Intelligent Manufacturing Process Model of Electric Vehicle Battery Pack and Experimental Verification

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Abstract. According to the manufacturing and assembly process of battery pack system, this paper proposes a common process model to realize the intelligent manufacturing of electric vehicle battery pack. And the experimental verification platform is designed and built. Several key links from the actual production links were extracted to the experimental verification platform. These not only represent the typical and key process in the production and assembly of electric vehicle battery pack, but also fully reflect the automation, information and intelligence of the manufacturing. It can simulate the intelligent manufacturing process of battery pack system in a small environment and verify the process model. It can simulate the intelligent manufacturing process of electric vehicle battery pack in small environment and verify the process this paper proposes.

Keywords: Assembly process, battery pack system, intelligent manufacturing, electric vehicle.

1. Introduction

Intelligent manufacturing is one of the important directions for the future development of the world's manufacturing industry. The so-called intelligent manufacturing refers to the intelligent design, manufacturing and equipment through intelligent perception, human-computer interaction, decision-making and execution technology based on advanced technologies such as modern sensing technology, network technology, automation technology and anthropomorphic intelligent technology. Intelligent manufacturing is the deep integration of information technology, intelligent technology and process equipment manufacturing technology. The strategies of "Industry 4.0" in Germany, "Industrial Internet" in the United States, and “Made in China 2025" are all carried out around intelligent manufacturing [1].

There are many modes of intelligent manufacturing. The most basic mode is the digital, networked and intelligent development of manufacturing, it is the integration of manufacturing technology, intelligent science and technology, new generation information technology and professional application technology applied in the entire life cycle of the manufacturing field. This is particularly prominent in the production companies related to the automotive industry [2].
Digital process design mainly takes the product process model as the carrier, which contains product related information such as process design, manufacturing, testing and evaluation. It transmits product information in the form of data [3]. This not only runs through the product design, process planning and manufacturing, forming a continuous and complete digital manufacturing chain, but also the product design information can be better understood and quantified [4]. In this way, it can not only form a continuous and complete digital manufacturing chain running through the whole complete period of product design, process planning and manufacturing, but also understand and quantify the product design information [5].

While the digital process technology is developing day by day, the standard research and formulation are lagging behind. China has not carried out the standardization of electric vehicles battery pack system industry. As a result, those related enterprises cannot get a good guidance [6].

In order to promote the engineering application of digital process technology in the manufacturing of electric vehicles battery pack system, research and formulation of digital process model technical standards for the intelligent manufacturing of electric vehicles battery pack system should provide enterprises with standardized guidance and scientific evaluation standards [7].

2. Establishment of digital process model
The intelligent assembly process of electric vehicles battery pack system covers the common assembly process of pouch cell, hard clad battery and cylindrical battery. And its assembly process is greatly affected by pack design. On the basis of extracting the common features, the general process of intelligent assembly of electric vehicle battery pack system is summarized into four parts [8]: cell pretreatment, module assembly, welding and battery pack assembly, as shown in Figure 1.

![Figure 1. The intelligent assembly process of electric vehicles battery pack system.](image-url)
places them in a fixed position according to the system instructions. The sensor detects the assembly accuracy and uploads the detection information. In the module fastening station, the module is fastened. Finally, the module is transported to the electrode detecting station, in which the vision system detects the cell series and parallel combinations in the module and uploads the detection information.

Welding includes bus bar installation, bus bar welding and welding quality inspection. The bus bar is installed on the module according to the specific position. Then the welding equipment welds the bus bar to the positive and negative poles of the module. The sensor detects the welding parameters and welding defects, and uploads the detection information. In the welding quality detection station, the detection equipment detects the welded module and uploads the detection information to the system. Finally, the coding equipment codes the modules to complete the binding of the information and the modules.

Battery pack assembly includes metal shell pretreatment, module installing, BMS installing, connector installing, cable and wire installing, pack parameter measurement, metal shell fastening, gas tightness detecting, pack hoisting and transporting, charge-discharge test [19]. The operator performs preliminary cleaning and visual inspection of the shell; In the module installing station, the manipulator grabs the module and puts it into the shell, and the vision system detects the position of the module and uploads the detection information; Then the workers install the connectors, cables and wires and upload the installation information; In the pack parameter measurement station, the electrical detection equipment detects the electrical parameters of the installed battery pack and uploads the detection information; In the metal shell fastening station, the pack shell is tightened and fixed, and the torque information is uploaded at the same time; In the gas tightness detecting station, the appearance test and air tightness test of the battery pack system are carried out, and the test information is uploaded; Finally, the battery pack system is hoisted off the production line and transported to the charge-discharge test station to for charging and discharging test. The test information is uploaded to the system.

The above process model reflects the most basic assembly process to fit the actual production situation of most domestic enterprises; On this basis, the technical requirements for intelligent manufacturing of battery pack system are added to guide some qualified advanced technology enterprises to realize digital, networked and intelligent battery production and manufacturing according to their own conditions.

