Occupational health and safety during development and usage of lithium-ion batteries

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Contents

21.1 Introduction

It has been repeatedly shown that the usage of lithium-ion batteries can harbor dangerous surprises, for example, in an incident in which a car battery caught fire several weeks after testing [1]. In addition to ensuring the safety of end users, this new storage technology poses new challenges in regard to occupational health and safety in industrial applications.

Everybody who handles electrochemical energy storage systems should be aware that, independent of whether a battery is "full" or "empty",

- there is no or only a limited possibility of switching off an individual battery cell's voltage.
- it contains a considerable amount of chemical energy.
- its battery cells' contents and reaction products are hazardous to health.

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© Springer-Verlag GmbH Germany, part of Springer Nature 2018
R. Korthauer (ed.), *Lithium-Ion Batteries: Basics and Applications*,
https://doi.org/10.1007/978-3-662-53071-9_21

Labor legislation's safety objectives have been established on a European Union level and are anchored in the German Occupational Health and Safety Act [2]:

> The employer has the duty to take the necessary occupational health and safety measures […] to influence the health and safety of workers.
>
> He has to examine the effectiveness of the measures and, where necessary, adapt them to changing circumstances […].

> When planning and implementing the measures […] the employer shall, in the light of the nature of the activities, […]
>
> 1. guarantee that they are appropriately organized and provide the necessary means, and
> 2. take precautions so that the measures are, if required, observed when performing all activities and incorporated into the management structures, and workers are able to fulfill their duties to cooperate.

The specific safety requirements from Table 21.1 have been developed on the basis of these regulations.

The requirements and safety measures depicted in Table 21.1 apply to every type and size of battery. However, the following factors specifically apply to industrial applications of lithium-ion batteries:

- Usage of batteries larger than consumer batteries means that there is more chemical energy that might be released in the event of an incident.
- Series connection of hundreds of individual cells results in higher voltages, which are perilous in the event of an accident.
- Operating conditions can change owing to circumstances, e.g., in road vehicles or depending on the load profiles.

Table 21.1 Battery-specific safety requirements and measures

Battery safety requirements	Safety measures, examples
1. Protection of electrical potential against inadvertent conductance	Galvanic isolation, sufficient clearance and creepage distances, electric shock protection
2. Securing controlled electrochemical processes	Safety-tested cells, electronic battery management, suitable storage temperatures, cooling
3. Verification of the battery cells' mechanical integrity	Casing, protected installation location, robust transport packaging

Moreover, the industry developing these new applications is to a certain extent navigating in uncharted waters. Newcomers and companies from other areas are joining the emergent battery production market. They do not have any experience regarding specific occupational health and safety.

21.2 Occupational health and safety during the battery life cycle

Table 21.2 displays the battery life of industrial applications. The core life cycle and all of its activities are shown side by side. The activities normally apply to each of the individual phases. On the left, logistics activities such as storage and transport are depicted; on the right, the accompanying activities development and incident handling are depicted.

Each of the activities has specific occupational health and safety requirements:

Cell production As cell production includes handling hazardous chemicals, the occupational health and safety requirements are similar to those of the chemical

Table 21.2 Battery life cycle

<table>
<tr><th colspan="6">Industrial battery life cycle phases</th></tr>
<tr><td rowspan="10">Storage</td><td rowspan="10">Transport</td><td>Cell production</td><td>Processing materials and substances into completed and functioning battery cells</td><td rowspan="10">Development/testing</td><td rowspan="10">Incident handling</td></tr>
<tr><td>Battery system cell integration</td><td>Electrical and mechanical cell integration. Integration of electronics and further interfaces (cooling, housing, etc.)</td></tr>
<tr><td>Battery integration in application system</td><td>Battery integration with high-voltage electrical system, electronic control, mounting, cooling system, etc. in an overall system, e.g., an e-drive.</td></tr>
<tr><td>Application system provision</td><td>Commissioning, testing, customer sale (if applicable)</td></tr>
<tr><td>Normal operation</td><td>Usage under intended operating conditions (vehicle, industrial application, etc.)</td></tr>
<tr><td>Maintenance and service</td><td>Periodical testing, troubleshooting, etc.</td></tr>
<tr><td>Repair</td><td>Dismounting and replacement of batteries</td></tr>
<tr><td>Decommissioning</td><td>Application system close-down, battery decommissioning</td></tr>
<tr><td>Disassembly</td><td>Disassembly of battery systems into modules, cells, other parts</td></tr>
<tr><td>Disposal/recycling</td><td>Suitable scrapping of cells, reclaiming of materials</td></tr>
</table>

industry. Correct cell production also serves as an important foundation for occupational health and safety in the subsequent phases, because manufacturing errors, which possibly lead to cell fires at a later stage, pose a potential danger for processing and usage.

