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# FLEXIBLE BATTERY CELL TESTING OF GEOMETRICAL PARAMETERS TO IMPROVE THE SUSTAINABILITY OF BATTERIES OVER THE ENTIRE LIFE CYCLE

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**Abstract**

*Ensuring the sustainability of battery production and usage is critical in today's energy landscape. The battery lifecycle demands 100% inspection of battery cells to optimize resource utilization and minimize waste. Establishing geometrical tolerance limits is crucial due to the lack of previous empirical data. Only by combining geometrical, gravimetric, electrical, and chemical parameters can a comprehensive condition assessment of battery cells be achieved. Setting tolerance limits too narrowly leads to high rejection rates, affecting both cell production and subsequent assembly into modules and packs. A flexible cell tester that inspects the geometrical conditions of battery cells is essential. This system adapts to a rapidly changing product portfolio and functions as a mobile device. The tester is useful not only in battery production but also for state estimation for second-life applications, significantly contributing to the sustainability of the battery lifecycle. The need for the inspection of geometrical battery cell parameters is given by the product specific deviation of dimensions. As the demand for batteries grows and the need for environmentally friendly production methods increases, the cell tester ensures efficient and sustainable battery cell production and utilization. This represents a crucial step toward a more sustainable future, meeting the dual goals of efficient production and waste minimization.*

***Key words****: battery cell inspection, flexible cell tester, geometrical parameters, production efficiency, resource optimization, second-life applications, sustainable battery lifecycle, waste minimization.*

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# 1. Introduction

The automotive industry is undergoing a profound transformation driven by the global shift toward electromobility, which includes electric vehicles (EVs), hybrid vehicles, and plug-in hybrid vehicles (Wu et al., 2023). The current landscape of electromobility is marked by rapid innovation, technological advancements, and growing acceptance of electric vehicles in the mainstream market (International Energy Agency, 2024). Governments and regulatory bodies worldwide are implementing stringent emissions standards and offering incentives to accelerate the adoption of cleaner, electric transportation, leading to significant research and development efforts in battery technology, charging infrastructure, and electric vehicle design (European Commission, 2023, 2024). This transition has also catalysed a broader ecosystem transformation, with major automotive manufacturers making substantial investments in electric vehicle platforms (Volkswagen, 2024) and new entrants challenging traditional automotive giants (Dau et al., 2022). Additionally, the entire value chain, including suppliers, infrastructure developers, and energy companies, is adapting to the evolving demands of electric mobility (World Economic Forum, 2019).

Amidst this rapidly changing environment, the diversity of battery cell manufacturers, cell types, and technologies presents significant challenges (Neef et al., 2022). Variability in cell parameters, has become a critical issue, as the tolerances between cells are often high. Ensuring the homogeneity and quality of these cells is essential, especially for their use in the automotive sector. While much of the current research focuses on the electrical and mechanical parameters of battery cells (AVL List GmbH, 2024a; Rojas & Khan, 2022), the importance of 100% inspection of geometrical parameters remains underexplored. The benefits of an automated and flexible testing device specifically designed to assess the geometrical parameters of battery cells is an area that has received relatively little attention in the existing literature. Such inspection is crucial for determining the suitability of cells for integration into battery modules and packs in automotive applications. Testing involves the classification and evaluation of various parameters that impact battery cell performance. This includes not only electrical parameters but also geometrical and mechanical parameters as well as additional parameters like temperatures. (see Figure 1).

The combination of all these parameters helps with the design and optimization of the entire battery system in terms of efficient use of resources. (Tendera et al., 2022).

The primary objective of this study is to highlight the necessity and benefits of geometrical parameter inspection using a universal testing device. This device is designed to accommodate various cell types and formats, making it particularly valuable in prototype development and small-scale production. Furthermore, the flexibility of the device ensures its relevance in a future where battery cell designs continue to evolve.

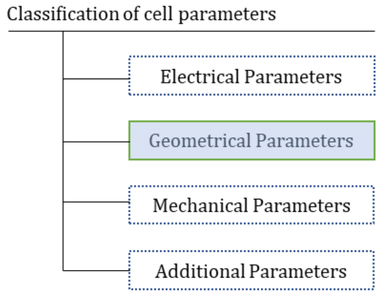



*Figure 1: Classification of cell parameters.*

## 2. Demand for a geometrical cell tester

The general need for testing battery cells can be summarized roughly in following aspects:

- High-quality products: To ensure the production and delivery of high-quality battery products, testing is crucial. Rigorous testing processes help identify and rectify any manufacturing defects or inconsistencies, contributing to the overall reliability of the batteries.
- Safety aspects: Testing plays a pivotal role in assessing the safety features of battery cells. It helps identify potential risks such as overheating, short circuits, or other safety hazards, allowing manufacturers to implement measures to enhance the safety of battery technologies. (Jaguemont & Bardé, 2023; Liu et al., 2020)
- Lifetime concerns: The lifespan of battery cells is essential to evaluate. By subjecting cells to various conditions and cycles, manufacturers can gather data on their durability and performance over time. This information is vital for designing batteries that meet or exceed the expected lifespan requirements. (Schlögl et al., 2024)
- Reuse/Recycling: For batteries intended for reuse or recycling, thorough testing is necessary. Testing helps determine the state of health of a used battery, making decisions about its suitability for second-life applications or the need for recycling. It contributes to sustainable practices within the battery industry. (Schlögl et al., 2024; Wett et al., 2024)

