Safe Design of Custom Lithium Batteries

Introduction: The World's Favourite Battery Chemistry?

Recent events involving the use of lithium batteries on aircraft have raised awareness of the potential hazards with the use of this battery technology, this has subsequently provoked significant discussion regarding its safety in all industrial and commercial applications.

The 787 was the first airliner to make extensive use of lithium batteries. Aircraft makers view lithium batteries as an important way to save on fuel costs, as they are lighter and can store more energy than other types of batteries of an equivalent size.

The Airbus A350 also makes extensive use of lithium ion batteries. Manufacturers are also looking to retrofit existing planes, replacing other types of batteries with lithium ion.

However, as we have seen, under some circumstances lithium batteries are more likely to short circuit and start a fire if they are damaged, if there is a manufacturing or battery assembly flaw or if they are exposed to excessive heat.

The benefits of lithium batteries have seen them adopted widely. Extreme applications such as the defence industry, oil and gas, environmental monitoring and sensing have used lithium batteries for many years.

Lithium battery technology is often preferred for portable equipment intended for use in harsh environments. Lithium batteries have a wide operating temperature range, and are known to have high tolerance of pressure, shock and vibration.

The batteries are also sealed, which allows use in any orientation and avoids the potential for accidental leakage experienced with other battery types such as lead-acid.

High energy density is a major advantage of lithium battery chemistry. This gives equipment designers greater freedom to optimise the overall size and weight while meeting or surpassing the target operating envelope.

With their outstanding energy density, lithium batteries are currently the preferred rechargeable energy storage medium in hybrid and full-electric vehicles.

This opens up a vast new application space for lithium batteries, in demanding markets that will also force the technology to improve in aspects such as cost, performance, reliability and safety.

Lithium batteries are available off the shelf in a variety of sizes and form factors; particularly those suiting laptop PCs, mobile phones or other handheld devices such as GPS devices or media players.

In specialised applications, however, a custom lithium battery pack may be needed. Engineering companies must be familiar with the technical constraints that feed into engineering a lithium battery pack. Moreover, an appreciation of the safety standards and compliance demands surrounding lithium batteries is absolutely necessary.

A wide variety of general-purpose and industry-specific safety standards and recommendations now exists, covering aspects ranging from battery design and application to handling, shipping and disposal. The standards continue to evolve, particularly in technologies and markets that are moving quickly, such as hybrid vehicles, mobile communications and handheld devices.

Design with Care

From a safety perspective, the main difference between lithium batteries and conventional primary batteries using aqueous electrolyte is that they contain flammable materials.

There is a risk of fire or explosion if lithium batteries are overcharged or allowed to overheat, or if the case becomes damaged allowing flammable material to escape. Hence it is important to consider safety during design, production, distribution, use and disposal of lithium batteries.

Ultimately, owners and operators need assurance that equipment powered by lithium batteries is safe and can be used without contravening laws applicable to their own businesses - such as duty of care regulations covering groups including employees using the equipment, others who may be nearby, or members of the public.

A number of standards have been developed by national and international bodies, such as Underwriters Laboratories (UL) and the IEEE in the USA, and the International Electrotechnical Commission (IEC), setting out requirements for safe design and handling of lithium batteries and equipment in which they are used.

The strategy behind these standards is to analyse each aspect of the system as well as the interactions between them, to ensure reliable operation and minimise the risk of faults giving rise to battery-related hazards.

All aspects of the system design are covered, such as individual cells, the battery pack, power supply and main functional subsections, and communication with the end user.

Time-related effects such as component ageing, environmental changes such as extremes of temperature and management of component failures are also covered. To achieve compliance, the design of each subsystem must be reviewed – followed by a review of the entire system - to ensure that individual faults, or combinations of faults, are unable to cause battery safety hazards.

Essentially, this advocates carrying out a comprehensive Failure Modes and Effects Analysis (FMEA) on all aspects of the system. UL1642 (and the more recent IEC 62133) is a general standard for lithium and lithium-ion batteries that sets out requirements on construction, performance and testing of batteries intended for use in technician-replaceable or user-replaceable applications.

The requirements are intended to reduce the risk of fire or explosion when lithium batteries are used in a product. The final acceptability of these batteries is dependent on their use in equipment meeting applicable product acceptance criteria.

The evolution of industry standards reflect the higher power levels of lithium batteries used in equipment. For customized battery packs, working with battery assembly companies with the demonstrable quality controls expected to manage complex battery designs is an important factor in the battery selection process.

Safety to resources will be heavily reliant on the selection of cell chemistry, protection control electronics, charging and battery management systems and the final design and assembly of the battery pack.

Shipping and Transportation

Since lithium is recognised internationally as a hazardous material, many of the published standards make particular reference to handling and shipping specifications.

Shipping regulations set out by national or regional bodies such as the United States Department of Transport (US D.O.T) are usually based on the United Nations specifications set out in the “UN Recommendations on the Transport of Dangerous Goods, Manual of Tests and Criteria”.

They document a series of tests, which are designated T.1 through T.8 and are often referred to as the UN “T” tests. The tests are applicable to batteries only; other documents such as the Class 9 Hazardous Materials Regulations define specifications for aspects such as packaging, marking, labelling, and the supporting documentation required for shipping.

