Research and Application of Flexible Manufacturing Line for Power Battery Module of New Energy Electric Vehicle

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Abstract. At present, due to the lack of national mandatory new energy vehicle power battery pack specifications and standards, so each production enterprise is fighting for itself, the size, connection mode and interface of the power battery pack are not unified, these factors seriously restrict the large-scale production and application of the power battery pack. Aiming at the characteristics of small batch and multi variety in the production process of new energy vehicle power battery pack, in order to realize the automatic assembly of multi variety power battery pack, on the basis of scientific and reasonable production process planning of power battery pack, a flexible automatic assembly and testing production line is developed. It is of great significance for power battery manufacturers to meet the needs of all kinds of customers and improve the level of intelligent manufacturing.

Keywords: Power battery module, Flexible manufacturing, Production line.

1. Introduction

At the present stage of China's economic development, energy transformation, industrial upgrading and low-carbon economy have become the main directions of China's future development. In this context, new energy vehicles have developed rapidly and become a national strategy, which also represents the future development direction of the world automobile industry. As the core component of the new energy vehicle, the power battery pack accounts for about one third of the total cost of the vehicle in terms of cost composition. At present, in the power battery production enterprises of new energy vehicles in China, the production line of power battery pack is basically semi-automatic assembly or manual assembly. As a result, the disposable products of power battery pack have low qualification rate, low automation rate and insufficient production capacity, which can not meet the urgent demand of domestic market for high quality, high efficiency and safe power battery system, and will seriously restrict the development of new energy vehicles in China.

With the fierce competition in domestic and foreign markets, the manufacturing industry needs to improve production efficiency, reduce production costs and guarantee delivery time. The manufacturing system based on rigid automation can not meet the production demand of multi-variety, medium and small batch products. Due to the insufficient development of China's new energy vehicle market, the production of power battery packs is characterized by multiple varieties and small and
medium batches. In order to realize the flexible manufacturing of various power battery packs, a flexible automatic assembly and inspection production line was developed on the basis of scientific and reasonable planning of the production process of power battery packs. The production line can be quickly adjusted according to the change of production orders, so that it can flexibly adapt to the production of many kinds of power battery pack products, and become an ideal tool for enterprises to improve production capacity and efficiency and carry out intelligent manufacturing transformation.

2. Process flow and layout design of flexible manufacturing line

In order to realize the flexible assembly production of power battery packs with multiple varieties and small batches, it is necessary for the control system to dynamically adopt the corresponding process flow according to the change of orders. By summarizing and analyzing the actual production process of power battery pack, the process flow of automatic flexible assembly line of power battery pack is planned as shown in Figure 1. The process flow of the production line is divided into two interconnected sections, i.e., cell pretreatment and module assembly, and each section contains several stations. Among them, the cell pretreatment section mainly completes the automatic on-line, electrical parameter detection, cell turnover and NG cell off-line. The module assembly section mainly completes the flexible stacking and pre-grouping of modules, and finally completes the loading and assembly of the side plates of the module shell volume to form the final product.

![Process flow flexible manufacturing production line.](image)

Based on the above analysis, the process layout of automatic flexible assembly line of power battery pack is determined as shown in Figure 2. From the process layout diagram, it can be seen that the power cell is put on the circulating transmission line by grasping the cell with a rectangular coordinate robot to complete the operations such as electrical parameter detection and cell turnover. Qualified batteries are grabbed by stacking robot to battery stacking station for stacking at battery offline station, and then integrally grabbed by module assembly robot to module pre-group station for subsequent module assembly, and unqualified batteries are transported to NG offline station for offline. The production line system can dynamically adopt corresponding process flow according to different types of power battery packs, thus realizing flexible mixed-flow assembly of power battery packs, and then realizing small batch and personalized manufacturing of products.
3. Overall structure design of flexible manufacturing line

According to the requirements of system function and process flow, the automatic flexible assembly line of power battery pack is mainly composed of mechanical system, pneumatic system, sensor and execution system, network system and application control system.

Mechanical system: The field layout and composition of mechanical system not only adopt modular design, but also the structure of key parts is flexible, which can meet the production needs of different kinds of power battery packs. The equipment layout of mechanical system is shown in Figure 3.

Pneumatic system is mainly composed of three parts: air pressure generator, control element and actuator.

