A Comparison of US and Chinese EV Battery Testing Protocols: Results

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A Comparison of US and Chinese Battery Testing Protocols

- Battery testing is a time-consuming and costly process
- There are parallel testing efforts, such as those in the US and China
- These efforts may be better leveraged through international collaboration
- The collaboration may establish standardized, accelerated testing procedures and will allow battery testing organizations to cooperate in the analysis of the resulting data
- In turn, the collaboration may accelerate electric vehicle development and deployment
- There are three steps in the collaborative effort
  - Collect and discuss battery test protocols from various organizations/countries
  - Conduct side-by-side tests using all protocols for a given application, such as an EV
  - Compare the results, noting similarities and differences between protocols and test sites

Battery Testing

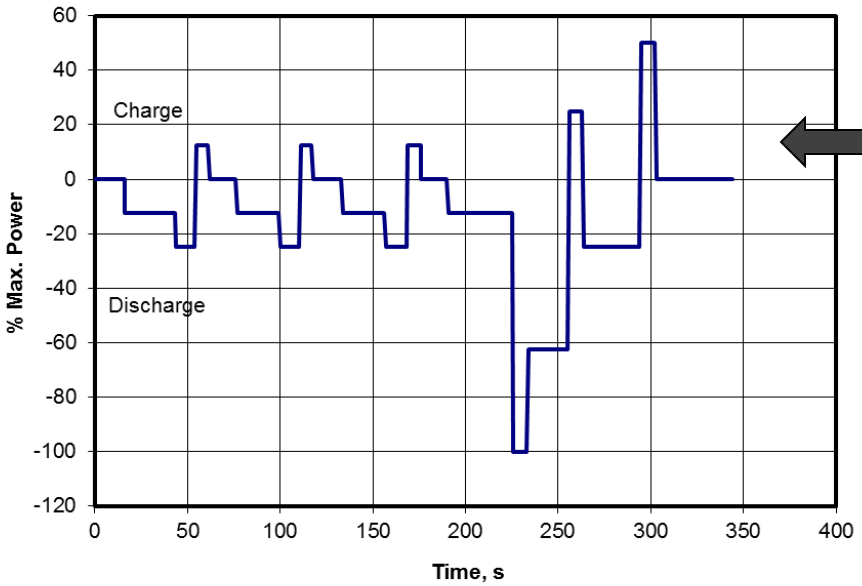
- Goal: Experimental comparison of the similarities and differences between the battery testing protocols used at the pre-competitive stage in the US and China
- The battery testing protocols from the US and China were collected and discussed
- Initial comparison of the collected protocols shows differences in testing assumptions, approach and philosophy
- Based on the genesis of the protocols, differences in the nature and level of stresses placed on the battery may be expected
- The test protocols, while similar in many respects, do have significant differences
- It is not known, therefore, how the results of the tests conducted with the two sets of protocols would compare with one another. For example, does one set of protocols stress the cell more than the other? Is the quality of the resulting data significantly different?

Battery Testing

- General testing philosophy
  - Obtain sufficient information in a limited amount of time to gauge the performance of a battery without exhausting it
  - The test procedures employ accelerated aging techniques
  - The test procedures used are applicable to cells, modules and complete battery systems
- Anatomy of battery testing
  - Characterize the performance of a battery
  - Age it under controlled conditions
  - Measure changes in performance by repeating portions of the characterization tests
    - A reference performance test

Conduct Side-by-Side Experiments

- A test plan based on an EV application was written and agreed to. Commercially-available batteries based on $LiFePO_4$ and carbon were procured. The batteries were distributed to participants. All participants will use both sets of test protocols on the batteries in common