Battery system cell integration During high-voltage battery production, the overall voltage increases with each cell connected in series. Electrical safety issues must be considered from 75 V DC upwards, because then the Low Voltage Directive applies [3].

The most important occupational health and safety measures during cell integration are:

- battery assembly only by qualified personnel (qualified electricians) with a lithium-ion battery safety briefing,
- employment of special tools and working clothing when working on live components,
- installation of warning and access control signs for non-qualified personnel.

Normally, the battery assembly results in a closed system, which not only integrates the mechanically and electrically connected cells, but also the following components:

- battery isolator and fuse
- electrical connectors (plugs) for high and low voltages as well as for communication purposes
- battery management electronics and sensor technology
- cooling system connections, if applicable
- housing

A system completed in such a fashion (Fig. 21.1) is not considered a direct hazard when used appropriately under the following conditions:

- The battery poles' electrical potential has been disconnected from the mains.
- The isolation resistance of high-voltage circuits to tangible parts is sufficiently high.
- During assembly and testing no errors have occurred that could cause cell damage.

As with cell production, appropriate quality assurance measures are the foundation for occupational health and safety at a later stage. Functional safety, i.e., the effectiveness of the battery management's electronic safety functions that protect the battery system against dangerous overloads during operation, is very important. The effectiveness of such protective functions is essential for safety during system integration tests and operating mode.

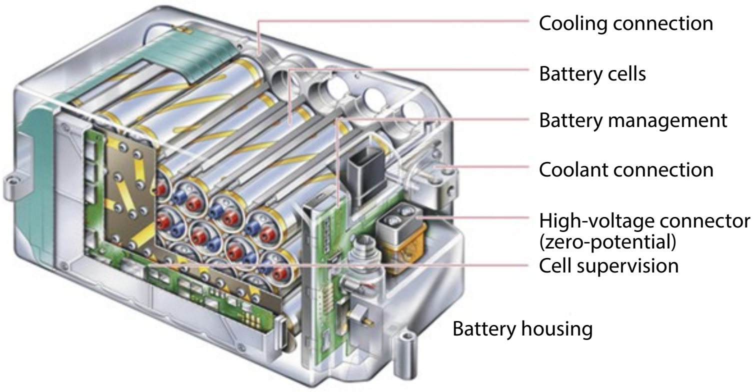

Fig. 21.1 Closed battery system

Battery integration in application systems Appropriate usage (prevention of mechanical or thermal overloads) of batteries, which are usually encased, is a requirement.

Based on these conditions, the occupational health and safety measures focus on electrical safety.

The foundation for occupational health and safety consists of qualified personnel (qualified electricians aware of battery-specific risks), suitable specialized tools for working on live components, and warning and access control signs for non-qualified personnel.

Application system provision and appropriate operation The occupational health and safety of the operators must be ensured if an application system with an integrated battery is used.

As a battery system has a design that enables it to be operated safely in normal operating mode, occupational health and safety measures generally focus on safety briefings and determining organizational procedures:

- briefings on identification of hazards (lightning sign, etc.)
- briefings on installation positions of batteries
- protection of batteries against unauthorized manipulation (insecure areas, if applicable)

Maintenance and service There is a distinction between the maintenance and service of the entire application and of the battery system.

In terms of occupational health and safety, it is most important that

- the battery cannot be damaged dangerously by modifications to the overall system (e.g., by introducing more heat).
- batteries cannot be damaged unknowingly (e.g., repair welding).

Furthermore, batteries that are out of order must be identified (e.g., via battery diagnostic interfaces), and battery repairs should only be performed by approved specialists. These last aspects require extensive organizational measures, which usually have to be settled in a timely manner between the OEM and the battery manufacturer (e.g., in the form of maintenance contracts). All diagnoses and, if applicable, alarm functions must be designed so that safety-relevant information can be assessed and processed in a target-oriented fashion.

