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Going Beyond Industry Standards in Critically Evaluating Lithium-Ion Batteries

Jan Swart, Yue Xu, Ashish Arora, Stig Nilsson
Exponent Failure Analysis Associates

The need for longer battery life in portable electronic devices has generated a high demand for Li-Ion batteries. Low cost, high energy density, and more importantly, low weight have made the Li-Ion battery the number one choice for powering a wide range of devices such as cellular phones, laptops, digital cameras and mp3 players.

With the ubiquitous use of Li-Ion cells, there has been an increase in the number of field failures. Multiple CPSC recalls and instances of Li-Ion batteries failing in portable electronic equipment applications are not unknown and have made the news on many occasions. [1,2]


Figure 1. Remnants of an overcharged Li-Ion battery pack.

Li-Ion and lithium polymer batteries are known to fail by overheating or with flaming combustion. A catastrophic failure could also involve a very undesirable rapid disassembly of the cell can (see Figure 1). The release of energy in the event of such a failure can be quite significant and catastrophic. Mitigating some of these potential failure modes requires extensive manufacturing quality controls and comprehensive battery management systems.

A variety of industry standards exist to evaluate the safety of lithium based secondary cells and battery packs. [3-6] The battery packs generally need to pass these compliance tests before they can be released into the market. Based on historical and other known failure mechanisms of the product, what is required is an evaluation that goes beyond the industry standards so that the compliance of the batteries to these standardized tests can be married to a critical safety evaluation of the battery and the intended product. A comprehensive safety evaluation of the battery would require the safety testing and the system safety evaluation to complement each other in discovering all of the failure modes that could possibly be experienced in the field.

Compliance Testing vs. Company Specific Safety Evaluation

There is a difference between compliance safety testing and safety evaluation. The first has well defined pass-fail criteria and is based on a set protocol generated by the industry and other organizations.

However, a safety evaluation is a dynamic evaluation process based on the response of a product to unique user usage patterns and possible environmental exposure. The need then is for a comprehensive safety evaluation regime to complement the industry standards and not to replace them (see Figure 2).

The Building Blocks for Product Safety Evaluation

For a safety evaluation to be effective the following criteria should be fulfilled:

- A third party, outside the product development group, should generate the safety evaluation criteria. This ensures complete emotional detachment between the product design and its safety evaluation.
- The third party employed should be knowledgeable of the control system design and chemistry limitations and also have extensive failure analysis and field failure analysis exposure. This provides for a knowledge transfer where by lessons learned from field failures allow for those failure modes to be mitigated in the evaluated product.

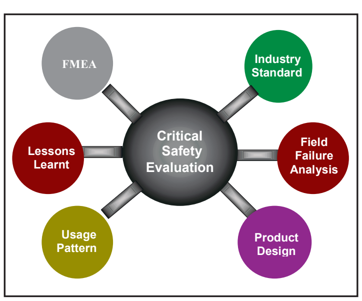

Figure 2. Requirements for a comprehensive critical safety evaluation.

- The critical safety evaluation should be based on the specific design, known foreseeable usage patterns, and field exposure. The engineer evaluating the product should have a clear understanding of what the intent of the test is. This is necessary so that the test procedure can be modified to ensure that the intent of the test is satisfied.
- Typically the unique features of the product will dictate usage patterns. Characterizing the normal usage of the product is somewhat subjective. Failures typically occur because the product is used in an environment or an application not anticipated by the designers. Thus, what is required is a characterization of the unanticipated and unforeseeable usage of the product and the effect that this has on the product's safety. A characterization of this nature requires historical knowledge of the product or similar products and other such resources. The lessons learned from field failure analysis of similar products are also an invaluable resource in this regard. These atypical usage patterns, in addition to the cell chemistry, the battery pack architecture, the charge-discharge regime, and the additional safety protection need to be taken into consideration during the safety evaluation. In addition, the following typical usage patterns need to be take into consideration:
- The geographical location (altitude, climate etc).
- The intended user market (i.e. target market).
- The foreseeable applications other than the intended application.
- The usage patterns (stationary vs portable).
- The known and foreseeable user abuse.
- Historical known and understood failure mechanisms of unique discrete components or circuits.

Safety Evaluation Beyond Industry Standards

Once a complete understanding of the design, the functionality, and usage patterns of the product have been completely understood and analyzed, the safety evaluation needs to be taken to the next level. This requires the generation of a Failure Mode and Effect Analysis (FMEA). A design specific individual FMEA should be generated for each unique product with a failure event depth up to three sequences of failure events. Experience, knowledge, and exploratory testing should be performed to verify the effective implementation of independent safety actuators that can minimize failures with event failure depths of two or more sequences of events. The evaluation needs to consider the interaction between the control systems and the safety features during normal operation of the product to eliminate control system overlaps or gaps that may result in unpredictable modes of operation. The same methodology should be applied on the safety control system. Safety actuators may overlap with the normal control systems resulting in gaps in the safety infrastructure whereby the product may potentially fail to respond to unsafe modes of operation. The aim is to determine situations that may result in an unsafe mitigation or a complete lack of protection against an undesirable failure event.