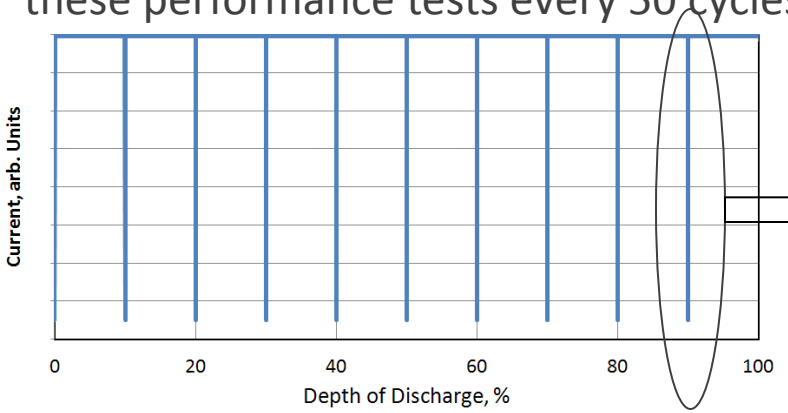


Dynamic Stress Test (DST) Profile

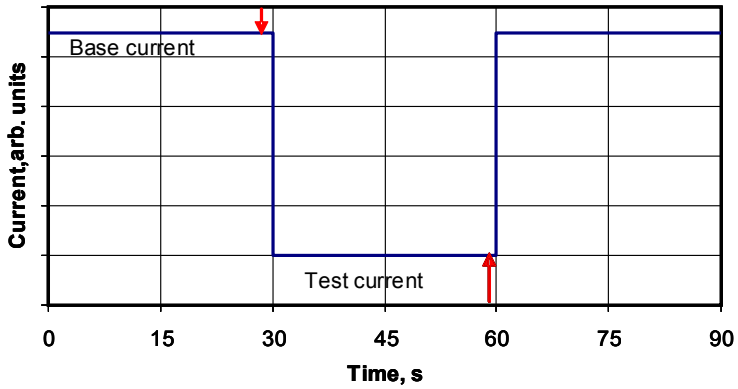
- The US cycle-life protocol consists of a dynamic, constant-power profile and constant-current charging
- The Chinese cycle-life protocol consists of constant-current discharges and charges (QC/T 743)
- Both cycle-life protocols terminate discharge at 80% DOD

Conduct Side-by-Side Experiments

- USABC Reference Performance Test consists of 2 capacity cycles, peak power pulse test at 10% DOD increments and full DST cycle. The cells are characterized using these performance tests every 50 cycles

