Keysight Technologies
Battery Temperature Profiling While Charging and Discharging
Why is Temperature Profiling of Batteries Important?

Charge and discharge currents increase the temperature of batteries and temperature directly affects the lifespan and storage capacity of batteries. Batteries tend to be efficient and provide a normal life span at room temperatures. When batteries are subjected to cold temperatures, their capacity is greatly reduced and as temperatures increase above room temperature, their life span is reduced. At extreme temperatures, batteries can break down in several stages: leakage, smoke, fire and explosion.

Manufacturers often perform abuse tests to determine the temperatures for each of the stages of breakdown. When batteries fail spectacularly with smoke and fire it is typically due to a short causing a rapid discharge and greatly increased heat. So newer batteries have an extra protection that acts as a fuse to avoid an external short circuit.

Lithium-ion (Li-ion) chemistry is very popular as they can hold a lot of energy in a small package and be quickly charged and discharged compared to other chemistries. Lithium-ion battery cells come in standard or custom configurations. Standard configurations are cylindrical with standard diameters and lengths. Custom configurations are designed to fit into compact devices such as mobile phones and tablets. Here are some examples of Li-ion configurations:

- 1 serial cell by 1 parallel cell (1s X 1p) for mostly mobile devices
- 1s X 2p, 1s X 3p for tablet devices
- 2s X 2p, 2s X 3p for notebooks or laptops
- Multiple serial by multiple parallel for driving electric motors, power tools, lighting, electric vehicles, hybrid electric vehicles, and so on

Flat multi-cell Li-ion battery pack for laptops

Li-ion battery pack for power tools

Standard 18650 single cell Li-ion used in battery packs.
The bump at the end of the teal battery provides added electrical protection against rapid current draw.

Flat single cell Li-ion battery for mobile phones
Temperature Profiling Setup for Battery Charging

**Instrument 1: A DAQ instrument**

Monitoring and measuring simultaneously across multiple points is necessary for accurate and effective temperature characterization during a battery performance test. We recommend a data acquisition (DAQ) instrument – such as the Keysight 34972A DAQ/Data Logger Switch Unit with the 34901A general-purpose multiplexer card which has the capability to measure temperature, current, voltage and frequency. You’ll also need a common J-type thermocouple sensor at least 2-feet in length, and a pair of wires to measure voltage across the Li-ion battery.

The diagram in Figure 1 illustrates the simple setup and connection to the DUT, PC and power supply.

**Instrument 2: A DC power supply**

Depending on the Li-ion battery charging characteristic, you need to use a DC power supply with sufficient voltage and current coverage to charge the device-under-test (DUT), in this case, the battery. In our test setup, we used the Keysight E36312A Programmable DC Power Supply because of its broad current range and ability to log current data down to 1 mA.

The diagram in Figure 1 illustrates the simple setup and connection to the DUT, PC and DAQ.

For the setup, be sure to set the current limit anywhere between half and the maximum charging rate (0.5 C -1 C). Set the voltage limit to the acceptable final float charge voltage level. As the battery DUT charges, the constant current will automatically transition to constant voltage once the set voltage level is reached. The charge current will automatically taper down as the battery continues to get more saturated with charge. Charge termination takes place when the charge current drops to about 3% of the full charge current value.

See Figure 2 for the Li-ion battery DUT charging characteristics.
Recording and Data Analysis Software

You may want to monitor and record measurement data, real time, for future analysis. Traditionally, this meant writing a program from scratch. Keysight made this easier with applications like the Keysight BenchVue software. In fact, BenchVue does more than ease data logging and visualization of measurements. In addition to its simple point-and-click usage for multiple instrument controls, BenchVue also automatically detects instruments connected to your PC and launches the respective instrument apps. With BenchVue, there is no need for programming and you can easily build your own automated tests with the Test Flow feature.

You will need the following BenchVue instrument apps for profiling temperature while the battery is charging:

**BenchVue DAQ app**

The BenchVue Data Acquisition Control and Analysis App (BenchVue DAQ app) and a J-type thermocouple can be used to measure the temperature of the battery. Simply connect the J-type thermocouple to the 34901A multiplexer card. For the purposes of this example, the multiplexer card is in slot 1, and the measurement channel is 101. Open the BenchVue DAQ app and configure channel 101 to measure temperature using a J-type thermocouple. A single temperature point should be sufficient for measurements on a single cell battery. A complex battery packaging may require measurements over multiple temperature points.

Next, set another channel for DC voltage measurement across the battery DUT. Figure 3 shows the channel configurations on the BenchVue DAQ app.

**BenchVue Power Supply app**

The BenchVue Power Supply Control and Automation App can be used to set the voltage to the maximum charging voltage of the Lithium-ion cell, in this case, 4.2 V, and the current at 1.2 A limit (approximately 0.5 C). Figure 4 shows the channel configuration on the BenchVue Power Supply app.

