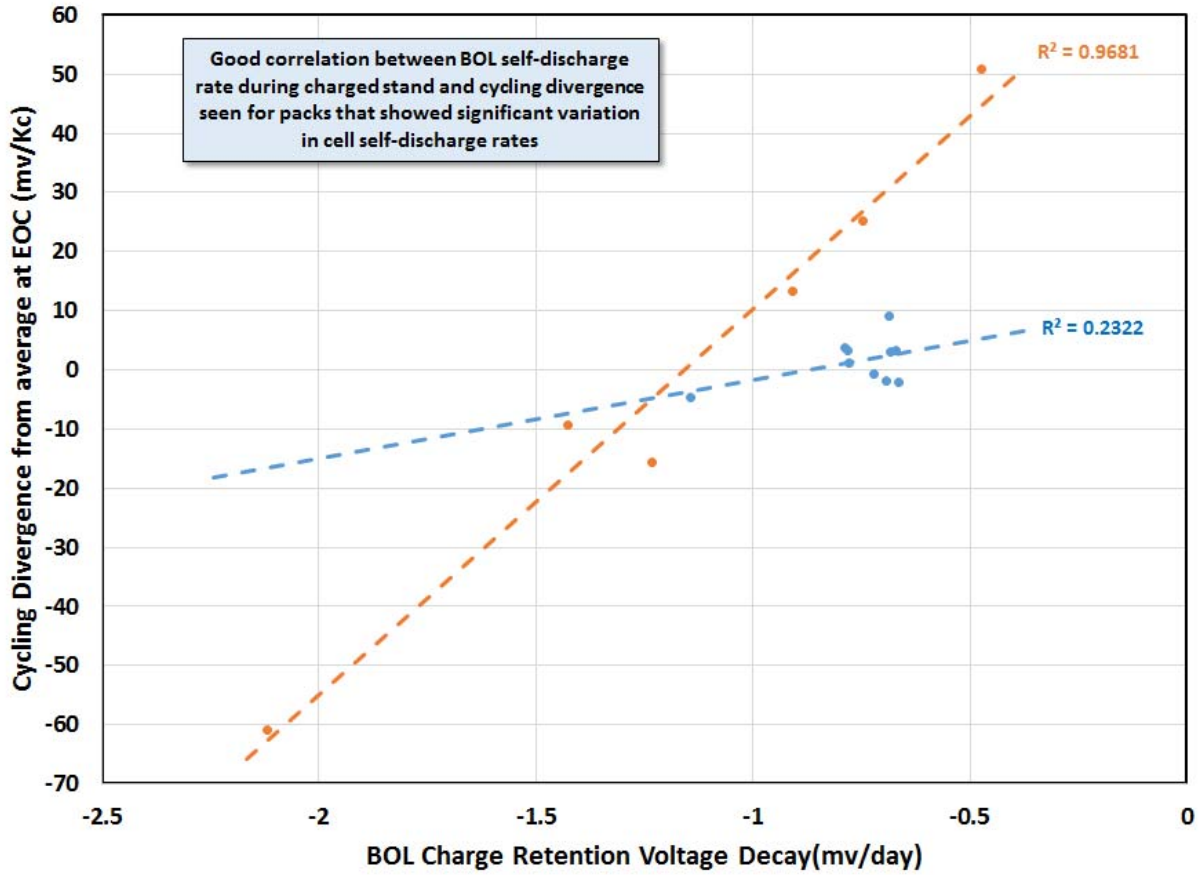
Cell Balance during Lithium-Ion Battery Operation