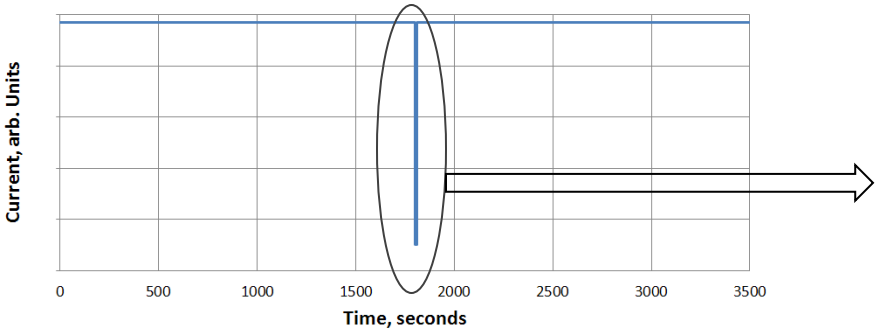


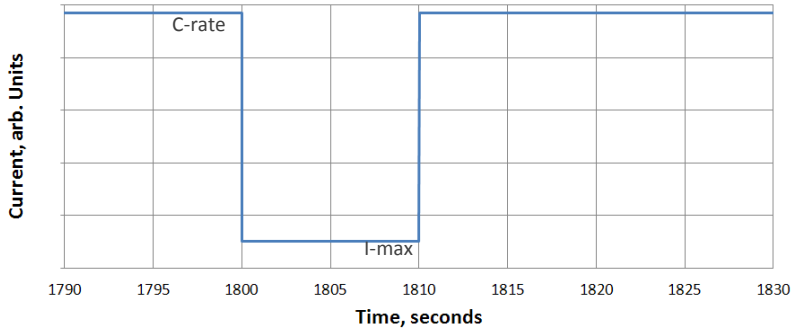
Peak power test



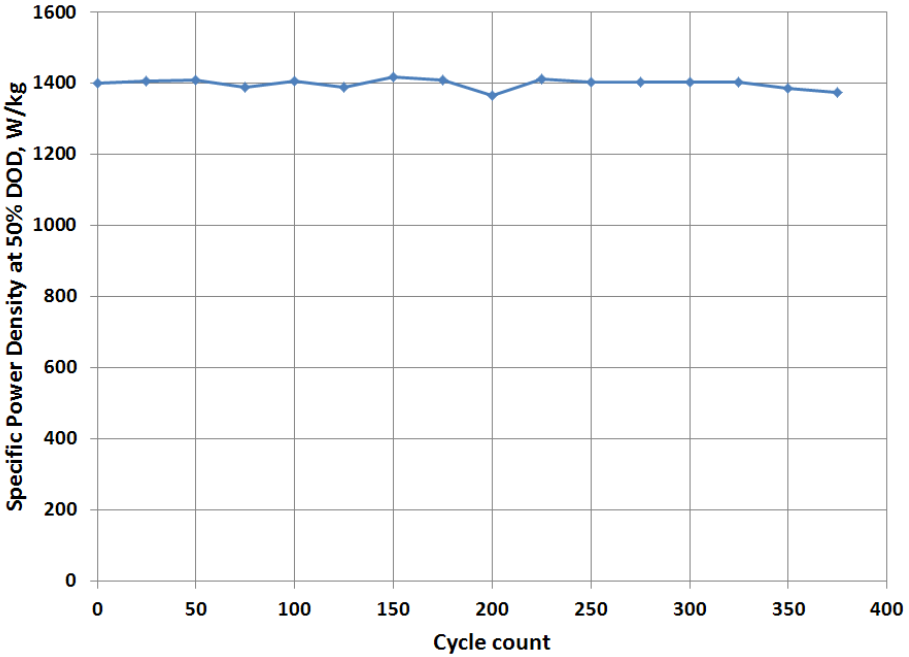
Peak power test profile (repeated at each DOD)

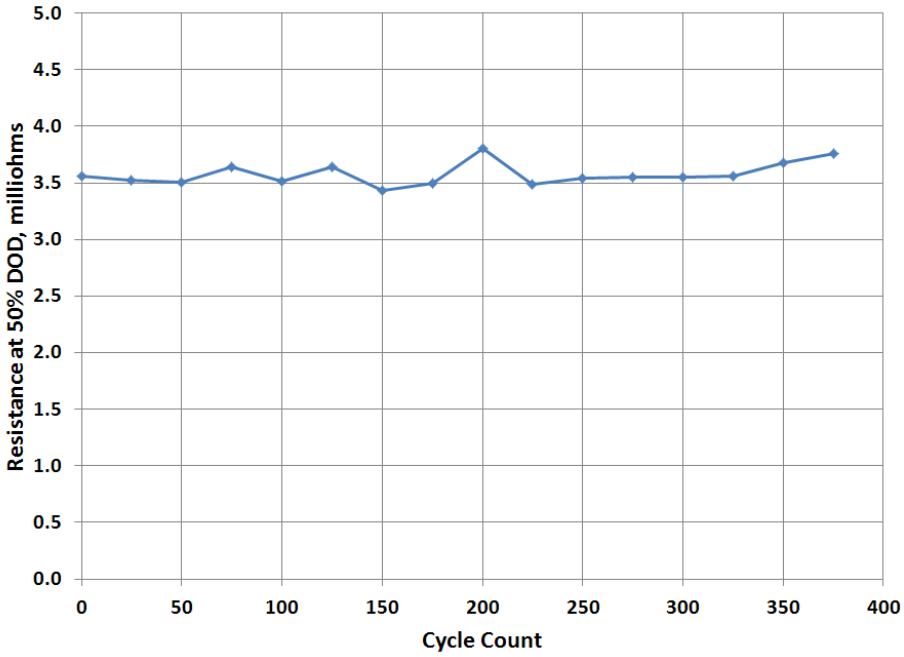
- China Reference Performance Test consists of 1 capacity cycle and 10 second discharge pulse at 50% DOD (per “863” test procedure). The cells are characterized using these performance tests every 25 cycles





