Safe Design of Custom Lithium Batteries

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Introduction: The World's Favourite Battery Chemistry?

Lithium battery technology is often preferred for portable equipment intended for use in harsh environments. Lithium batteries also have a wide operating temperature range, particularly at low temperatures, 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 batteries 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 some 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 and shipping. The standards continue to evolve, particularly in technologies and markets that are moving quickly, such as hybrid vehicles.

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 such as 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.

Standards Guiding Safe Battery Design

Among the standards published, IEEE 1625 and IEEE 1725 are particularly valuable to design communities, since they set out a system-level approach to lithium battery safety. The standards were developed by manufacturers of lithium batteries, power-management ICs and end-user equipment; IEEE 1625 is specific to portable computers, and IEEE 1725 to cellular telephones.

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 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. A similar international standard, IEC 62133, is expected to replace UL1642 by 2012.

Part 4 of the IEC 60086 standard for primary batteries describes safety tests for lithium batteries and also provides guidelines addressing safety issues during the design of lithium batteries and of equipment where lithium batteries are installed. The evolution of this standard, which is now in its third edition, reflects the generally higher power levels of lithium batteries used in equipment such as consumer electronic devices. The latest revision was introduced to harmonise with transportation tests published in IEC 62281.

Among the safety standards for batteries aimed at more demanding or hazardous applications, BS 2G 239 presents specifications for primary active lithium batteries for use in aircraft. Is referenced in defence procurement standards such as DEF STAN 61-21 General Specification for Batteries

In addition, the growth in world markets for electric and hybrid-electric vehicles is focusing the automotive industry's attention on safety issues surrounding lithium batteries. The Society of Automotive Engineers (SAE) in the US has published SAE J 2464, which presents general guidelines for safety and abuse testing of rechargeable energy-storage systems. The UL 2580 standard, Batteries for Use in Electric Vehicles, is also being developed.

Shipping and Transportation

Since lithium is recognised internationally as a hazardous material, many of the published standards (including, but not limited to UL1642 and IEC 60086-4) 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". The document defines eight 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.

Table 1 summarises the scope of the T tests and they key criteria that the battery must pass.

Test	Description	Test conditions	Pass criteria
T1	Altitude simulation	Store batteries at 11.6 kPa for over 6 hours (simulates cargo area in unpressurised aircraft at 15,000 m altitude)	No mass loss, leaking, venting, disassembly, rupture, or fire. Voltage within 10% of pre-test voltage.
T2	Thermal shock	Expose batteries to 10 temperature cycles between -40°C and +75°C: • Transition in less than 30 mins • Hold for 6 hours at each temperature	
T3	Vibration	12 sine sweeps in 3 hours. Three mutually perpendicular axes: 7Hz – 200Hz – 7Hz in 15 minutes.	
T4	Shock	Apply half-sine pulse: • 150g for 6ms (small cells/batteries) • 50g for 11ms (large cells/batteries) • Both directions in all three axes • Three pulses per direction	
T5	External short circuit	Stabilise at 55°C, then apply short circuit (<0.1Ω). Maintain s/c for at least 1 hour after temperature returns to 55°C. Remove short circuit. Monitor for further 6 hours.	Case temperature must not exceed +170°C. No disassembly, rupture, or fire within 6 hours of test. Activation of protection device or venting mechanism permitted.
T6	Impact (primary and secondary cells only)	Place 15.8mm diameter bar across top of battery. Drop 9.1kg bar once from height of 61cm. Monitor for 6 hours after test.	No disassembly or fire within 6 hours of test. Activation of protection device or venting mechanism permitted.
T7	Overcharge (rechargeable batteries only)	Apply 2x overcharge current, at above maximum recommended charge voltage, for 24 hours	No disassembly or fire within 7 days of test. Activation of protection device or venting mechanism permitted.
T8	Forced discharge (primary and secondary rechargeable cells only	Connect in series with 12V DC power supply and load resistor sized for maximum battery discharge current. Test duration calculated from rated Amp-hours of cell.	

Table 1. Description of UN "T" tests, which provide the basis for various national battery-safety specifications.

Conclusion

Lithium batteries offer advantages such as high performance, long recharge intervals, compact dimensions and low weight in demanding industrial, military and transportation applications. They can 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.