3. Experimental Verification Platform

According to the assembly process, the experimental verification platform can be divided into cell picking station, cell parameter measurement station, cell turnover station, cell pre assembling station, module stacking station and electrode detecting station. Logically, it can be divided into mechanical system, electrical control system and software system.

The electrical control system and software system interact with each other in OPC mode, and the SCADA system and standard verification system interact with each other in OPC UA mode, as shown in the figure.

3.1. Part of Mechanical Design

The hardware system of intelligent manufacturing standard comprehensive experimental verification platform for electric vehicle battery pack system is composed of cell kicking station, remote control box of production line, cell parameter measurement station, cell turnover station, main control cabinet, 1# control cabinet of 6-axis robot, 2# control cabinet of 6-axis robot, module stacking station, cell assembling station, server and cell transmission device. It is shown in the figure 3.

The intelligent cell feeding rack has two boxes which are rigidly connected but used for independent feeding. WIA-FA detection sensors are set at the bottom of each cell’s location. When one of the boxes is feeding, the other box can be fed manually. The two groups of boxes are used alternately. If the box at the feeding position has no cells detected by WIA-FA sensor, the intelligent
cell feeding rack can automatically switch to another box with cells. The main function of the cell feeding robot is to realize the automatic grasping and feeding of the cell, and it has two modes: automatic grasping and manual, which can be freely switched when needed. Its grasping hand mechanism has four degrees of freedom, which can quickly and freely carry out a series of actions such as grasping, code scanning, rotation of the cell.

Figure 2. The architecture of experimental verification platform.

The main function of the cell assembling robot is to use the vacuum adsorption device to absorb the qualified cells from the production line and stack cells on the pre-grouping device. The stacking work of different types and specifications of modules can be completed according to the demands of the control system. Then, the camera on the robot is used to take pictures of the positive and negative pole arrangement sequence of the group of cells for the control system to judge whether the cells are consistent with the design sequence.

The main function of module stacking robot is to grasp the assembled cells and stack them to module. The robot has two kinds of grasping devices: claw and vacuum suction to complete different actions and functions. Firstly, the vacuum adsorption device on the robot is used to absorb the shell of the module and places it in the positioning slot on the assembly device. Secondly, the robot hand claw is used to grab the qualified cells and places it in the corresponding shell of the module. Finally, the vacuum adsorption device on the robot is used to absorb the side plates on both sides of the module shell to complete the assembly action and form a qualified component of the cell module.

3.2. Part of Electrical Design

The network topology of production line, that is, the layout of communication bus of the whole system. The whole production line includes industrial control computer, switches, PLC master station, PLC slave station, RFID reading and writing system, visual monitoring system, production line drive motors. The PLC master station and PLC slave station, and the equipment-level field network (such as cylinder magnetic switch, workpiece detection, button, indicator light, photoelectric switch, etc.) all use industrial Ethernet communication (Profinet bus protocol). The network topology is shown in figure 4. The system network topology is shown in figure 5.
3.3. Function of Software and Interoperability Consistency

Electric vehicle battery pack system assembly intelligent manufacturing standard comprehensive experimental verification platform information system architecture is composed of enterprise resource management system, digital process planning guidance system, production execution management system, OPC UA, power battery system assembly execution site, and mainly includes the following functions: The information system structure of the electric vehicle battery pack system assembly intelligent manufacturing standard comprehensive experimental verification platform information system structure is composed of an enterprise resource planning system, a digital process planning guidance system, a manufacturing execution system, OPC UA, and an on-site assembly execution. It mainly includes the following functions:

Order management and query: release new production order in enterprise resource planning system. The functions of adding, modifying, deleting and querying orders are provided in the interface. Production process, BOM and production capacity for new orders can be generated.

Product information management of electric vehicle battery pack: The structure of the electric vehicle battery pack system is analyzed, demonstrated and decomposed based on the final design information and assembly process characteristics of the electric vehicle battery pack system, so as to manage the product design information, structure composition, module category, module composition and cell category of the battery pack.

Process planning: The content of the overall assembly process plan established in the previous stage is divided into different assembly steps with high operability. The production process of the product is planned in detail from different levels of section, station and procedure step by step. Then the assembly sequence and content of the electric vehicle battery pack are specified.

Production monitoring: The real-time production data tracking is provided. The work-in-process information of the workstation, the number of orders (the number of modules completed), the material status (quantity) and environmental parameter information are displayed on a large screen. The system monitors 7 stations, the equipment status of each station in real time. It can display the production process and equipment operation rules of each station, and prompt the operator to produce according to orders.

According to the process and information flow of the intelligent manufacturing digital workshop for the electric vehicle battery pack system, this project achieves consistency and interoperability on three aspects: the network plane, the control plane and the application plane. It covers all levels of consistency and interoperability.

It includes the following contents:

1) Network plane: it involves the consistency and interoperability of network communication, resource management and other physical constraints, mainly including different protocol stacks, function modules, service and management modules, support modules (power supply, computing, storage and interface), and the interconnection and interworking of communication module datas.
(2) Control plane: It involves the consistency and interoperability of the manipulated variables and parameters in the closed-loop system composed of the controlled object, controller, actuator and sensor. This plane is built above the network plane to collect measurement and status data of sensors and actuators. It estimates, predicts, interprets and maps the data, so that the state of the controlled object meets the overall expectations of users. It specifically involves the interconnection and intercommunication of various data in time trigger mode, event trigger mode and self-trigger mode.