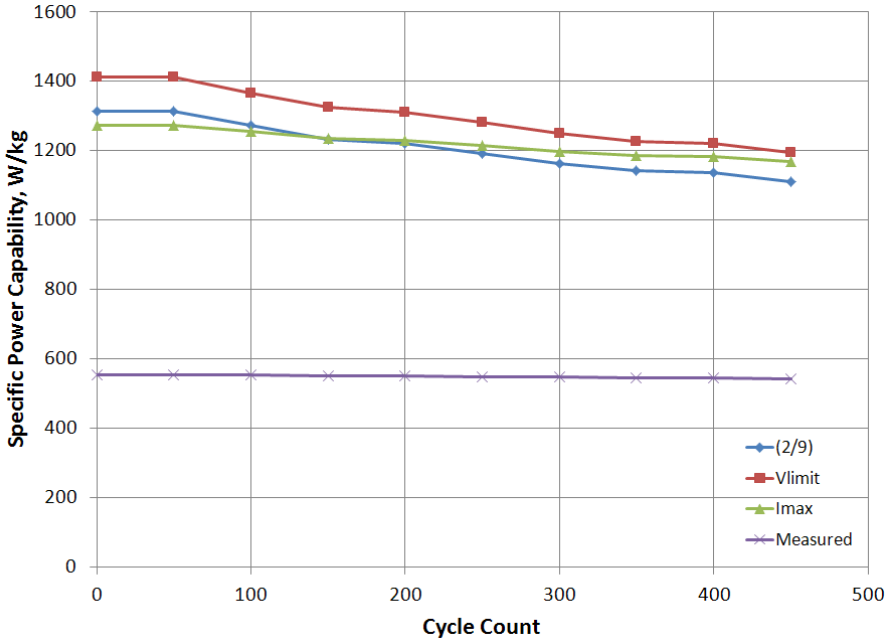
Chinese Protocol Results – Effects of Cycling on Resistance and Power

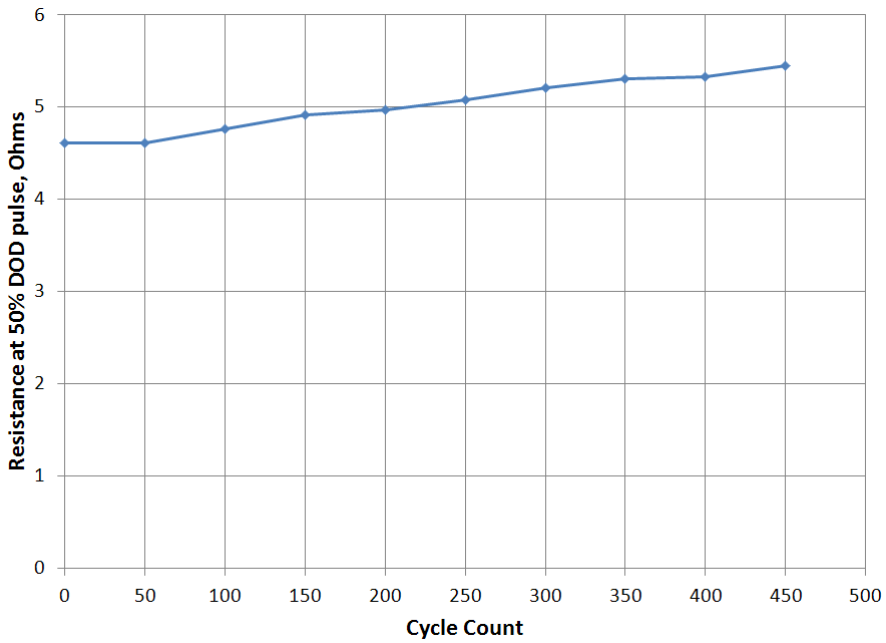




-The effect of the Chinese constant current cycles shows no significant aging or degradation in resistance and power capability.

