A Precision Contact Stress Sensor for Monitoring Swelling in Li-Ion Cells

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James Kaschmitter
james.kasch@gmail.com
(925) 570-7251

MicroMetrics, Inc.
Livermore, CA
Introduction to MicroMetrics’ CSS

- MicroMetrics (MMI) Contact Stress Sensors (CSS) provide precision, repeatable measurement of contact stress between two surfaces
  - A CSS is not a “pressure sensor” which measures gaseous or fluid pressure, and which are commonly available

- MicroMetrics CSS unparalleled attributes include:
  - Ultra-thin form factor (≤150μm or 0.006”)
  - Holds factory calibration over life of the sensor so it can be permanently embedded in products
  - Can also measure temperature, replacing thermistors or thermocouples
  - Utilizes inexpensive MEMS (Micro-Electro-Mechanical Systems) chip technology mounted on commercially available flex cabling

- These attributes make it ideal for use in cells and/or battery packs:
  - Laboratory measurements of swelling in developmental Li-ion cells/packs
  - Embedded in production battery packs for life of the system for monitoring performance and early warning of cell or pack problems
• MicroMetrics is an affiliate company of SpectraPower in Livermore, CA which performed the sensor/battery integration and testing: www.spectrapowerllc.com

• SpectraPower’s battery lab performs contract R&D, cell and electrode builds, and consulting for major companies, government agencies, startups, etc.

SpectraPower's capabilities for battery and supercapacitor development includes complete cell fabrication and test:
1) Powder preparation and slurry mixing
2) Electrode coating, drying and calendaring
3) Electrode prep and tabbing with ultrasonic welding
4) Cell assembly and electrolyte fill
5) Cell packaging and sealing
6) Formation, performance and cycle life testing
7) Environmental and safety testing

SpectraPower’s team has unique experience in high volume commercial manufacturing of all major form factors:
Sensor Specifications

• Accuracy: ±3% over the calibrated range (0 to 250psi)
  • Maximum pressure: >1000 PSI
• Ultra-thin (≈150 microns)
• Holds factory calibration over life of the sensor and temperature range
  • Design life: 30 years
• Standard Calibration temperature range: -40°C to +70°C
• Maximum operating temperature range: -40°C to +125°C
• Maximum operating frequency:
  • ≥500 kHz (Sensor Only)
  • 1 kHz (Sensor Development Kits)
• Dynamic response ≥500 kHz
• Cycle life >10,000 full load cycles
• Low-cost MEMS technology
• Can be supplied in custom arrays

Flex Cable Interconnect

CSS: Silicon MEMS Chip
CSS Holds Calibration over Cycling

Output Voltage for Pad-On-Chip Sensor
10 Load Cycles from 5-250psi (Input Voltage = 12V DC)
Monitoring Swelling in Li-Ion Cells

~5Ah Si Anode Li-Ion Cell
(note apparent swelling)

Test Fixture w/CSS inserted between cell and clamping plates
Test Results: Swelling in Li_Ion Cells

- CSS monitoring swelling in a ~5Ahr pouch cell with Si anode
- Cycling at C/5
- Simultaneous monitoring of cell voltage
- Small variations are due to day/night temperature fluctuations
- ~10% increase in swelling pressure over 30 cycles
- Data shown is as-displayed by MicroMetrics-provided software
Measuring Cell Deflection with the CSS

• It is possible to obtain a measurement of the physical deflection of the side of a cell by using Hooke’s law (the deformation of an elastic object is proportional to the stress applied to it) with pressure data collected from the CSS:
  • \( P = kY \), where \( P \) = pressure, \( k \) = spring constant, \( Y \) = displacement
• The following test setup was implemented to perform the test:
  • Two similar pouch cells with silicon anodes were tested independently during charge-discharge cycling:
    • First cell had an array of 6 contact stress sensors (CSS)
    • Second cell had 3 mechanical deflection probes
    • The cell with the CSS was inserted between metal plates with “finger-tight” clamping pressure to provide uniform pressure
    • The cell with the mechanical deflection probes was not clamped, the probes were positioned against the top of a metal cover plate that was allowed to move freely on top of the cell
• Both cells were cycled while taking measurements once per minute
• Tests were performed at Zeptor, Inc., Sunnyvale, CA, using Zeptor pouch cells
Pressure Measurement with CSS

Change in Pressure during One Cycle
Red and Blue are sensors on yellow tape

“MMI Cell with 6 CSS in an array
Note: yellow tape over tabs created a high spot

Unexpected result – right side of cell swells more than left side
Measurement of cell displacement using three mechanical probes
Green front measurement was used for comparative analysis
Pressure Change vs. Cell Deflection

Sensors on raised yellow tape showed higher spring constant “A”

\[ \Delta P = A \Delta L \]
Average value for A (71.2) was used for comparison.

\[ \Delta L = \Delta P / A \]

Data from MMI sensors (MMI cell)  \[ A = 71.2 \]

Data from deflection probes (Zeptor cell)

Zeptor cell has lower capacity
Qualitative Comparison

Average from deflection probes on Zeptor cell
Pressure can be Correlated to Deflection

- Pressure during cycle
- Average from deflection probes on Zeptor cell
- PI tape on steel clamping plate created area with highly compressed foam.
Conclusions

• Deflection results obtained by measuring pressure on a cell with MMI contact stress sensors agrees well with measurements taken using deflection probes

• Swelling pattern measured by 6 MMI sensors correlates well with theoretical understanding of processes during cell charge/discharge (silicon anode swelling)

• More accurate results on deflection can be obtained with MMI sensors using interface materials with known and more linear stress/strain mechanical behavior

• MMI can supply custom sensor arrays designed to fit customer-specified cells
CSS Application in Battery Packs

Contact Stress Sensor

- Mounting a thin CSS between cells provides detection of swelling due to internal gas generation

- Gas generation in pouch cells is an indication of potential cell failure due to internal parasitic reactions
  - Poor quality leading to cell failure
  - Potential safety event

- The CSS can double as a temperature sensor, minimizing cost, while monitoring both swelling and temperature
Application in Li-Ion Battery Packs

• One or more CSS sensors can be applied individually, or in arrays on the outside of pouch or prismatic cells to monitor swelling and temperature
• Signals from each CSS can be multiplexed to reduce wiring
CSS Eval Kits: Instrument for R&D

- MMI’s standard kits include everything necessary for R&D and Product Development:
  - Contact Stress Sensor(s)
  - Cabling
  - Smart Interface with USB to computer
  - Software for monitoring and recording CSS output
- “Sync” input allows simultaneous monitoring of battery voltage
- Up to 16 sensors per Smart Interface
MicroMetrics’ CSS provides a simple and inexpensive means of monitoring battery and cell swelling

- Ultra-thin form factor is non-intrusive
- Long cycle life means it can be permanently installed in products
- MicroMetrics’ CSS kits make the sensor easy to evaluate and use

Custom designs are available for NRE charge

A broad range of markets and applications insures continued support and product improvements

Contact:
James Kaschmitter
james.kasch@micrometricsinc.com
(925) 570-7251