A summary of the scope of the T tests and the key criteria that the battery must pass are detailed in the tables on the next page. These tests required by UN 38.3 are to be carried out in order.

Conclusion

The grounding of 50 Dreamliner aircraft in January 2013 after unexplained overheating issues resulting in a battery on one 787 melting mid-flight, while a battery caught fire on another Dreamliner after it had landed in Boston means that the topic of lithium battery safety will remain high on the agenda for some time.

Catastrophic incidents relating to lithium battery power will continue to be discussed and the US Federal Aviation Authority (FAA) will investigate root cause of recent Boeing 787 lithium-ion battery incidents.

Lithium batteries offer advantages such as high performance, long recharge intervals, compact dimensions and low weight in demanding industrial, military and transportation applications, these benefits will mean a continued use and investment in safe lithium battery technology with the emphasis placed upon the choice of safe chemistry, reliable manufacture and professional battery assembly performed by reputable companies.

Lithium batteries offer high reliability and withstand harsh environments, provided relevant safety criteria are met. Knowledge of the applicable standards, and how these co-exist with acceptance criteria for the end product, can help designers of battery packs deliver robust, high-quality solutions assuring high standards of safety for customers, users and the environment.

Description of UN “T” tests, which provide the basis for various national battery safety

T1: Altitude Simulation	
REASON	Low pressure testing
APPLICA-BLE	Primary Cells / Primary Batteries Secondary Cells / Secondary Batteries
TEST	Store Batteries at 11.6kPa for > 6 hours at ambient.
CRITERIA	No Mass Loss, Leaking, Venting, Disassembly, Rupture, or Fire. Voltage within 10% of pre-test voltage
T2: Thermal Test	
REASON	Integrity check during rapid and extreme temperature changes
APPLICABLE	Primary Cells / Primary Batteries Secondary Cells / Secondary Batteries
TEST	· 6 hours @ -40°C (12 hours for large cells/batteries) · <30minute transition · 6 hours @ +75°C (12 hours for large cells/batteries) · <30 minute transition · Repeat for total of 10 cycles
CRITERIA	No mass loss, leaking, venting, disassembly, rupture, or fire. Voltage within 10% of pre-test voltage
T3: Vibration	
REASON	Simulates vibration during transportation
APPLICABLE	Primary Cells / Primary Batteries Secondary Cells / Secondary Batteries
TEST	Sine Sweep: 7Hz – 200Hz – 7Hz in 15 Minutes; 12 Sweeps (3 hours); 3 mutually perpendicular axes
CRITERIA	No mass loss, leaking, venting, disassembly, rupture, or fire. Voltage within 10% of pre-test voltage
T4: Shock	
REASON	Simulates shock during transportation
APPLICABLE	Primary Cells / Primary Batteries Secondary Cells / Secondary Batteries
TEST	· Half-Sine pulse · 150G/6ms for small cells/batteries · 50G/11ms for large cells/batteries · 3 pulses per direction · 6 directions (+/-z, +/-x, +/-y)
CRITERIA	No mass loss, leaking, venting, disassembly, rupture, or fire. Voltage within 10% of pre-test voltage
T5: External Short Circuit	
REASON	Simulates external short circuit
APPLICABLE	Primary Cells / Primary Batteries Secondary Cells / Secondary Batteries
TEST	Sample case monitored for temperature. Stabilise sample at temperature of +55°C Apply short circuit (<0.1 Ohm) across terminals. Maintain at least hour after sample temperature returns to +55 +/-2°C. Remove short circuit and monitor sample for additional 6 hours.
CRITERIA	Case temperature does not exceed +170°C No disassembly, rupture, or fire within 6 hours of test

T6: Impact	
REASON	Simulates impact to case of cell
APPLICABLE	Primary Cells / Secondary Cells
TEST	Sample placed on flat surface, temperature monitored. 15.8mm diameter bar placed across the centre of the sample. 9.1kg mass dropped onto bar above sample from 61cm height. One Impact per sample. Sample monitored for 6 hours after test.
CRITERIA	Case temperature does not exceed +170°C No disassembly or fire within 6 hours of test
T7: Overcharge	
REASON	Simulates overcharge on rechargeable battery
APPLICABLE	Secondary Batteries
TEST	Sample connected electrically to a DC power supply or battery charger/cycler, with programmable voltage and current control. An overcharge current of 2x the manufacturers recommended charge. Current shall be applied for 24 hours. **Charge voltage applied:** · If recommended charge voltage is 18V or less: · 2x charge voltage, up to 22V · If recommended charge voltage is >18V: · 1.2 x maximum charge voltage
CRITERIA	No disassembly or fire within 7 days of test.
T8: Forced Discharge	
REASON	Simulates forced discharge of cells
APPLICABLE	Primary Cells / Secondary Cells
TEST	Sample connected in series with +12V DC Power Supply and load resistor. Load resistor shall be sized to provide the maximum discharge current of the battery with 12V applied in series. Duration is calculated from the rated Amp hours of the cell Duration (h) = rated Ah / Initial Current (A)
CRITERIA	No disassembly or fire within 7 days of test

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