### 2.1 Battery specific information within battery lifecycle

Figure 2 shows a typical battery lifecycle (BLC) for the main application in an EV. A wide variety of information is generated for an energy storage device over the course of its life. Starting with the raw materials used and their origin, through the production of battery cells themselves, their subsequent assembly into battery modules and packs and their integration into the vehicle, the most basic production data has been generated. A cell incoming inspection (CII) is particularly necessary at the interface between cell production and subsequent assembly into the overall energy storage system. Not only should the minimum requirements of geometrical specifications be checked, but also a further classification into performance classes should be carried out. The aforementioned combination of all parameters provides information about the condition of the specific cell. Clustering aims to install 'identical' cells in modules and packs in the sense of cell balancing and the integration of product data into the production process also enables process and design optimization.

This information is supplemented by data monitoring in the use phase in order to be able to make data-based decisions for potential second life applications. This requires 100% inspection to provide the specific data of each cell for the entire BLC to record condition changes.

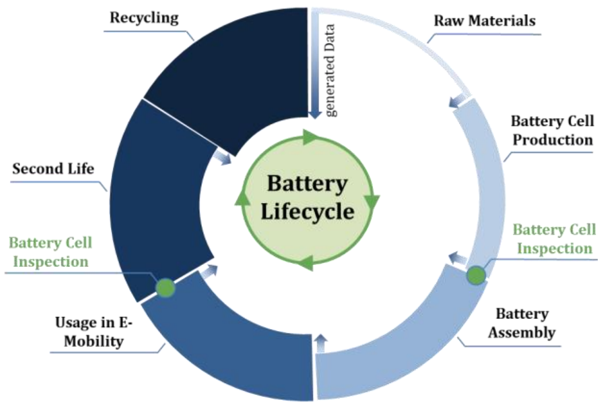



*Figure 2: Data generation in battery lifecycle.*

The data acquisition in the CII is performed from a combination of several sources. In order to be able to define tolerance limits and to generate any proper measurement values at all, the nominal data of the battery cell must be known. Based on this, the permissible deviations and required accuracies can then be defined. During the incoming inspection itself, the measurement data is acquired, which is then used to make decisions about the condition and suitability of the cell for usage in traction batteries (Figure 3).

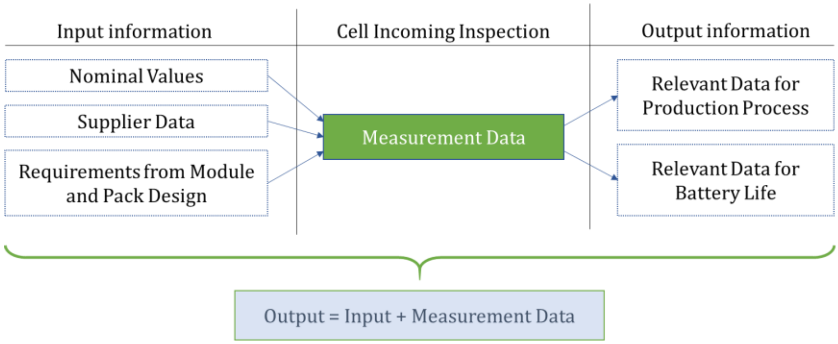



*Figure 3: Information enhancement with measurement data.*

## 3 Geometrical battery cell parameters

To inspect the geometrical parameters, an universal cell tester has been developed that is capable of testing a broad range of battery cell types and formats. This device aims to provide precise and flexible inspection of the geometrical parameters of battery cells, ensuring comprehensive quality assessment.

The battery cells analysed in this study are from various manufacturers and cover the dimensions commonly used in the automotive industry. Nevertheless the focus is on cells used in prototype and small-series production, as seen at the Battery Innovation Center of AVL List GmbH in Graz (AVL List GmbH, 2024b). The testing device is utilized to measure geometrical parameters such as length, width, thickness, and volume. These measurements are automated and performed in real-time, facilitating 100% CII.

The overall requirement on the geometrical cell tester is to inspect battery cells from different cell types and formats. In general three different cell types are used for automotive applications: cylindrical cells, prismatic cells and pouch cells. Following cell dimensions where defined to be inspected with the cell tester to cover the majority of the cells on the market (Neef et al., 2022):

- Cylindrical cells: 18650, 18700, 21700, 33100 and 4680.
- Prismatic cells with lengths of 100 mm to 600 mm, heights of 80 mm to 150 mm and thicknesses up to 50mm.
- Pouch cells with lengths of 140 mm to 600 mm, heights of 90 mm to 180 mm and thicknesses up to 20 mm.