USABC protocol results - Effects of Cycling on Resistance and Power at 50% DOD

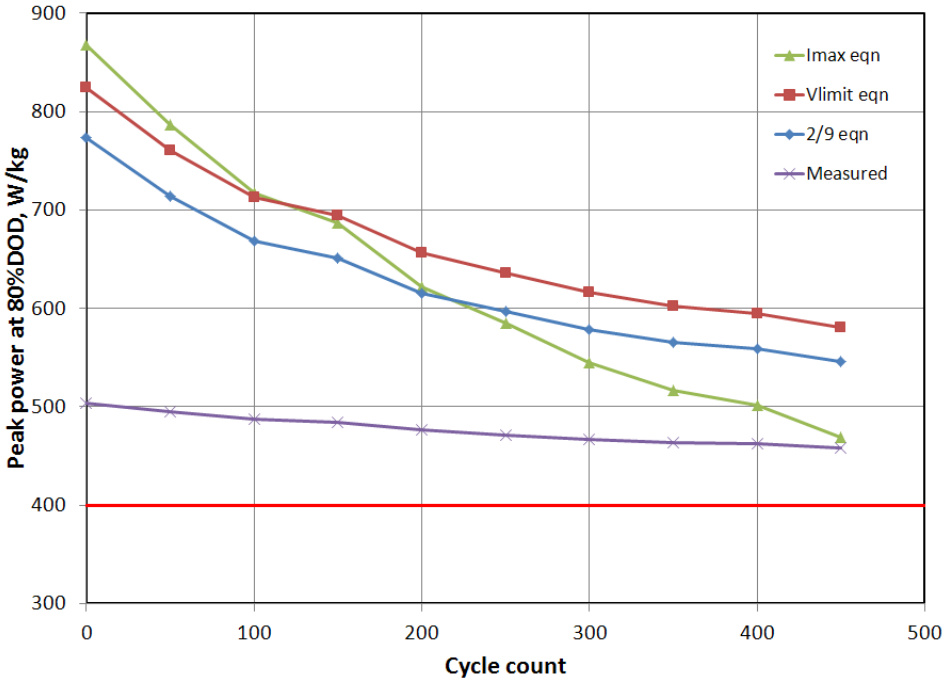


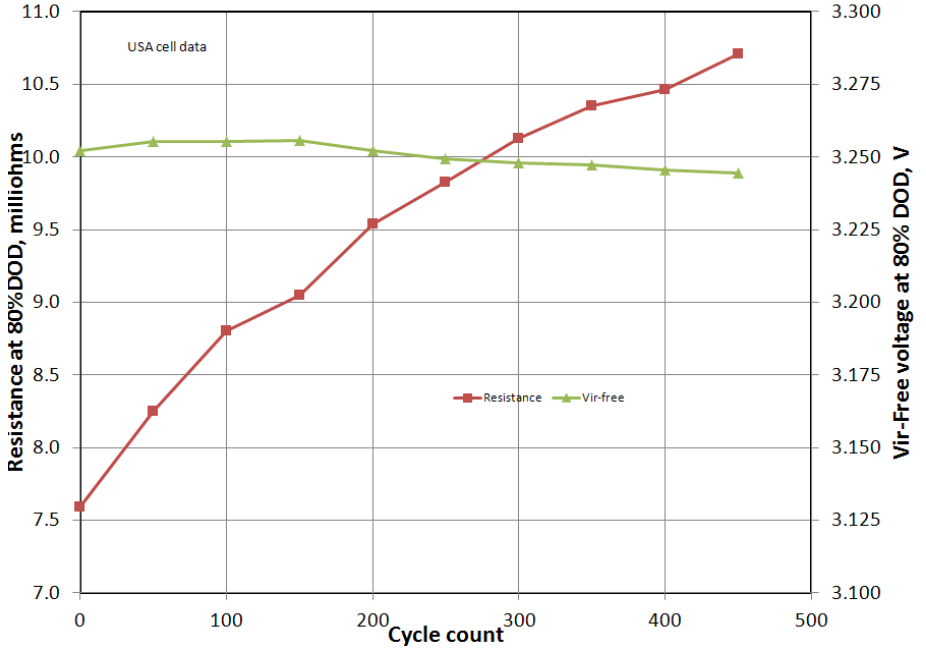


-The effect of USABC DST cycles shows a clear degradation and aging trend in resistance and power capability.

-Comparing the 50% DOD pulse show similar beginning of life capabilities for both test methods.