- **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

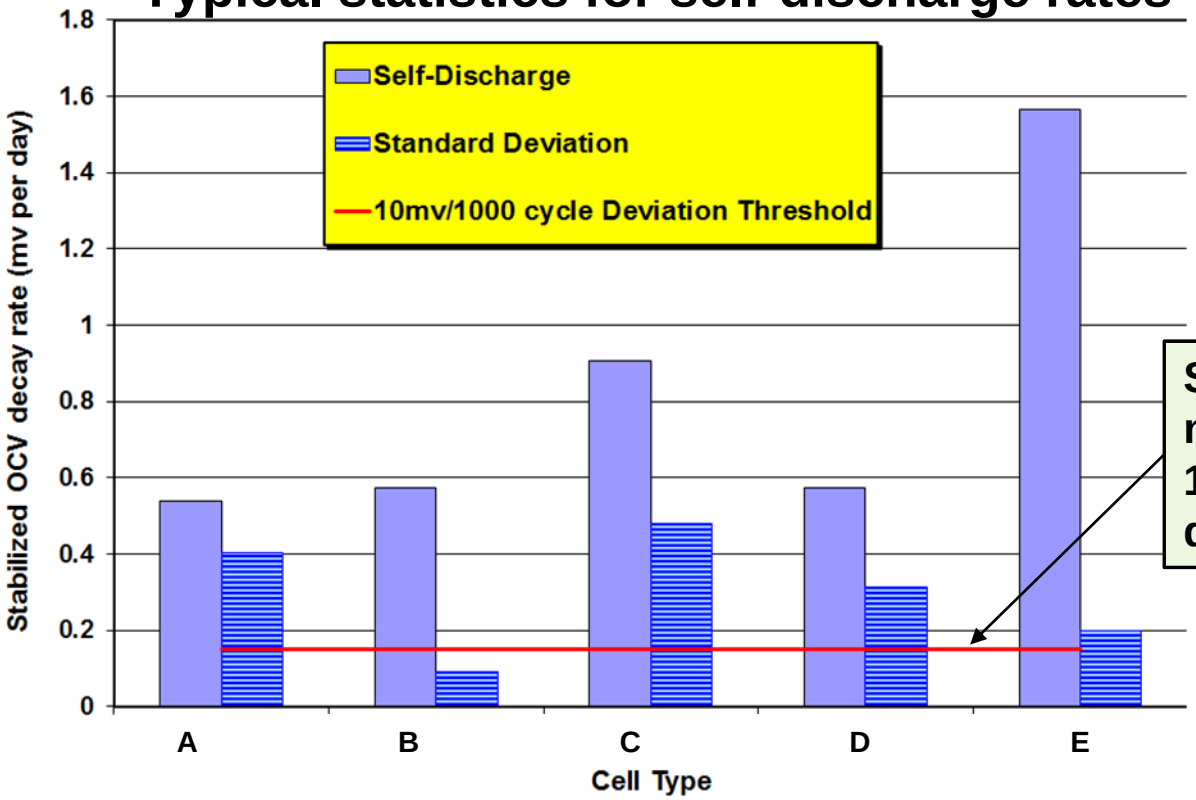
- ***Self discharge***
- ***Temperature variations***
- ***Cell compression***
- ***Case isolation***
- ***Cell degradation***

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

Role of BOL Cell Matching

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

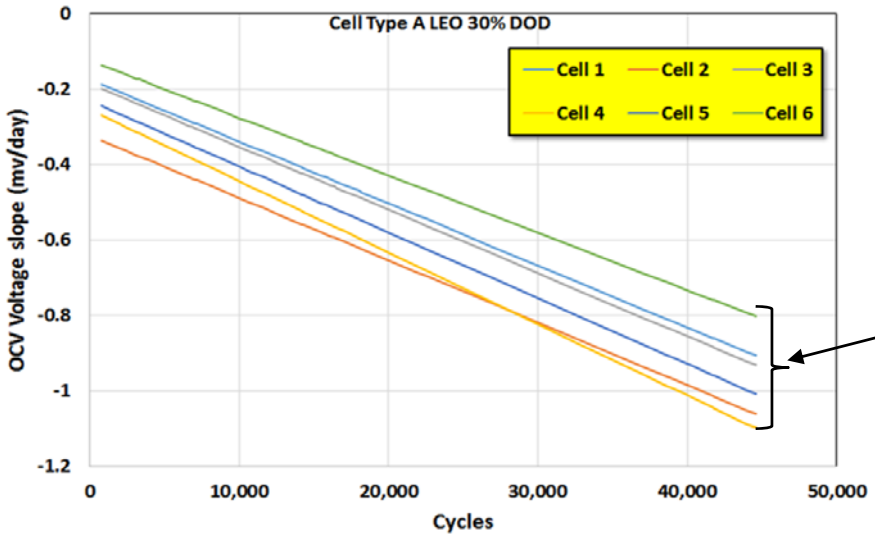
Typical statistics for self-discharge rates