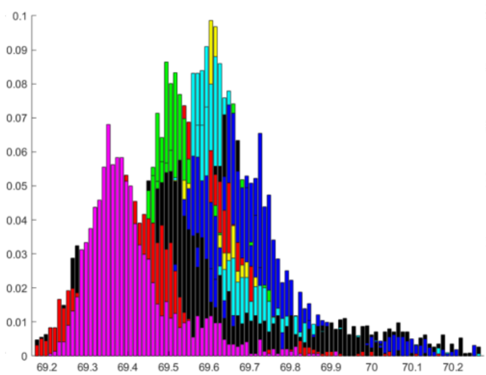
Geometrical parameters vary from cell type to cell type due to the different design, but also differ between manufacturers (Neef et al., 2022). In addition, the geometric specifications of a battery cell are often defined with a wide tolerance range. Table 1 shows an excerpt from representative typical geometrical parameters of a cylindrical cell, their nominal values and the upper and lower tolerance limits. It is also evident that not all geometrical dimensions are quantitatively determined, like battery cell surface conditions.

*Table 1: Excerpt of geometrical parameters of an 18700 cylindrical cell.*

| Properties | Parameters | Unit | Nominal Dimension | Min. Tolerance | Max. Tolerance |
|---|---|---|---|---|---|
| **Cell Case** | Diameter (overall) | mm | 18 | 17,85 | 18,15 |
| | Height (overall) | mm | 69,72 | 69,17 | 70,27 |
| | Height (without terminals) | mm | 67,57 | 67,37 | 67,77 |
| **Terminal** | Neg. terminal diameter | mm | 9,925 | 9,85 | 10 |
| | Pos. terminal diameter | mm | 7,925 | 7,85 | 8 |
| | Neg. terminal height | mm | 0,5 | 0,425 | 0,575 |
| | Pos. terminal height | mm | 0,55 | 0,4 | 0,7 |
| | Condition (defects,...) | -- | -- | -- | -- |
| **Cell Surface** | Scratches | -- | -- | -- | -- |
| | Unevenness, bulges | -- | -- | -- | -- |

As it can be seen in Table 1, an obvious parameter to emphasize is the cell height, as the overall height has in this case a tolerance range of 1.1 mm.

In the course of the CERES project, project partner AVL List GmbH has statistically analysed an extensive data set of several 10000 cells from one cell supplier, where the overall cell height of cylindrical 18700-cells have been investigated. In order to achieve statistical significance, only batches with more than 1000 cells have been examined. Figure 4 shows the cell height deviation in two diagrams, where the cell height in mm is plotted on the respective x-axis in 0.1 mm steps. In the diagram at the left, the cylindrical cells of the same batch are colour-coded. It is evident, that each batch has a different average cell height, but a normal distribution can be identified in almost all batches. In the diagram on the right side, the battery cells of all batches are combined and the overall distribution is shown. A normal distribution can also be seen here, the cell heights vary between 69.2 and 70.3 mm. The number of cells is plotted on the y-axis, so it is clear that a majority of the battery cells analysed have a height of 69.4 to 69.8 mm.



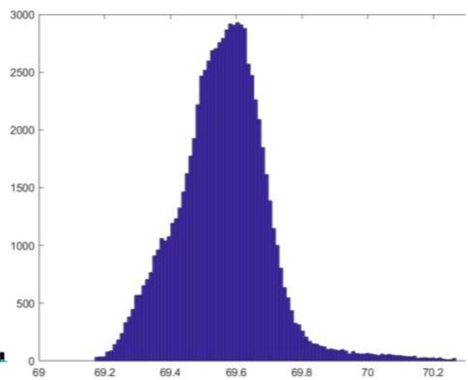




Figure 4: Cell height deviation of 18700 cells of different batches (left) and overall (right).

## 4. Discussion and Conclusion

The study found significant variability in tolerances between cells, underscoring the need for comprehensive geometric inspection. In comparison to previous studies, which have predominantly focused on electrical and mechanical parameters, this research contributes important insights into the necessity of geometrical parameter inspection, particularly concerning the suitability and traceability of battery cells. The findings suggest that geometric inspection is critical for ensuring the quality and deplorability of battery cells in the automotive sector. It allows for the selection of cells with the appropriate properties for integration into modules and packs, ultimately ensuring their successful deployment in vehicles.

This study has shown that a universal testing device for the 100% inspection of the geometrical parameters of battery cells is essential for ensuring the quality and utilization of these cells, not only for incoming inspection in the module and pack assembly but also for assessing the reusability of cells in second-life applications. This makes it possible to reduce the number of rejected cells in the production of first- and second-life applications and minimise the amount of subsequent waste. A potential limitation of this approach lies in the scalability of the testing device for mass production, as the current tests are limited to prototype and small-series production.

Future research should focus on optimizing and scaling the testing device for use in mass production, as well as integrating additional parameters to further enhance quality assurance also using artificial intelligence algorithms for failure detection. In conclusion, this study emphasizes the importance of comprehensive quality inspection for battery cells, especially in a rapidly changing and expanding market. The proposed testing device offers a flexible and future-proof solution, applicable in both prototype development and small-scale production within the whole BLC.

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