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Limitations of Internal Protective Devices in High-Voltage/High-Capacity Batteries Using Lithium-Ion Cylindrical Commercial Cells

Most commercial cylindrical 18650 Lithium-Ion (Li-Ion) cells have two internal protective devices: the Positive Temperature Coefficient (PTC) and the Current Interrupt Device (CID). The PTC protects the cells under external short conditions and the CID protects the cells under overcharge conditions. While proven to be effective at the single cell and small-size battery levels, these devices do not always offer protection when used in high-voltage and high-capacity battery designs.

Applicability

This information is applicable to those considering the use of Li-Ion batteries comprised of cells with PTC and CID internal protective devices.

Background

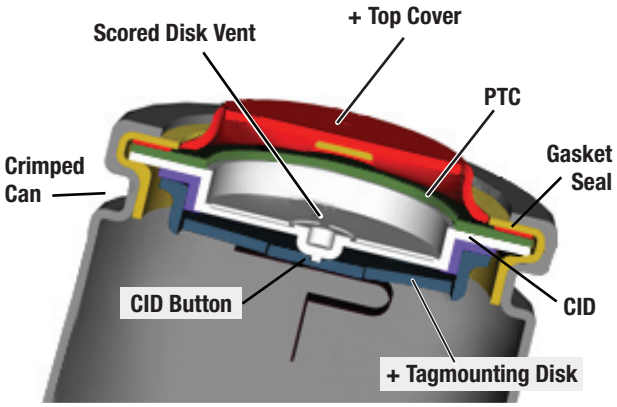
The internal protective devices (PTC and CID) used in the most common commercial-off-the-shelf (COTS) Li-Ion cells (cylindrical 18650's) have been extremely reliable at a single-cell level and have resulted in total prevention of the cell reaching a hazardous condition. However, test programs have indicated that batteries built with cylindrical COTS cells in multi-cell configurations (series and/or parallel) have experienced thermal runaway under various test conditions. Test data analysis indicated that the two major causes for the thermal runaway are overvoltage (overcharge) and external short conditions.

In these cases, the internal protective devices were either not protecting as expected or were a cause for the hazards encountered. PTC ignition above its withstanding (threshold) voltage has been shown to cause thermal runaway under external short conditions in high-voltage battery modules. Thermal runaway has also been observed during overcharge conditions in high-voltage and high-capacity modules, indicating that the CIDs did not protect the cells from catastrophic events, as seen in single cells. The NESC-sponsored study was conducted to understand the causes for the thermal runaway in high-voltage and high-capacity battery modules, and to determine the limitations of the cell internal protective devices.

Data and Analysis

PTC characteristics and limitations vary with cell manufacturer and are rarely provided. This information should be obtained by testing prior to considering a battery design for a specific application. The cell series voltage should not exceed the PTC withstanding voltage. For high-voltage batteries, diodes added to a series string of cells can improve their safety under external short conditions. The diodes must be carefully matched to battery characteristics.

In high-voltage and high-capacity batteries where the CID is used as a level of safety control, overcharge tests need to be performed to confirm its safe operation. The number of cells recommended for use in parallel depends on the charge current. The total charge current used to charge a bank (cells in parallel) should in no way cause an increase in PTC resistance of any single cell. In other words, in the event that all cell CIDs but one have opened, the current seen by the remaining cell should not cause an increase in PTC resistance. The CID voltage tolerance should also be characterized. The charger voltage limit should be set so that the difference between the voltage limit value and the end-of-charge battery voltage does not cause CID arcing. The main causes of failure that prevent the CID from proper safing are the charge current (causing inadvertent PTC activation), high temperatures (causing PTC activation or uncontrollable thermal runaway), and high voltages (causing PTC ignition).



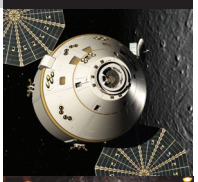
Cross-Section of a Typical 18650 Cylindrical Li-Ion cell showing the PTC (in green) and CID (in white)

References

NASA Aerospace Flight Battery Program Year 1 Report – Part 1, Volumes 1 and 2, Generic Safety, Handling and Qualification Guidelines for Lithium-Ion (Li-Ion) Batteries, Li-Ion Batteries, Maintaining Technical Communications Related to Aerospace Batteries (NASA Aerospace Battery Workshop), NESC Document Number RP-08-75.

This work was led by Judith Jeevarajan, NASA Johnson Space Center, and Michelle Manzo, NASA Glenn Research Center.

For information contact the NESC at www.nesc.nasa.gov



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