USABC protocol results - Effects of Cycling on Resistance and Power at 80% DOD





- USABC test method focuses on 80% DOD capability.
- 80% DOD is considered worst condition of EV operating range.
- Increase in resistance and decrease in power capability are more pronounced at this Depth of Discharge.

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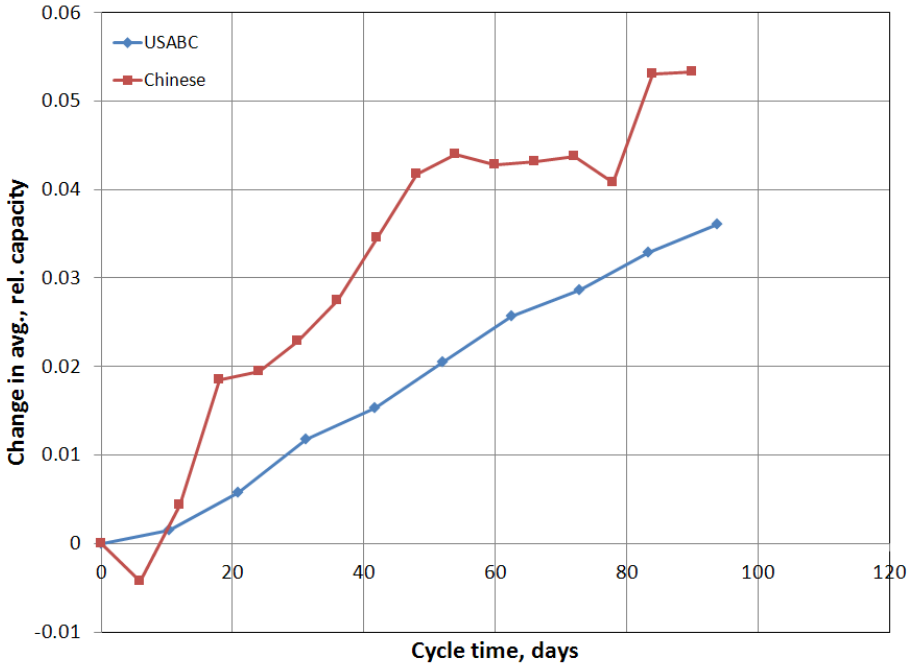
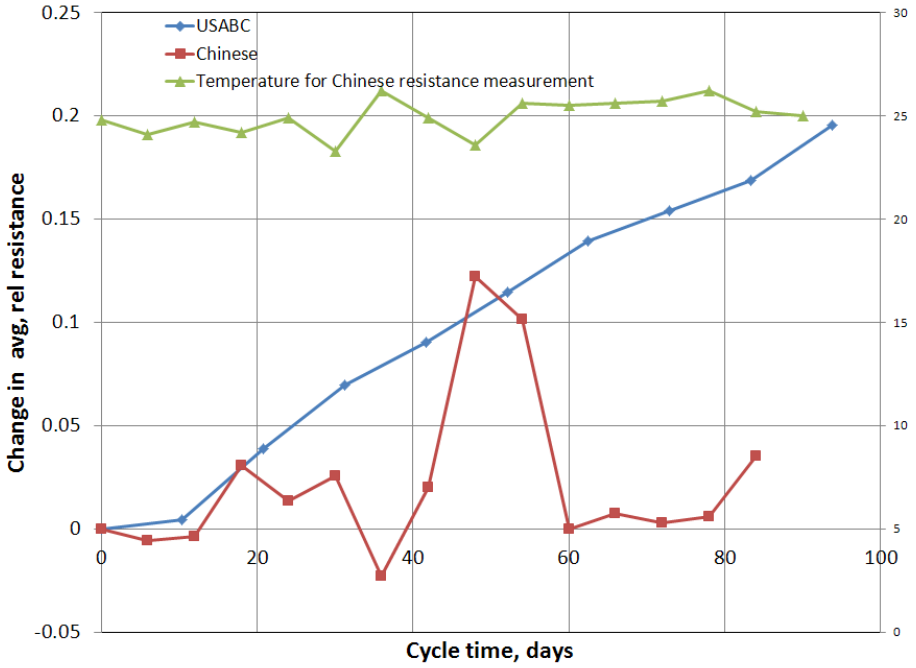
Normalized capacity and resistance trends





