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Non-destructive quality testing of battery separators

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Abstract

The growing demand and new fields of application compel battery manufacturers to higher product quality. As the battery separator is the main safety element of a battery cell, defect-free separators are a prerequisite for safe lithium-ion batteries. Hence, typical production defects have to be reliably detected by 100-percent inspection methods. For that reason, this paper presents the design of a non-destructive inspection approach for battery separator quality testing. Based on a requirements analysis the most appropriate test method is selected. Subsequently, a detailed implementation concept is derived and proven within a real production scenario.

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Keywords: Non-destructive testing; Battery separator; Optical inspection; Machine vision.

1. Introduction

Lithium-ion cells were the enabler for the market growth of mobile communication and information technologies, such as mobile phones or portable computers. Today, significant new applications involve their short- and medium-term use in electric vehicles and in stationary storage systems [1]. Hence, a reconsideration of the quality requirements is needed. Due to the high energy contents of these cells, the most important aspects are safety and reliability [2].

The main safety element of a cell is the battery separator (see Figure 1) [3]. This flat, porous membrane provides a physical and electrical isolation of the opposite electrodes. Its basic functionality involves preventing an electron flow within the cell and ensuring, in conjunction with the electrolytic fluid, the ion transport between the electrodes. Every discontinuity in the separator such as pinholes, gel particles or contaminations can influence the cell function by internal short circuit [4]. In the worst case scenario a resulting “hot spot” leads to a local melt down of the membrane. Consequently, the increased cell temperature causes a degradation of further cell components by partially exothermic reactions. This self-accelerating process is called “thermal runaway” [5]. In addition, the following cascade-like spread to other cells releases high amounts of energy to the environment.

Moreover, internal short circuits can occur at every stage of the battery life cycle. This fact has led to much-noticed recall actions of portable computers, airplane batteries or automotive batteries [3].

Thus, defect-free battery separators are a prerequisite for safe lithium-ion cells. In order to ensure this, a non-destructive, 100-percent testing of the membranes has to be performed. Due to the complex process chain this evaluation has to be made in causation, i.e. before the cell assembly [5].

Material	PE, PP
Thickness	7-40 µm
Porosity	30-50 %
Pore size	0,03-0,1 µm

Figure 1: Appearance and properties of microporous battery separators

Nomenclature

NDT	Non-destructive testing
RB/RD	reflection bright/dark field illumination
T	transmission

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2. Quality testing of battery separators

2.1. Battery separator inspection

A standard method for the detection of local defects in battery separators does not exist so far [6], [7]. A way for automated detection of battery separator defects, including their location and type, is the machine vision approach presented by ISRA Vision AG and Dr. Schenk GmbH [8], [9]. Both approaches are based on line scan camera systems with LED bar illumination. The implemented image processing and analysis algorithms are derived from continuous web inspection systems. A major drawback of this approach results from the huge variety of separator types. As the properties of separator membranes (e.g. thickness, porosity) are fitted to the respective application (e.g. cell type, cell chemistry) [6], there is a huge range of materials, production processes and structures as well as separator properties [4], [10]. Consequently, today's vision systems cause high manual adaptation efforts for every change of production setup. In addition, the derivation of image processing parameters is done based on expert knowledge. This is less reproducible and requires expensive specialist staff. Moreover, an adequate system design has to be performed in respect of occurring material defects. A systematic collection of defects, defect tolerances in battery separators and their causes does not exist in literature. Smith has presented a defect compendium for web materials which is partially transferable [11]. A first analysis was done by Huber et al. [12]. Subsequently, an approach for the automated classification of detected events has been shown [13]. This distinction of events is especially important due to many different occurring discontinuities with completely different impact to the membrane quality. A missing element in this context is the selection of a suitable machine leaning algorithm.

2.2. Non-destructive testing

A non-destructive testing (NDT) method is a technical process for determining quality characteristics of a material or product, where the used energy interacts with the material without affecting its properties or the designated use behaviour [14]. In contrast to metrology, where quantitative (e.g. geometry) parameters of an object are determined, the aim of an NDT method is to evaluate the quality of the specimen. In the given context the quality is dependent on the presence of discontinuities. According to Steeb a discontinuity is an irregularity in a test object which was detected by means of a certain test method. Whether a discontinuity is actually a defect must be decided based on a test specification [15]. Available NDT methods can be classified into several groups. Therefore, the ASNT proposed five criteria: energy source, signal nature, detection method, method of recording and interpretation method [16]. Based on existing literature [16], [17], the taxonomy shown in Figure 2 was derived. This depiction comprises optical, acoustic, thermal, electrical, irradiation, magnetic and capillary methods.

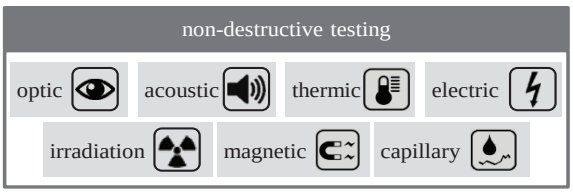

Figure 2: Taxonomy of non-destructive testing methods

3. Methodical approach for the design of a test system

Each NDT method involves specific advantages and disadvantages [17]. Subsequently, the best method for the present use case has to be selected. Moreover, a classification method based on machine learning algorithms has to be selected as the final element within the NDT approach. The high complexity of battery separator testing requires a specific testing approach for the signal recording, signal processing and classification. Hence, this paper presents a methodical design of a NDT system for battery separators (see Figure 3). In a first step a non-destructive test class is selected based on technical requirements concerning material characteristics, and constraints of the production process. Furthermore, process requirements concerning signal processing and classification have to be taken into account for the design of the specific test method in step 2. The test design for battery separators is addressed within the following sections.

3.1. Deduction of requirements

A NDT method for battery separator testing must fulfil the following technical requirements:

- Typically polymers like in most cases polyethylene or polypropylene with a high porosity is used as battery **separator material**. Thus, the NDT method must be suitable for inhomogeneous and electrically non-conductive materials.
- A classification of discontinuities requires a description of detected objects by **features**.
- The production process of battery separators comprises a foil extrusion with resulting continuous web material transport **speed** of 100 m/min.
- According to the "golden rule of metrology", the measurement uncertainty of a measurement system has to be at least by a factor of 5 lower than the required tolerance [18]. As battery separators are not produced in cleanrooms and thus are exposed to dust, a detection of objects smaller than 100 microns is not useful [19]. At the same time, a detection of the smallest possible disconti-

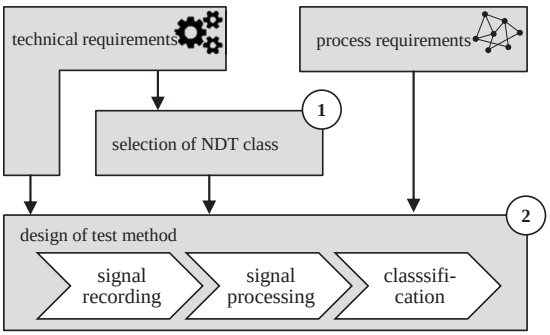

Figure 3: Methodical test design

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