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Quality-oriented production planning of battery assembly systems for electric mobility

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Abstract

Electric mobility seems to be a viable solution for individual mobility in future. However, the use of these alternative drives is accompanied by high costs caused by the battery production. One approach to reduce the production costs is to reduce the rejection rate by integrating appropriate quality assurance measurements in assembly systems. To avoid subsequent, expensive modifications, those measurements must be integrated into the assembly system planning. Therefore, possible integrated measurement technologies for quality-critical characteristics have to be developed and evaluated for the use in the battery assembly. The results are integrated in a planning system to support assembly planners.

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Electric Mobility; Quality Assurance; Assembly Planning

Introduction

Individual mobility is highly important for a constantly growing number of people. For example, from 2000 to 2030, the passenger car density in emerging countries like India, Brasil or Indonesia is expected to increase by more than 400 percent. [1] The increasing demand for individual mobility and thus the need for fossil sources of energy faces several challenges in the future. The worldwide climate change leads governments to implement tighter regulations by reducing pollutant emissions and energy consumption. Also the availability of fossil fuels, that today enable the individual mobility, is limited and only locally available. In consequence, increasing energy costs lead to a strong need for new technologies that enable mobility in future. [2]

Challenges of battery assembly

Electric mobility seems to be a viable solution for these manifold challenges. One the one hand, pollutant emissions can be reduced locally by up to 97% through substituting the fuel consuming engine with an electrical powertrain that mainly uses lithium-ion batteries as energy source. [3, 4] One the other hand, the high manufacturing costs of batteries impede the market success of electrified cars. In order to seriously compete with conventional mobility solutions, the efficiency of battery production has to be increased by improving associated production systems. Especially further developments of battery assembly systems show great potential to improve the situation. [5]

In this context, uncertain market developments caused by unknown political and economic influences prevent the optimization of assembly systems for special sales volumes. Hence, assembly systems for flexible output volumes have to be designed. Furthermore, different existing variants of batteries and a missing standardization of battery designs as well as a great number of usable process technologies prevent assembly systems from becoming more competitive. [6] Modularly constructed assembly systems could provide a solution. [7]

A further impediment of increasing the efficiency of battery assembly is the minimization of the rejection rate. To prevent defective high-value products (the rejection rates of

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single process steps are in part in the high one-digit percentage range) from further processing, capable quality assurance measurements have to be integrated in the assembly processes. This way, safety hazards for workers and future customers arising from defective products can be excluded. [8, 9] In addition, a significant reduction of manufacturing costs by reducing scrap, could lead to achieving the best possible goals of selling electric vehicles at acceptable prices from 11.000 € to 25.000 €. [6]

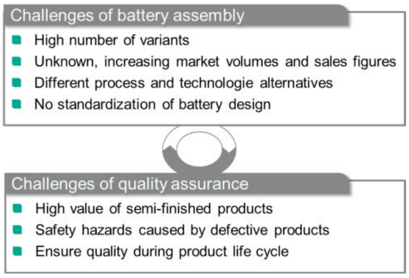

Fig. 1. Challenges of battery assembly and quality assurance

Because of the existing interactions between the product development, assembly systems and quality assurance, those three aspects have to be considered at the same time in the early planning phase (see figure 1). [10] This way, subsequent expensive hardware modifications can be avoided and an optimization of the use of assembly technologies and quality strategies at an early stage may be facilitated. To integrate quality assurance measurements in the assembly planning process, quality methods and measurement equipment have to be evaluated in advance for this application.

Battery assembly process

Regarding a pouch cell battery for electric vehicles, the battery assembly can be divided into the module and the battery assembly. [8, 11] The module assembly starts with extracting and gripping the cells. Depending on the battery module concept, different assembly sequences are conceivable. Usually the cells are stacked, sensors are integrated and their terminals are connected by screwing or welding, which are the currently used manufacturing technologies for this process step. [12] Afterwards, cooling components can be installed. The sensors and connections can be checked by an inline test. After the module housing is mounted, a final check of the battery module is conducted as a final process step. [12, 13] In the battery assembly, several modules are inserted in the lower part of the battery housing, depending on the type of battery. Following the assembling of the contact bars for the modules, the battery management system and the cooling system are inserted and fixed. Also the cells are charged to a desired level. In the end, the battery lid is applied and the battery is subjected to a tightness test. [13, 14]

Quality assurance during battery assembly

Quality assurance during battery assembly always depends on the various types and variants of parts to be assembled, e.g. cells, cooling components and housings and different assembling technologies that need to be taken into account. In fact, the use of measurement equipment for quality assurance that can be integrated in the assembly line (the so-called inline quality assurance the approach focuses on) heavily depends on each special application. [15]

In general, different types of cells and components, which are usually marked by different kinds of barcodes, have to be identified by optical measuring systems like camera systems or laser scanners. Similar systems are used to solve tasks in the area of correct positioning of various components, like cells during cell stacking, or cells and contact bars when connecting by welding. [16] In addition, completeness checks are common tasks for camera systems. Electric measurement devices are used to observe electrical characteristics, like voltage, the state of charge and the internal resistance of cells and modules, and finally to check the characteristics of the entire battery system.

The inspection of joining locations poses the main task to quality assurance systems during the battery assembly. [17] Besides camera systems for position recognition and completeness checks, process parameters like the torque or the turning angle are verified when joining parts by screwing. To detect failures in the welding processes, the parameters of such processes have to be controlled. Failures on the surface of the weld seam can be checked by several optical measurement systems. Different volumetric defects like inclusions or pores that cannot be detected by observing the weld seam surface, have to be excluded by the selection of appropriate welding process parameters that were previously defined by the help of destructive laboratory tests (e.g. tensile tests). [16] The controlling of the transition resistance by electrical measurement devices does not necessarily determine the quality of the joining. Non-destructive test procedures like thermography or acoustic systems first have to be qualified for the use in battery assembly. During the application of glue for glue joints or during the application of heat transfer media, the position and geometric shape of the bead can be measured by camera systems, laser triangulation or a combination of both. In order to check the tightness of the cooling components and their attachments, pressure and leakage tests are carried out. [13]

At the end of the assembly process, software systems have to be checked and electrical characteristics are controlled again as part of the end-of-line test. Also, a possible coating of the housing has to be visually checked. In addition, the dielectric strength of the battery system has to be checked to ensure electric isolation. Visual inspections as well as weight controls for different module and battery components accompany the process all the way. [13]

4. Deficits in quality-oriented production planning

Regarding the planning of assembly systems, several approaches exist to compute a minimum cost assembly line by balancing included assembly processes [18, 19, 20] or choosing ideal product mixes on one line. [21] There are also methods to configure assembly lines by taking product requirements into account. However, none of the approaches