Storage Appropriate storage of cells or batteries is a primary requirement for safe handling. This applies to

- compliance with specified storage temperatures and permissible climatic conditions. In particular, high temperatures damage the cells; in extreme cases this can result in so-called thermal runaway.
- storage with suitable states of charge. An extreme deep discharge must especially be prevented, because it might lead to irreversible cell damage.
- protection from mechanical damage (e.g., by means of adequate packaging).

Also, the storage location must be suitable to facilitate fire protection ensuring that

- batteries are protected from other fire hazards (e.g., in containers with fire protection classification F90).
- battery fires do not spread to other parts of the storage location (e.g., by means of storage in separate buildings).

Transport Aside from the extensive legal requirements concerning transport safety on public roads [6], the following points should be observed for all transport:

- there should be no mechanical overload (vibration, shock, etc.).
- the temperature limits must be heeded.
- there is appropriate protection against climatic influences.

Caution must also be exercised during packing and unpacking. Especially the elastic surface of pouch cells could be critically damaged by sharp or pointed objects. It has been reported that severely scratched cells are frequently rejected because their boxes are opened with a knife [4].

In terms of occupational health and safety, the quality assurance measures enable safe handling of cells and batteries. This includes performing appropriate visual and functional tests on cells (if applicable) before they are installed in a battery system.

Development/testing The battery life cycle depicted at the very beginning is of course an ideal; it is based on harmonized procedures and sophisticated technology. However, the innovative field of new battery applications requires further development and optimization of both the products and the processes. This is why it is advisable to take into consideration the respective level of development to add occupational health and safety measures, if applicable, especially in the following situations:

- testing of cells without safety certification
- testing of systems without validated safety functions
- relevant modifications of cells, battery, and application system design.

Developing cells, batteries, and systems with a focus on safety will remain an essential requirement for occupational health and safety in regard to their handling.

The slogan for industrial battery application development must be “Design for Safety”. Chemical, mechanical, electrical, and electronic cell design requires utmost diligence.

To fight electrical hazards, it should be rendered impossible or at least very difficult for assembly staff to touch dangerous circuitry during the construction of modules due to simple handling mistakes. This can be achieved by employing suitable electrical connector geometric designs. In addition, fully integrating the battery should factor in risk-reducing elements in the event of a battery fire: Potential fire effluents should be diverted into inaccessible areas, preferably into the open air.

Destructive battery tests and tests with an increased cell damage risk should be performed in special laboratories with the facilities to competently handle reaction products that pose an explosion or health hazard.

Fig. 21.2 Electric vehicle after a battery fire following a crash test. The subsequent fire spread to four nearby vehicles [1]

The incident in which a battery fire started three weeks after a vehicle crash test and spread to other electric vehicles shows that peculiar risks inherent to batteries can surprise even experienced institutions (Fig. 21.2).

Incident handling As long as shortcomings in the quality of integration and supply cannot be completely ruled out, each involved organization needs to incorporate the eventuality of a cell or battery fire into their emergency regulations. The more cells involved in a fire, the higher the release of

- heat,
- toxic and very acidic substances,
- and possible build-up of explosive compounds.

Firefighting can become problematic because lithium-ion battery fires are “self-sustaining”, so damping down the fire is very difficult. Other firefighting issues are the battery casing, which is necessary to mechanically protect the batteries, and the almost inaccessible and heavily protected locations where batteries are installed (e.g., in the vehicle undercarriage).

It is therefore important to prevent the fire from spreading and to ensure that personnel or bystanders seek shelter. Protective breathing apparatuses, flame-resistant clothing, and shelters, if applicable, must be available for personnel in an emergency situation.

A specific disaster recovery plan for batteries should be agreed on with the (plant) fire brigade and practiced regularly. When defining disaster recovery measures for electrical accidents, it needs to be taken into consideration that direct current has additional physiological effects on organisms compared to alternating current in the same voltage range. Chemical disintegration within the human body can be more pronounced and, in some cases, requires special treatment in a hospital.