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Figure 3. BenchVue DAQ app channel configuration

Figure 4. BenchVue Power Supply app channel configuration
Temperature Profiling Setup for Battery Discharging

Instrument 1: A DAQ instrument
As with the battery charging setup, we recommend a DAQ instrument for battery discharging. In this exercise, we will use the same Keysight 34972A DAQ/Data Logger Switch Unit with the 34901A general-purpose multiplexer card, J-type thermocouple sensors and wires across the Li-ion battery.

The diagram in Figure 5 illustrates the simple setup and connection to the DUT, PC and electronic load.

Instrument 2: A DC electronic load
The electronic load functions as a battery discharger for the DUT, simulating real applications that can drain battery power. We used the Keysight 6063B DC Electronic Load for this setup. Set the mode to constant current at 0.5 C (half of the full charge rate per hour).

You need to be aware of the end of discharge voltage, 3.0 V in this case. Beyond the 3.0 V cutoff, the voltage rolls off very quickly.

The diagram in Figure 5 illustrates the simple setup and connection to the DUT, PC and DAQ.

Figure 5. Temperature profiling while battery is discharging, using the Keysight 34972A DAQ, 6063B DC Electronic Load and BenchVue software.
Software: A data logging application

As with profiling temperature for battery charging, applications that aid data recording and visualization are a tremendous help in reducing program development and test times. We recommend the same Keysight BenchVue software because of its useful features and ease of use. You will need the following BenchVue instrument apps for profiling temperature while the battery DUT is discharging:

BenchVue DAQ app

Utilize the same setup as shown for profiling temperature on a charging battery as shown on Figure 3.

BenchVue Electronic Load app

The BenchVue Electronic Load Control & Automation App can be used to set the 6063B as a constant current load at 1.2 A (approximately 0.5C). Figure 6 shows the channel configuration on the BenchVue Electronic Load app.

![Figure 6. BenchVue Electronic Load app configuration](image-url)
Analyzing the Results: Temperature Profile of Battery While Charging and Discharging

With BenchVue's intuitive graphical user interface (GUI) and various graphical visualization options – including strip charts, XY charts, histograms and more – you can quickly validate your tests and further troubleshoot or test the next DUT. Where reporting is necessary, you can also export measurement data and screen images easily with just a few clicks.

**Figure 7** shows two strip chart results with BenchVue. On the left is the current and voltage profiles, as data logged with the E36312A DC Power Supply. On the right is the temperature profile of the battery while charging, as recorded with the 34972A DAQ/Data Logger Switch Unit.

**Figure 8** shows the battery temperature and voltage across it while discharging, as data logged with the 34972A DAQ/Data Logger Switch Unit.

Figure 7. Temperature, voltage and current profiles shown in strip chart format on the BenchVue software while battery is charging.

Figure 8. Temperature and voltage profiles shown in strip chart format on the BenchVue software while battery is discharging.
Other Related Tests

We’ve covered the basics on how you can easily characterize temperature during a battery performance test using just a handful of instruments with sufficient specifications that meet your test requirement. The DAQ instrument can be a scalable investment beyond the application we’ve covered, as you can see in the table below.

Table 1: Keysight 34972A DAQ/Data Logger Switch Unit as a scalable investment.

<table>
<thead>
<tr>
<th>Scalability needs</th>
<th>Keysight 34972A DAQ/Data Logger Switch Unit Features and Module/Card Specifications</th>
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</thead>
<tbody>
<tr>
<td>1 Number of temperature test points</td>
<td>The DAQ mainframe has 3 slots. Each slot can take up to 40 test points.</td>
</tr>
<tr>
<td>2 Data logging scanning speed</td>
<td>The 34902A multiplexer input card can scan up to 250 channels per second, with 16 channels per card. The 34908A multiplexer input card can scan up to 60 channels per second with 40 channels per card.</td>
</tr>
<tr>
<td>3 Universal inputs</td>
<td>The DAQ and its modules/cards have incredible flexibility to measure across various input types including temperature (supports 8 types of thermocouples, 2/4 wire RTD, Thermistor), AC/DC voltage, AC/DC current, 2/4-wire Ohm, Frequency and Period.</td>
</tr>
<tr>
<td>4 Switches</td>
<td>Besides the scanning multiplexer cards, this general purpose DAQ has switching features for more complex test solutions. The 34903A card has 20 channel actuator/general-purpose switch.</td>
</tr>
<tr>
<td>5 High voltage depending on usage</td>
<td>The multiplexer input cards and switching cards can measure a maximum voltage of 300 V.</td>
</tr>
</tbody>
</table>

Additional Information

For more information on Keysight general-purpose DAQ / Data Loggers, please go to:
www.keysight.com/find/34970A
www.keysight.com/find/34972A

For more information on the Keysight BenchVue software platform, please go to:
www.keysight.com/find/BenchVue

For more information on the Keysight E36300 Series DC Power Supplies, please go to:
www.keysight.com/find/E36300

For a more in-depth information on temperature measurements, download the “Practical Temperature Measurements” application note.

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