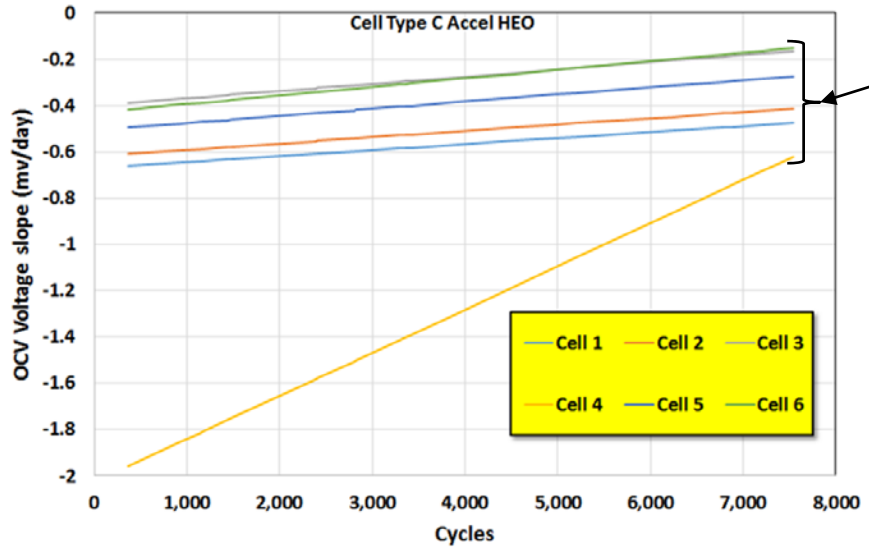
Standard deviation needed for desirable 10 mv/1,000 cycles divergence rate