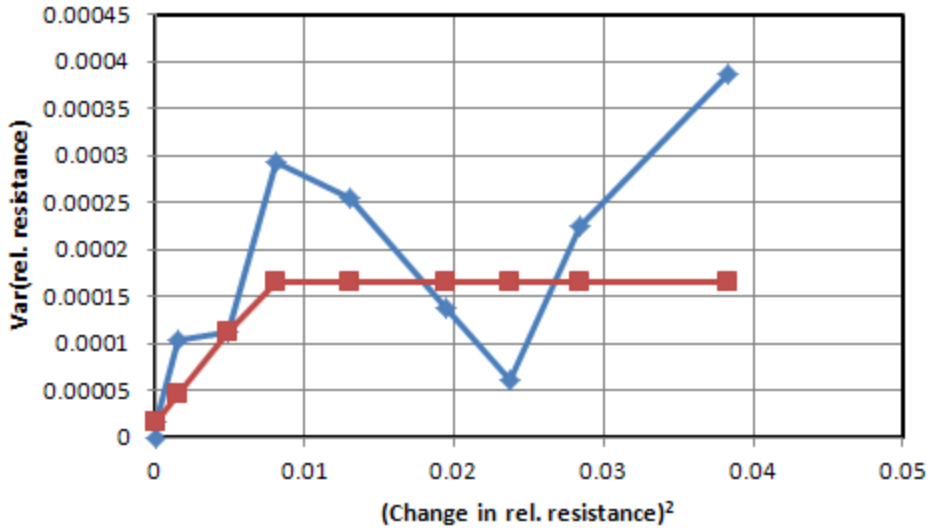
- Capacity degradation observed in both cycling methods.
- Resistance increase was more significant for USABC protocol.
- Temperature had a strong effect on noise of Chinese resistance.

Comparing the Results Shows…

	USABC	China
DOD (Energy) Window	0-80% DOD	0-80% DOD
Temperature	25 °C	25 °C
Capacity measurement rate	C/3	C/3
End of Test criteria	80% degradation	80% degradation
Cycle Type	Dynamic, Power based	Constant-current
Power Capability Measurement	Peak Power Pulse Estimation at 80% DOD	Pulse Power Density at 50% DOD
Pulse duration	30 seconds	10 seconds
Pulse Current	75A	225A
RPT Frequency	50 cycles (10.5 days)	24 cycles (6 days)
RMS power of cycle	50-51 W	12-13 W
RMS current of cycle	15-16 A	3.5-4 A
Average Voltage of cycle	3.17V fading over time	3.27V without fading
Energy throuput of cycle	27 Wh	19.5 Wh

- Results indicate that the USABC test protocol stresses the cells more than the Chinese test protocol when comparing 50% DOD performance.

Error Estimation – USABC Test Results



Cell to cell variation: 14.1%
Measurement error: 1.3%

- For cells tested using the USABC protocols, the existing error model form, $Var(Y) = f((Y\text{-}1)^2)$, seems plausible for response variable
- However, the precision associated with fitting this error model will necessarily be poor due to limited number of experimental conditions (and cells per condition)
- A non-linear model was used to estimate measurement error and cell-to-cell variation

$$Var(Y) = \begin{cases} {\sigma_\pi}^2 + {\sigma_\delta}^2\left\{\left(\overline{Y}-1\right)^2 - k\right\}, \left(\overline{Y}-1\right)^2 \le k \\ {\sigma_\pi}^2, \left(\overline{Y}-1\right)^2 > k \end{cases}$$

where ${\sigma_\pi}^2$ represents measurement error and ${\sigma_\delta}^2$ represents cell-to-cell variation

Summary

- Testing progressing smoothly
- Based on power and resistance, the results indicate that the USABC protocols stress the batteries more than those used in China. However, those batteries tested with the Chinese protocols show greater capacity loss than those tested with the USABC protocols. We are investigating possible causes

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