21.3 Company-specific occupational health and safety

Only a competent target-performance analysis can determine whether and to what extent additional occupational health and safety measures need to be employed in companies that develop, test, and process lithium-ion batteries. Practice has shown that this requirements analysis needs to be performed in a structured manner.

A systematic record should be kept of premises in which batteries or battery cells are transported, stored, processed, tested, or used (Fig. 21.3). The activities there should also be recorded, the risk hazards determined, and safety measures defined. Table 21.3 shows a simplified example. For more detailed planning and implementation of safety measures, the know-how of several areas of expertise are needed: technology, occupational health and safety, fire protection, and organization.

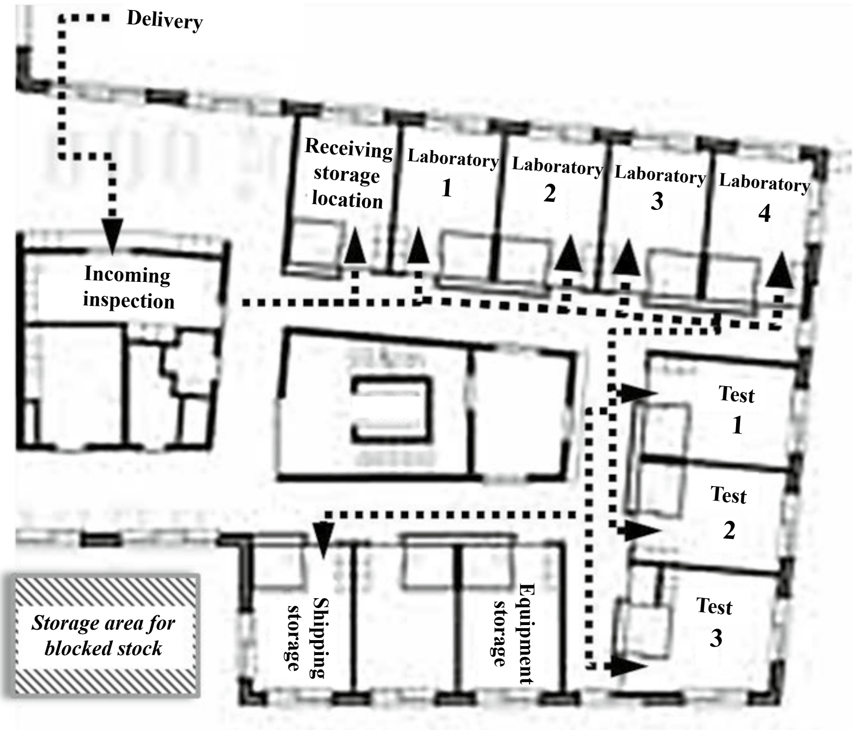

Fig. 21.3 Fictitious diagram of battery prototype production (example)

Table 21.3 Determination of specific safety measures (example)

Location/path	Activities	Risk hazards	Safety measures
Delivery	Incoming goods (cells); incoming goods (rejects)	Falls/shocks; contact with water; contact with heat; pre-damaged rejects	Level paths; roofing; immediate incoming goods (rejects) in quarantine (store)
…	…	…	…
Laboratory 1	Electrical module assembly	Exposed live parts; electric arc; mechanical cell damage	Isolated tools; personal protective equipment; constructional design of connectors; …
…	…	…	…

21.4 Outlook

Before introducing or extending company activities to the industrial production of lithium-ion batteries, it is essential that awareness for battery-specific safety issues is acquired. This also applies to management. All personnel concerned must have a basic knowledge of the potential electrical and chemical hazards, because small product defects or carelessness can have a grave outcome. Systematic battery-specific occupational health and safety measures can be constructively implemented and tailored to company needs. Currently, no official standardized regulations for the safe handling of batteries are available [5]. For this reason, battery safety specialists need to be involved in addition to external and internal occupational health and safety experts.

All companies, from those responsible for cell production and battery assembly to those involved in rejection and recycling, need to employ special activities because the risk hazards and operators' knowledge about the technological characteristics of batteries and battery systems differ.

Health and safety requirements for the implementation or extension of battery-related operations are always tailored to a company's specific needs. For this reason and because of the limited experience with lithium-ion battery industrial production, this topic should be approached from an interdisciplinary perspective in order to implement constructive measures adapted to the technology.

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