Effect of PHEV and EV Duty Cycles on Battery Performance

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1977 – Incorporation of Moli Energy Limited
- The name comes from Molybdenum and Lithium metal battery technology
- Founded by scientists from the University of British Columbia

1990 – Japanese Ownership (NEC & Others)
- Incorporation of Moli Energy (1990) Limited
- Began new R&D approach using lithium-ion
- First in North America to produce lithium-ion batteries (1995)
- First to commercialize a Manganese-Oxide lithium-ion battery (1996)

2000 - Merged with E-One Energy Technology Corporation
- New company name: E-One Moli Energy (Canada) Limited
- First to produce 2.4Ah, 18650 cell (2003)
- First to produce 2.0Ah, 10mm prismatic (2004)
- Cordless Tool battery, IMR26700 (2005)
Cylindrical Production (Moli Plant)

- Location: Maple Ridge, BC, Canada (Vancouver)
- Established: 1986
- Land: 450,000 ft²
- Building: 120,000 ft²
- Employees: 370
- Production Capacity:
  - Line 1: 26xxx/18650 - 1.2M/mo
  - Line 2: 18650 – 0.5M/mo
Duty Cycle Determination

- Development of power optimized cells for cordless tools showed the importance of application duty cycles on cell efficiency

- Cells generate heat via internal impedances and this is dependant on the RMS current, not just the average current
Duty Cycle Determination


- EV and PHEV duty cycles are even more complex incorporating charge steps as well as discharge steps

- This makes some method of describing duty cycles even more important as the mean current is 0 for charge neutral profiles
Duty Cycle Determination

- We define a unit-less quantity the Duty Cycle Eccentricity
  \[
  DCE = \frac{\sqrt{\bar{I}^2 - \bar{I}^2}}{\bar{I}}
  \]

- This ratio provides a simple method of describing the “peakiness” of the duty cycle current profile

- Still need to treat charge profiles and discharge profiles separately

- Coulombic efficiency can be obtained from mean current, \( \bar{I} \)

- Energy efficiency also depends on power dissipation, \( I_{\text{RMS}} = \sqrt{\bar{I}^2} \)
Duty Cycle Determination

- A couple of simple examples
Definition of Efficiency

- **Coulombic Efficiency**

\[
E = \frac{\text{amp} \cdot \text{hours (Discharge)}}{\text{amp} \cdot \text{hours (Charge)}} \times 100\%
\]

- Dependent on side reactions that can run parasitic currents

- **Energy Efficiency**

\[
E = \frac{\text{watt} \cdot \text{hours (Discharge)}}{\text{watt} \cdot \text{hours (Charge)}} \times 100\%
\]

- Dependent on coulombic efficiency plus internal impedances that vary due to over-potentials and concentration gradients
• First need to define a fully charged reference state where
coulombic efficiency is still close to 100%

• Constant current cycle at C/10 so we can neglect concentration
gradients and electrode over-potentials

• Can see the effect of side reactions as the NiCd cell charges
NiMH – Coulombic Efficiency

- Similar story with NiMH
• Li-Ion cell uses constant voltage charging, usually to 4.2V

• Insignificant side reactions until approximately 4.7V where electrolyte decomposition starts to occur
Discharge Energy Efficiency

- We measure energy efficiency as a function of discharge duty cycle for a round trip of 10% of state of charge.
  - Performed at maximum charge state as previously defined
  - All profiles have $I = 3.3C$
- Clearly see the effect of peaky duty cycles
Discharge Energy Efficiency

- For higher current pulses, 2 series packs were used for the lower voltage chemistries.
  - Test equipment limitation
- Li-Ion and NiCd are very similar, and both are a slight improvement on the NiMH for very high current pulses
We also measure the energy efficiency as a function of charge duty cycle, for a round trip of 10% SOC.

- Performed at maximum discharge state of 2.5V for Li-Ion and 0.9V for NiCd and NiMH.
- Li-Ion clearly shows increased efficiency, likely due to the high charge voltages initiating side reactions in the NiCd and NiMH cells.
• Accelerating Rate Calorimetry (ARC) during a 20A (6.7C) discharge indicates initial rapid heating which we attribute to the formation of concentration gradients.
• Further into the discharge, cell heating reduces the overall impedance slightly.
• Entropic effects are seen at the end of discharge.
Summary

• The application duty cycle plays an very important role in determining the energy efficiency of a cell

• The duty cycle needs to be known in advance in order to properly compare the efficiency of different chemistries and future designs, since approximation by constant current methods is insufficient

• The E-One Moli IMR-26700 cell indicates excellent viability for use in applications requiring high efficiency such as HEV, PHEV, and grid load levelling

• Cell efficiency during short duration pulses like HEV and PHEV duty cycles is compromised by rapid initial heating that we attribute to concentration gradients. Reducing these gradients will be a good avenue for design improvements