3.1. Mechanical system design

Mechanical system, as the supporting foundation of the whole automatic flexible assembly line of power battery pack, plays an important role in the stable and reliable operation of the whole system.
The design and selection of mechanical system equipment should not only meet the requirements of production line process flow, but also have reasonable and compact layout and smooth connection. At the same time, it also has the characteristics of flexible clamping and transportation, and realizes the autonomy, safety and controllability of the production process. The following is a detailed introduction from several important special plane equipment.

3.1.1. Intelligent feeding frame for cell. The intelligent charging frame of the cell has two boxes which are rigidly connected but used for independent feeding, and detection sensors are set at the corresponding position of the cell discharging slot at the bottom of each box. When one of the boxes is feeding, the other box can be fed manually, and the two groups of boxes can be used alternately. If there is no part in the feeding position box detected by the sensor, the box will automatically switch to another box with an electric core. The three-dimensional model of the intelligent feeding frame of the cell is shown in Figure 4, and its functions can be summarized as follows:

1) The two groups of material boxes are fed alternately, and the continuous feeding without shutdown can be realized when the line works;
2) The feeding position is set outside the feeding position, and the operation of the feeding position personnel is safe and reliable;
3) The bottom of each cell slot of the material box is detected by a sensor, so that the manipulator can grasp the material in order to avoid the empty position;
4) The two boxes on the frame can automatically switch the feeding level to meet the requirements of continuous feeding.

![Figure 4.](image)

3.1.2. Special machine for electric core turnover. The special machine for turning the cell performs the position change between the positive and negative poles of the flat cell and the tray, that is, the flat cell turns 180 degrees. Among them, the signal of whether the cell is turned over or not is provided by the control system according to the order situation, and the cylinder position signal of each part is provided by the position sensor installed on the cylinder. The action sequence of the battery cell turnover special machine is that the battery cell gripper descends to grab the battery cell driven by the cylinder, and then the battery cell gripper returns to the starting position and turns over 180 degrees. After turning over, the cell gripper descends to place the cell in the positioning slot of the tray, and finally the cell gripper recovers its initial state. The three-dimensional model of the special cell turnover machine is shown in Figure 5.
3.1.3. **Flexible manipulator of module assembly robot.** The main function of module assembly robot is to grasp and assemble qualified battery modules. The flexible manipulator of the module assembly robot has two grasping devices, namely, clamping and vacuum suction, to complete different actions and functions. Firstly, the vacuum adsorption device of robot hand is used to suck the outer shell of the battery module and place it in the positioning slot on the assembly platform, then the qualified battery module is grasped by the gripper of robot hand and placed in the corresponding outer shell of the battery module. Finally, the vacuum adsorption device of robot hand is used again to suck the side plates on both sides of the outer shell of the battery module to complete the assembly action to form a qualified battery module finished product. The number of cells grasped by the flexible manipulator is provided by the control system according to the order, and its three-dimensional model is shown in Figure 6.

**Figure 5.** Three-dimensional model of the special cell-turning plane.

**Figure 6.** 3D model of flexible manipulator of modular assembly robot.

3.2. **Design of pneumatic system**

The use and purpose of pneumatic system in the whole production line mainly include the following points:

1. Realize the function of stopping and lifting the pallet on the circulation conveying line.
2. The intelligent feeding frame of the cell, the secondary positioning device of the cell stacking platform and the linear reciprocating rotation of the electrical parameter detection equipment; Linear reciprocating motion, rotary motion and clamping action of the cell turnover machine; The grasping function of flexible manipulator of Cartesian coordinate robot and module assembly robot.
(3) It can provide the suction of the robot hand vacuum sucker to absorb materials. According to the use and purpose of pneumatic system, the circuit schematic diagram of pneumatic system is designed and completed as shown in Figure 7.

![Figure 7. Schematic diagram of pneumatic system circuit.](image)

The air source of pneumatic system is provided by oil-free piston air compressor with air storage tank, which stably outputs compressed air with pressure of 6bar after filtering and decompression. The pneumatic control is realized by Siemens PLC and festo valve island. PLC can miniaturize the control part and easily realize interlocking signal processing. At the same time, all kinds of logic and additional operations can be carried out in PLC, which makes the pneumatic circuit part of the whole transmission control circuit very simple. The valve island is a new generation of gas-electricity integrated control components, which not only ensures the easy wiring of electrically controlled valves, saves and optimizes the space layout, but also greatly simplifies the debugging, performance testing, diagnosis and maintenance of complex systems [3].