(3) Application plane: this plane is closely related to system application. It is oriented by network application and independent of network plane and control plane. The consistency and interoperability requirements of this plane involve the mutual mapping, understanding consistency, and the unification of visualization and humanized data in the comprehensive coordination mechanism set by the user, the performance analysis and evaluation system and the user interface.

4. Experiment and Conclusion
We have built an experimental verification platform for intelligent manufacturing of the electric vehicle battery pack system, as shown in the figure 6. And then the following two aspects are tested: assembly process model and consistency interoperability.

![Figure 6. Physical picture of experimental verification platform.](image)

According to the demands of practical production, the flexible manufacturing and data consistency interoperability of the production line are verified. The verification scenario is: the production line is producing type A modules, and ERP places an urgent production order for type B modules. The verification process is as follows:

(1) The production line is producing A-module. ERP sends a B-module urgent production order to MES, including production capacity data, product definition data and production scheduling information.

![Figure 7. Physical picture of experimental verification platform.](image)
(2) MES sends the production suspension request of type A module to PLC, and PLC sends the production suspension response of type A module to MES after the production of the latest type A module (the status of execution is successful).

(3) MES splits the B-type urgent order and sends the B-type module production operation request, equipment operation rules, production process, quality inspection request and quality inspection rules to PLC.

(4) PLC receives B-module production operation request, quality inspection request and returns B-module production operation response (the status of execution is successful) and quality inspection response (the status of execution is successful) to MES. The production line starts to produce. And PLC sends control instructions data of cell processing, module assembling and bus bar assembling to equipment of the production line.

(5) Equipment of the production line uploads status information and measured value in the process data of cell processing, module assembling and bus bar assembling to the PLC. PLC uploads the production related information of cells, modules, material rack, environment and quality to MES;

(6) When the order production has been completed, MES sorts out the production data in the B-type module order and uploads the relevant production completion status to ERP, including production performance information.

(7) MES sends a request for the production and operation of the A-type module to the PLC to continue the production of the A-type module.

(8) When the order production has been completed, MES sorts out the production data in the A-type module order and uploads the relevant production completion status to ERP, including production performance information.

We propose a process model which can completely describe the function, structure, information and control of the battery pack assembly. A stable, coherent and reconfigurable model framework has been established. And through the experimental verification platform built by the laboratory, the interoperability matching detection under the individual service needs has been solved. The problems, such as incomplete information interaction, multiple roles and explosion of global state combination, in the interoperability of detection under personalized service are solved. It can locate and correct the mismatch accurately with low cost in a large amount of interoperability information.

(1) The top-down standard architecture design concept is adopted to realize the integration of process flow and information flow. According to different business needs, various technologies of business, service, data resources, common support, network and perception are cut and combined to form a flexible and customizable solution.

(2) The process flow and information flow are combined. For the operation process of each station, a quantifiable automatic detection method is proposed to realize the whole process quality traceability.

(5) It reflects the flexible characteristics of intelligent manufacturing process of battery pack system, that is, the system can dynamically adopt the corresponding process according to the changes of processing product or raw materials, so as to realize the small batch and personalized manufacturing of products.

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References
[1] Sun X, Li Z, Wang X, et al. “Technology Development of Electric Vehicles: A Review,” Energies, vol 13, Dec. 2019.
[2] Ryan D’Souzaa, John Patsavellasa, Konstantinos Salonitis, “Automated assembly of Li-ion vehicle batteries: A feasibility study,” Procedia CIRP, vol. 93, 2020, pp. 131-136.
[3] Zhenhe Li, Amir Khajepour, Jinchun Song, “A Comprehensive Review of the key Technologies
[4] WANG Tianran, KU Tao, ZHU Yunlong, YU Haibin. Smart Manufacturing Space. Information and Control, 2017, 46(6): 641-645.

[5] ZHANG Yi, FENG Yiping, RONG Gang. Intelligent Manufacturing-Oriented Technical Transformation of Manufacturing Execution System. Information and Control, 2017, 46(4): 452-461.

[6] XU Ying, LI Li. Development and Prospect of Manufacturing Big Data. Information and Control, 2018, 47(4): 421-427.

[7] LIU Qian, GUI Jianjun, YANG Xiaowei, QU Yanli. Research Status and Development Trends for Sensing and Control Technologies of Industrial Robot from the Viewpoint of Patent Analysis. ROBOT, 2016, 38(5): 612-620. DOI: 10.13973/j.cnki.robot.2016.0612.

[8] ZHAO Wei, WANG Kai, XU Aidong, ZENG Peng, YANG Shunkun, SUN Yue, GUO Haifeng. An Industrial Robot Health Assessment Method for Intelligent Manufacturing. ROBOT, 2020, 42(4): 460-468. DOI: 10.13973/j.cnki.robot.190438.