Proper Lithium-Ion battery charging and safety

Steve Taranovich - January 19, 2013

We do not yet know what the official cause of the Boeing 787 Lithium-Ion battery breakdown was on the two aircraft until the full investigation has been completed. However, we have some good advice from experts in the industry that show how critical a good protection scheme is in a critical design such as on a commercial aircraft.

PowerStream inputs: Every lithium ion battery pack should have a safety board or IC which monitors the charge and discharge of the pack, and prevents improper conditions. The specifications of these safety boards are dictated by the cell manufacturer, and may include the following:

- Reverse polarity protection
- Charge temperature--must not be charged when temperature is lower than 0° C or above 45° C.
- Charge current must not be too high, typically below 0.7 C.
- Discharge current protection to prevent damage due to short circuits.
- Charge voltage--a permanent fuse opens if too much voltage is applied to the battery terminals
- Overcharge protection--stops charge when voltage per cell rises above 4.30 volts.
- Overdischarge protection--stops discharge when battery voltage falls below 2.3 volts per cell (varies with manufacturer).
- A fuse opens if the battery is ever exposed to temperatures above 100° C.

From Walt Kester and Joe Buxton, Analog Devices: Li-Ion Charging: Li-Ion batteries commonly require a constant current, constant voltage (CCCV) type of charging algorithm. In other words, a Li-Ion battery should be charged at a set current level (typically from 1 to 1.5 amperes) until it reaches its final voltage. At this point, the charger circuitry should switch over to constant voltage mode, and provide the current necessary to hold the battery at this final voltage (typically 4.2 V per cell). Thus, the charger must be capable of providing stable control loops for maintaining either current or voltage at a constant value, depending on the state of the battery.

The main challenge in charging a Li-Ion battery is to realize the battery's full capacity without overcharging it, which could result in catastrophic failure. There is little room for error, only ±1%. Overcharging by more than +1% could result in battery failure, but undercharging by more than 1% results in reduced capacity. For example, undercharging a Li-Ion battery by only 100 mV (-2.4% for a 4.2-V Li-Ion cell) results in about a 10% loss in capacity. Since the room for error is so small, high accuracy is required of the charging-control circuitry. To achieve this accuracy, the controller must have a precision voltage reference, a low-offset high-gain feedback amplifier, and an accurately matched resistance divider. The combined errors of all these components must
result in an overall error less than ±1%.

**Overcharging Lithium-ion from Cadex Electronics Battery University**

Lithium-ion operates safely within the designated operating voltages; however, the battery becomes unstable if inadvertently charged to a higher than specified voltage. Prolonged charging above 4.30V forms plating of metallic lithium on the anode, while the cathode material becomes an oxidizing agent, loses stability and produces carbon dioxide (CO$_2$). The cell pressure rises, and if charging is allowed to continue the current interrupt device (CID) responsible for cell safety disconnects the current at 1,380kPa (200psi).

Should the pressure rise further, a safety membrane bursts open at 3,450kPa (500psi) and the cell might eventually vent with flame. The thermal runaway moves lower when the battery is fully charged; for Li-cobalt this threshold is between 130-150°C (266-302°F), nickel-manganese-cobalt (NMC) is 170-180°C (338-356°F), and manganese is 250°C (482°F). Li-phosphate enjoys similar and better temperature stabilities than manganese.

Lithium-ion is not the only battery that is a safety hazard if overcharged. Lead- and nickel-based batteries are also known to melt down and cause fire if improperly handled. Nickel-based batteries have also been recalled for safety concerns. Properly designed charging equipment is paramount for all battery systems.

Texas Instruments has the bq24314C which protects against:

- Input overvoltage, with rapid response less than 1 us
- User programmable overcurrent with current limiting
- Battery overvoltage

The bq24314C is a highly integrated circuit designed to provide protection to Li-ion batteries from failures of the charging circuit. The IC continuously monitors the input voltage, the input current, and the battery voltage. In case of an input overvoltage condition, the IC immediately removes power from the charging circuit by turning off an internal switch. In the case of an overcurrent condition, it limits the system current at the threshold value, and if the overcurrent persists, switches the pass element OFF after a blanking period. Additionally, the IC also monitors its own die temperature and switches off if it exceeds 140°C. The input overcurrent threshold is user programmable.

The IC can be controlled by a processor and also provides status information about fault conditions to the host.
This type of application circuit could be used as an extra-added protection to the Lithium-Ion battery during charging in critical applications like the Boeing 787.

I am certain that the FAA and other experts will find the root cause of these two battery failures and implement corrective action to ensure flight safety in this amazing aircraft design. More to come as the investigation unfolds.

See also "Boeing 787 and Lithium Ion battery failures"