4. Overall design of control system for flexible manufacturing line
The control system of flexible manufacturing line includes field control cabinet (PLC control cabinet, touch screen control cabinet, water and gas unit box), robot system, field equipment detection unit (proximity switch, photoelectric switch, etc.), field actuator (motor, solenoid valve, etc.), and field safety equipment (safety relay, safety isolation grating, etc.). The control system of flexible manufacturing line is based on industrial Ethernet bus communication technology, which receives input signals and sends control instructions to field devices through PLC. It can be said that this part is the most important and core part in the flexible manufacturing line of power battery pack.

4.1. Hardware design of control system
The hardware of the control system is mainly composed of industrial computer, switch, PLC, RFID reading and writing system, visual inspection system, driving motor of circulating conveying line, various sensors, cylinders and other actuators. The network topology diagram of the production line, that is, the layout diagram of the communication bus of the whole system is shown in Figure 8. The main control PLC of the control system adopts Siemens S7-1500 series to complete the detection, control and communication of the whole line. The system has advanced and reliable hardware foundation and software foundation, and more than 15% space is reserved for input and output, which is convenient for future system expansion [4]. The industrial computer can monitor the equipment of the whole production line and build the whole process model to ensure the stable and reliable operation of the production line. The RFID reading and writing system is used to record the data information of the battery cells at five stations in the circulating conveying line, and to record, transmit and trace the data of the square battery cells. The visual monitoring system is firstly used for reading and transmitting the positive and negative data of square batteries in the battery feeding station, and secondly used for judging whether the positive and negative sequence of square batteries in the module stacking station is correct or not. All sensors (photoelectric switches, proximity switches, etc.) and valve island wiring problems are all in the form of quick plug-in and close to the I/O module, which improves the stability and safety of the system and makes the maintenance more convenient and
quick. The main control PLC communicates with each subsystem and equipment layer field network by Profinet bus protocol, and the whole control system allows manual/automatic switching, so that each station can work independently when necessary.

![Production line network topology diagram.](image)

**Figure 8.** Production line network topology diagram.

The HMI control box includes Siemens 12-inch touch screen, control buttons, indicator lights and terminal blocks, etc. The HMI man-machine interface can simulate and display the process flow, detect the current status of I/O signals and distinguish them by different colors. When there is a fault in the production line, the system will continue to alarm, and the HMI will display the alarm information, so that the staff can check the fault. Industrial HMI, as the field operation platform of production line, can realize the adjustment, optimization and flexible configuration of process parameters.

### 4.2. Control system software design

The software design of control system is developed based on SIEMENS programming software TIA Portal V13, and is designed with structured and modular programming ideas, so that users can optimize and change the process flow by themselves in the future [5]. The software system consists of MAIN program module, all flow modules, conveying line setting module, alarm information module, system picture module, project information module, user management module, historical information prompt module, monitoring module of each station and so on. The structure diagram of control system software is shown in Figure 9.
The MAIN program main module calls all software modules, system function blocks and data blocks as the main thread, and completely realizes the order-based production task of the flexible manufacturing line of power battery packs. Each monitoring module can collect, process and transmit the battery cell status and data information of each station. Other modules can display the process flow, conveying line setting, warning information, system operation picture, project information, user information and historical information of the whole flexible manufacturing line, which is convenient for users to quickly learn and master the operation mechanism and process of the whole production line. All links involving personal or work piece safety control shall be protected by double interlocking in terms of hardware and software. In the automatic mode, the software can command each actuator to run in sequence according to the signal status. Once the next operation cannot be performed due to a certain signal failure, the corresponding alarm page pops up in HMI. Whether the fault only affects the operation of this station or the operation of the whole line depends on its safety-related attributes, or according to the user’s designation.

5. Conclusions
In this paper, a flexible automatic assembly inspection production line is designed to meet the requirements of automatic assembly production of new energy vehicle power battery packs with multiple varieties and small batch orders. After the test, it can solve the problem of automatic production of multi-variety power batteries, at the same time, it can achieve the economic indicators of increasing production efficiency by more than 20% and reducing unqualified product rate by more than 20%. The test site of flexible manufacturing production line is shown in Figure 10. If it is popularized and applied, it will effectively solve the problems such as lack of production capacity, backward technology and low production efficiency of the power battery pack manufacturers of new energy vehicles, and at the same time improve their intelligent manufacturing level, thus helping and promoting the development of new energy vehicles in China.
Figure 10. Control system software structure diagram.

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