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

Effects of Cell Age on Self-Discharge



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

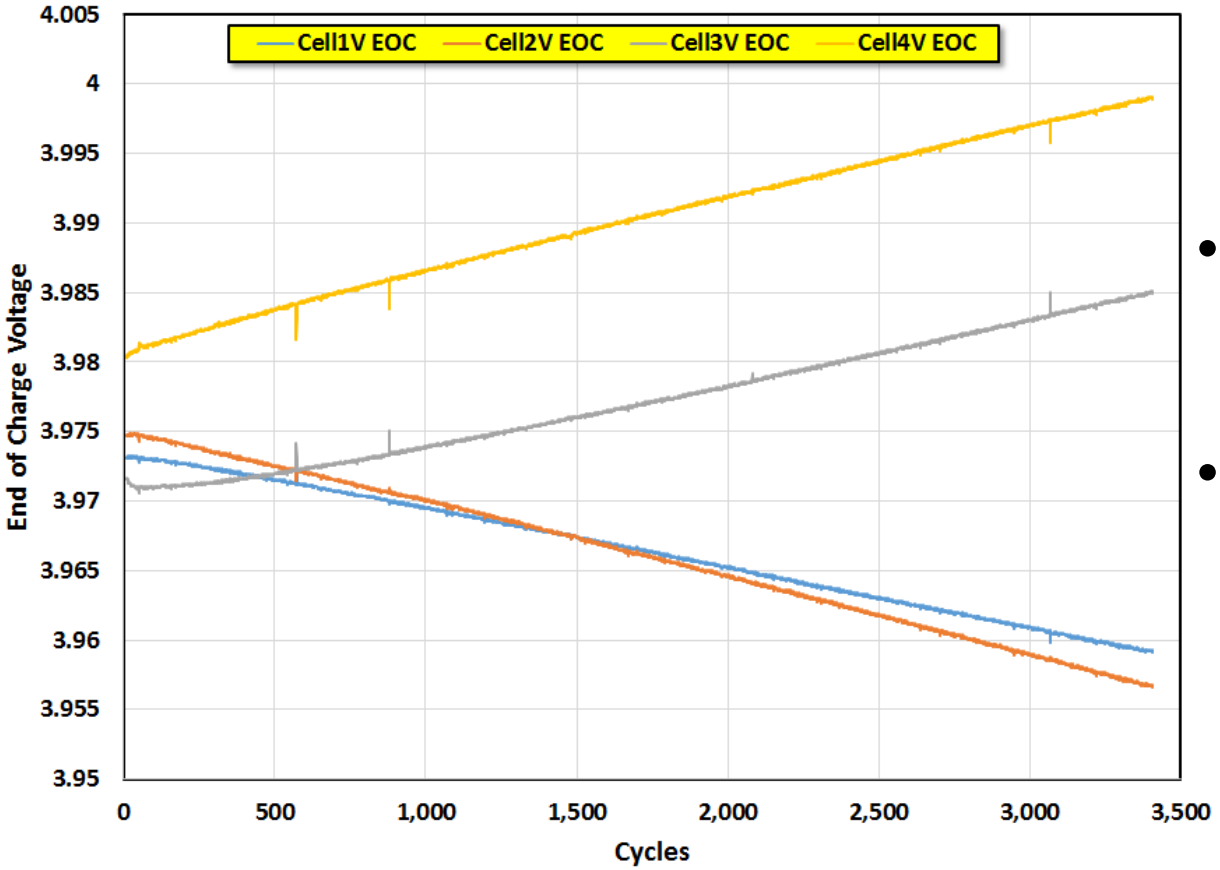


Relative position of cells in group has converged over nine years of HEO cycling

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

Cell Divergence in Pack-Level Life Tests

- Tends to increase during LEO cycling until rebalancing is performed

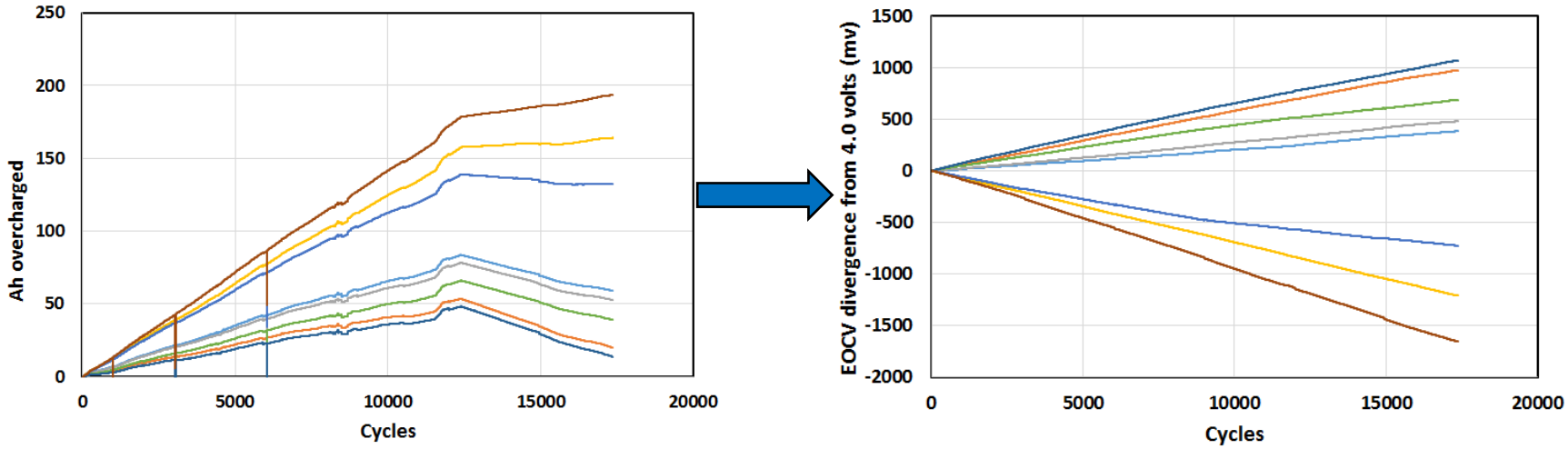


- Voltage divergence is typically nearly linear with time
- Indicates self-discharge rates do not change