The battery pack designers often ignore the compatibility of a cell in the battery pack. A very important aspect of the evaluation includes evaluating the cell chemistry and the cell behavior to a failure stimulus and in conjunction with the cell datasheet to determine if the control system for the battery pack actually fits the profile of the cells. Profile mismatch may result in an unsafe battery pack during an over-stress stimulus.

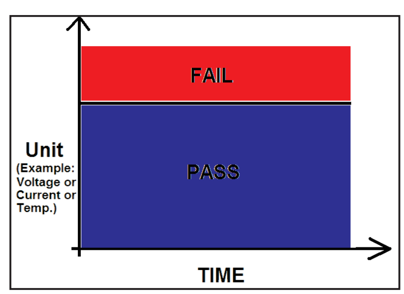

Figure 3. The graph shows the Unit (voltage, current or temperature) versus time and the method in which a safety test pass-fail criteria is defined.

Once a FMEA is created the pass-fail criteria should be determined. This is the critical area delineating the testing to an industry standard and a critical safety evaluation of the product. Testing to an industry standard has a clear defined pass-fail criteria (see Figure 3).

The FMEA should follow the

industry standard pass-fail criteria but should also take into consideration other more stringent pass-fail criteria generated by individual companies based on the design and application of the cells and the battery packs.

If the evaluation is to be performed on a new product with limited field exposure, a more rigorous test procedure should be developed such that the design of the battery pack or battery cells is validated in addition to the normal manufacturing related tests. Also, those test results close to the pass/fail region of the pass/fail plane should be carefully examined. This is illustrated as a region labeled the "Critical Region" in Figure 4 below.

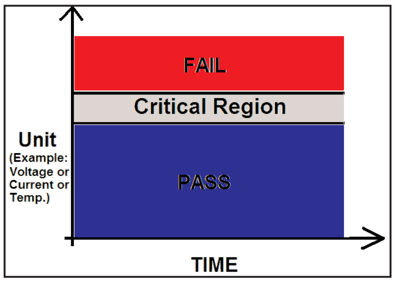

Figure 4. The graph shows the Unit (voltage or current or temperature) versus time and the critical area deciding the pass-fail criteria and when further analysis should be performed.

The reasons for this are the following:

- By understanding the test failures close to, and on either side of the pass/fail boundary, the design may be modified to avoid excessive test failures, which will improve the manufacturing yield.
- By understanding the reasons for the close-to-fail test results, possible safety defects may be detected, which may later prevent an expensive product recall. Thus, there is an economic incentive to evaluate the critical region sandwiched between the test-pass and fail regions.

The evaluation of Lithium-Ion cells and battery packs should be performed by generating a test protocol based on the predicted product exposure, foreseeable usage and known field failure modes such that the desired failure mechanism is tested, hence satisfying the intent of the test. The following should be evaluated:

- Packaging of the cells or battery pack
  - Design and layout
  - Manufacturing process
  - Materials used
- Mechanical impact analysis
  - Some form of cell impact
- Environmental analysis
  - Excessive temperature
  - Shock and vibration
  - Vacuum
- Management System (BMS) failures
  - Over and under temperature related failures.
  - Over and under voltage charge and discharge
  - Over current charge and discharge battery

Implementation Strategy

A company product specific safety standard should be developed considering that:

1. The internal development team is not the best resource for developing the test strategy because it does not always understand the safety issues relating to new technologies.

2. An OEM/ODM organization may not understand the risks associated with the products carrying their label.

Many companies may have in-house expertise from many years of development and failure analysis experience. This safety experience and knowledge base may assist a company in developing a company and product specific safety evaluation protocol. Companies hesitating may initially use the safe route and rely on outside consulting firms with a clear track record and reputation for working with the Lithium-Ion industry. These firms may be able to provide the necessary guidance and initial safety evaluation protocol development specifically drawn up for their products. Usually the firms can also provide educational seminars to the development teams educating them on Lithium-Ion safety and design practices.

In addition, it is of the utmost importance that a company evaluate its exposure in the field from a product failure standpoint and very importantly, from legal exposure which may result in exposing a company to subrogation, tort and class action law suites in the event of undesirable product performance including failures.

Conclusion

There is a significant difference between industry safety testing and the safety evaluation of Lithium-Ion products. These two safety regimes must compliment each other to provide a safe product to the consumer. The critical areas in a safety evaluation are the following:

- A safety evaluation should be performed once the design, foreseeable use, and exposure of the product are well known and understood.
- The safety evaluation of a product is design specific and the test results should be interpreted with pass-fail criteria. In addition, a "critical region" should be defined so that test results falling in this area shall be further investigated. Personnel having extensive experience in Lithium-Ion cells should perform the safety evaluation, battery design and safety related failures, as well as field failure analysis experience. The safety evaluation should be design specific and should take into consideration the unique design features and the known field failure stimuli.
- The critical region in the pass-fail criteria should be defined and analyzed. Further investigation and conclusions should be based on defensible scientific data. This could be used as lessons learned, narrowing the critical region for future safety analysis.
- Every aspect of the cell or battery pack should be evaluated from the cell level up to the system integration level and the safety evaluation protocol should be viewed as a dynamic protocol for each new product to be evaluated and not as a static protocol.

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