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Safety and reliability considerations for lithium batteries

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Abstract

Battery safety and reliability are closely related and, in some instances, safety may be considered a subset of reliability. However, safety is a concern from manufacture through disposal. Reliability can be approached through three different perspectives: lot reliability, individual cell reliability, and root cause analysis of failed cells. To ensure a quality product, a good reliability management program must be established as part of the manufacturing process. Reliability can be designed into cells through the use of fault tree analysis, while root cause analysis of failed cells is determined by a thorough post mortem analysis of individual failed cells. An existing fault tree can help focus the analysis. Battery safety can be classified as to the different types of hazards according to their effect on personnel and equipment, e.g., physical, chemical, equipment damage, and environmental. To maximize safe performance, each cell and battery should be designed specifically for its intended use. Battery packs must be designed to maintain the safety features designed into individual cells. However, the ultimate responsibility for battery safety lies with the consumer, who must insure proper storage conditions, train personnel in proper handling techniques, and dispose of them in accordance with government regulations.

Keywords: Lithium batteries; Safety; Reliability; Disposal; Fault tree analysis

1. Reliability

Cell reliability can be addressed through three different approaches: lot reliability, individual cell reliability, and root cause analysis of failed cells. A statistical approach is used to estimate the reliability of cell lots. This approach involves three steps: sampling, testing, and statistical analysis. The sampling must be random, which means every cell in the lot has an equal chance of being selected. A number of methods are available to obtain a random sample, from the use of tables of random numbers to statistical methods [1]. Cell testing can be either real time or accelerated. The number of tests to be performed are normally controlled by the time and money available. However, confidence in the test results is determined by the number of tests conducted. The smallest number of tests, n, required to demonstrate a reliability $\geq R$, with confidence C can be obtained from the following expression

$$R^n \leq (1-C) \tag{1}$$

A number of factors concerning reliability arise during the manufacturing process. Among the most important are: chemical factors, i.e., impurities and concentrations; corrosion, both the corrosive environment on metal parts due to active components and stress that may occur on formed parts; joining procedures; materials processing and cell closures, either hermetic or crimp. To ensure a quality product, a good reliability management program must be established prior to the start of manufacture.

Individual cell reliability can be improved through the use of fault tree analysis [2]. This approach involves the use of deductive reasoning, or backward analysis, to yield a graphic model showing combinations of faults that will result in specific failure. The analysis can be expanded to include defects in the device the battery is powering. Failure probability can be estimated by the use of simple assumptions. The root cause analysis of failed cells is determined through a postmortem analysis. If a fault tree is available, it can help focus the postmortem, otherwise all possibilities must be considered equally. A good postmortem analysis always compares the failed cell with good cells, both fresh and discharged.

2. Safety

2.1. Cells

Hazardous conditions may arise when the contents of a cell or battery escape from its container. The release of these materials may be benign, mild, or violent, e.g., a leak, vent

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of materials under pressure, or case rupture. Battery safety may be classified by the different types of hazards according to their effect on personnel and equipment, e.g., physical, chemical, equipment damage, and environmental [3]. Physical hazards are normally due to battery rupture, the extent of the damage incurred being proportional to the size of the battery. Chemical hazards are the result of leakage or venting of corrosive or toxic materials. Equipment damage is caused by either explosions or leakage of corrosive materials which can corrode electrical components or contacts. Environmental issues are related to the hazardous nature of lithium, which is classified as reactive and a flammable solid, and/or the potential leakage of toxic materials from cells or batteries that are disposed of in an improper manner.

Explosions and ventings are due to an increase in internal pressure caused by gas generation and/or excessive heating. These may result from internal defects, e.g., spontaneous physicochemical processes, or shorts; or from external sources, including defective devices or abuse by the user, e.g., reversal, charging/overcharging, or shorting. Leakage is normally due to corrosion of the cell container or through mechanical or electrical abuse by the user.

Even the most hazardous battery chemistries, e.g., $Li/SOCl_2$, can be designed to operate safely under most conditions. To maximize safe performance with the high energy lithium systems, each cell and battery should be designed specifically for its intended use. A number of design features need to be considered when choosing cells for a specific application: these include rate capability, and the use of vents, internal or external fuses, or fusible separators. Some chemistries are inherently more hazardous than others. For example, Rayovac (cited in Ref. [4]) looked at the thermal stability limits of the commonly used 4 V lithium-ion cathode materials, $LiCoO_2$, $LiNiO_2$, and $LiMn_2O_4$ [4]. The tests were conducted in 'AA' cells by placing them in an oven and ramping the temperature at 2.2 °C/min. Exotherms occurred at temperatures ranging from 183 °C for $LiNiO_2$ to 223 °C for $LiMn_2O_4$, with the manganese material having a much smaller exotherm than the other two materials. In the same study, discharged cells exhibited a higher degree of stability than fully charged cells.