- Rebalancing should be often enough to keep cells reasonably matched
- If divergence is too rapid, rebalancing can become difficult

Cell Divergence in Cell-Level Life Tests

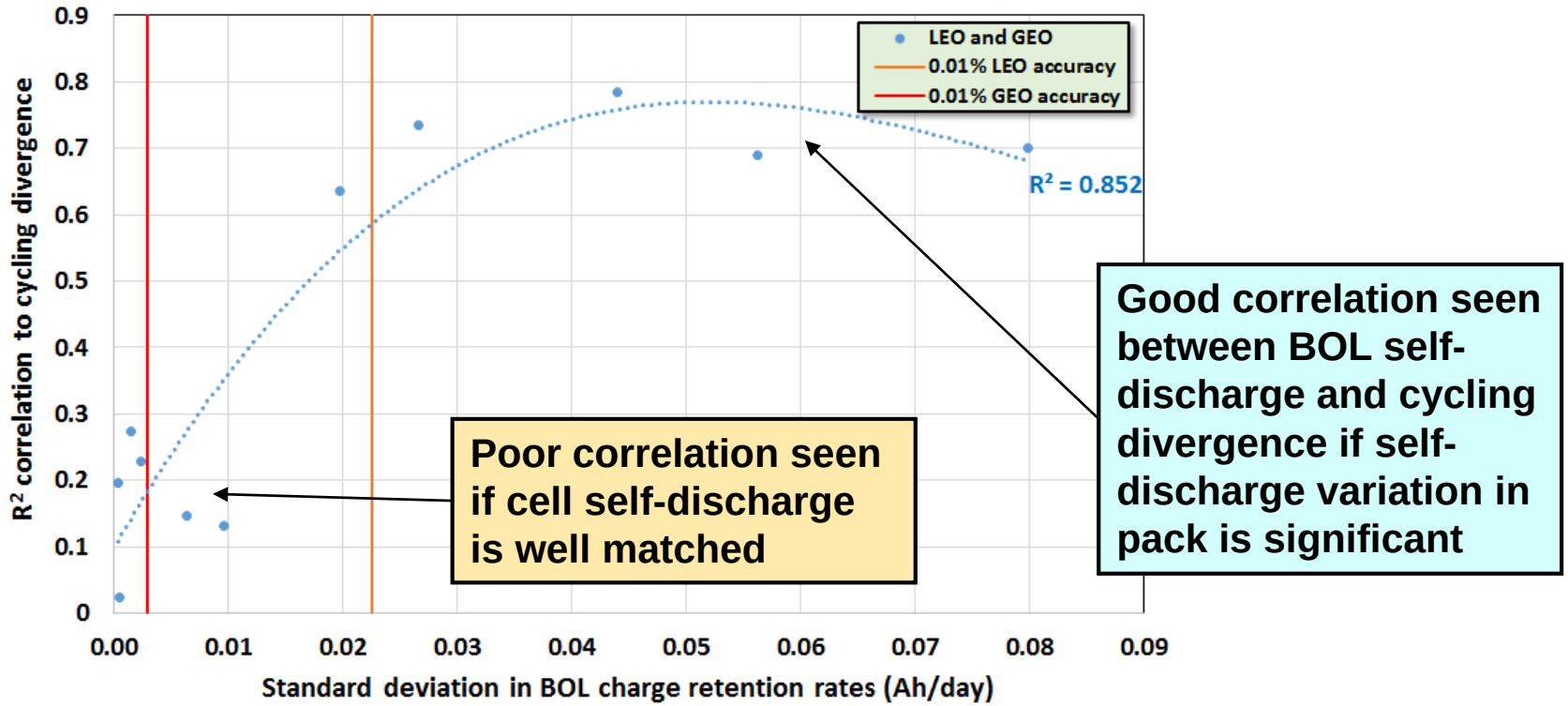
- Ah return is sufficient to keep all cell charge voltages matched
- Cells with greater self-discharge get a higher Ah return
- Can be translated into voltage divergence rate, based on mv/Ah, if all cells received the same Ah return, as in pack level control



- 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**

Acknowledgement

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