2.2. *Battery packs*

When designing multicell battery packs, care must be taken to ensure that the safety features designed into the individual cells are not negated. Thermal management is critical. The arrangement of cells in the battery pack, as well as the location of the battery in the device must be considered. The pack design must allow a path for vented gasses to escape from the battery, or into a void space within the battery, if venting of the gas may cause a problem. Another option is to force the gas to pass through a getter material. Cells having the lowest power and still able to meet the electrical requirements should be used. All cells within the battery pack should be of the same chemistry and size and, if possible, cells from the same manufacturing lot with the same history should be used. Center taps should never be incorporated into the battery design. Additional safety devices such as fuses, current limiting resistors, thermal switches, and blocking diodes, if parallel strings of cells are present, should be used as appropriate. Other safety measures that should be considered are the use of durable connectors and leads that can withstand any environmental stresses the battery may incur during its life and electronic protection devices for rechargeable batteries to prevent overcharge and/or overdischarge of individual cells.

3. Disposal

In the USA, disposal of waste batteries is regulated by several statutes [5]. The Resource Conservation and Recovery Act of 1976 (RCRA) defines hazardous solid waste in two general categories; listed or characteristic. If not listed on the Environmental Protection Agency's (EPA) list of hazardous waste, an item is considered hazardous waste if it exhibits one of the characteristics of hazardous waste: ignitability, corrosivity, reactivity, or extraction procedure toxicity. All waste lithium batteries are considered RCRA solid waste and must be treated to render them nonhazardous prior to disposal. A number of treatments are available, including: incineration, hydrolysis, encapsulation, recycling, plus special treatments for specific systems. When incinerating waste batteries, scrubbers must be used to clean the smokestack discharge, and the residue must be analyzed to insure no hazardous materials remain. The hydrolysis procedure involves opening the cells, usually by a hammer mill, treating with copious quantities of water, and use of a scrubber to clean the released gasses. EPA characteristic waste may be encapsulated with a nonhazardous waste, e.g., cement, to render it nonhazardous. Recycling involves an initial hydrolysis step, followed by reclamation of the recycleable materials. A technique developed by the US Army specifically for Li/SO_2 batteries involves the incorporation of a resistor into the pack with a switch located on the exterior. Prior to disposal, the resistor is switched into the circuit which ensures full discharge of the battery. Since a balanced design is used, all the active materials are reacted and the battery can be disposed of as nonhazardous waste.

4. Summary

Safety and reliability are important considerations in the design of cells and batteries. There is a strong relationship between the two, and both are affected by the same parameters. Reliability can be approached through three different perspectives: lot reliability, individual cell reliability and root cause analysis of failed cells. Lot reliability is estimated through the use of statistical analysis, reliability can be designed into and estimated for cells through the use of fault tree analysis, and root cause analysis of failed cells is determined through postmortem analysis.

To maximize safety, cells and batteries should be designed for the end-use application. Although some chemistries are inherently safer than others, all systems can be designed to operate in a safe manner. Thermal management is critical in the design of multicell battery packs. Both the location of cells in the pack and of the pack in the device must be taken into account. Disposal of waste batteries must be done in accordance with government regulations.

Ultimately, the responsibility for battery safety lies with the user. The user must choose the proper batteries for the application, store them properly prior to use, train all personnel in the proper techniques for handling them, insure that the batteries are only used in the application for which they are intended, and dispose of them in accordance with all government regulations.

References

[1] W.G. Cochran, *Sampling Techniques*, Wiley, New York, 1977.

[2] P. Bro and S.C. Levy, *Quality and Reliability Methods for Primary Batteries*, Wiley, New York, 1990.

[3] S.C. Levy and P. Bro, *Battery Hazards and Accident Prevention*, Plenum, New York, 1994.

[4] L. Xie, D. Fouchard and S. Megahed, Material Requirements for Lithium-Ion Batteries, *Proc. Symp. Materials for Electrochemical Energy Storage and Conversion — Batteries, Capacitors and Fuel Cells*, Materials Research Society, Pittsburgh, KS, USA, 1995.

[5] P. Bro and S.C. Levy, Batteries and the Environment, in *Environmental Oriented Electrochemistry*, Elsevier, Amsterdam, 1994.