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Research on Intelligent Correction Welding System for Lithium-Ion Aluminum Shell Module

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Abstract:- Given the unstable welding quality caused by the core size deviation and tooling positioning deviation in the new energy vehicle power supply system, This study proposes a weld quality control strategy that relies on laser positioning and automatic correction to achieve intelligent correction of welding trajectories during module welding, ensuring stable and reliable weld quality. This strategy can effectively improve the one-time welding qualification rate of welds, avoid the problem of welding equipment failure and shutdown caused by weld deviation, reduce the mean time between failures (MTBF) of equipment, and improve the overall efficiency of equipment (OEE), which has strong practical significance.

***Keywords**: Aluminum shell module, Laser locating strategy, Intelligent correction welding system, mean time between failures, overall equipment efficiency.*

1. Introduction

With the increasing severity of global ecological pollution and the worsening global energy crisis, automobiles are increasingly developing towards energy conservation and environmental protection. The power battery pack is the driving force of new energy vehicles, and it plays a decisive role in the performance of new energy vehicles [1,2]. At present, the stacking welding process of aluminum shell battery modules uses industrial robots instead of manual operation, and CMT welding process or laser welding process is used to complete the welding work of the stacking modules [3-5]. Among the many factors that affect the performance of power battery packs, the welding quality of battery modules plays a significant role [6]. Due to the accumulation of size errors in the battery cells, there may be changes in the position of the weld seam during the welding process. If the welding robot cannot automatically adjust the welding trajectory according to the changes in the weld seam position, it will cause welding defects to occur. Therefore, it is of great significance to study how to enable welding robots to intelligently find reserved positions for battery module welds and ensure the quality of module welding.

In recent years, many scholars have conducted research on battery module stacking and welding control systems to improve the quality of battery module stacking and welding.

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Stavropoulos [7] proposed a data-driven approach to evaluate the resistance and maximum tensile shear strength of Tab to Tab Al Cu laser joints, and optimized two different machine learning models. Asirvatham [8] studied the effects of nickel plating methods and thickness on the laser welding performance of aluminum busbars in lithium-ion battery interconnection, providing valuable insights for optimizing nickel coating parameters to improve weldability and the performance of aluminum busbars in battery cell interconnection. Choi [9] developed an automatic defect detection algorithm to inspect the non-contact and non-destructive laser welding condition of cylindrical lithium-ion battery covers. Li [10] improves the robustness of the ultrasonic metal welding process for lithium-ion batteries through innovative real-time controllers and new transducer geometry designs. Shin [11] proposed a non-contact, non-destructive, and real-time inspection technique for detecting weld defects in cylindrical lithium-ion battery covers, which can detect internal weld defects between the outer shell disk of the battery cover and the current collector. Mo [12] studied the impact of cold welding on battery module inconsistency and thermal safety, providing new ideas and theoretical value for the improvement of consistency in power lithium battery packs. Mohan [13] used the principle of a single-sided N-2-1 fixture to control the thermal instability phenomenon during laser welding of battery casings, which can reduce the thermal induced buckling deformation from 15 millimeters to about 2 millimeters when using the proposed method. Qian [14] proposed a model based on direct learning mechanism and improved ant colony algorithm to obtain the optimal solution of welding process parameters and achieve control of welding porosity. Hong [15] uses pulse infrared thermal imaging technology to detect the quality of laser welding of lithium batteries. Through transmission front detection and reflection back detection, it can be distinguished whether the weld has reached 100% welding. Lv [16] built a machine vision based welding quality inspection system, introduced deep learning object detection algorithm, and proposed an improved welding defect recognition algorithm to achieve intelligent detection of welding defects.

Traditional battery module stacking and welding processes have many shortcomings, which cannot guarantee the welding quality of battery modules, resulting in frequent occurrence of module welding defects. To solve the problem of unstable welding quality caused by the deviation of module welding seam position, a welding seam quality control strategy relying on laser positioning and automatic correction is proposed to achieve intelligent correction of welding trajectory during module welding process, ensuring stable and reliable welding seam quality. Firstly, analyze the module production process to determine the cause of the problem. Then, a laser positioning and automatic correction control strategy is proposed, and the hardware and software design of the system is completed. Finally, experiments were conducted on the D173F120 lithium iron phosphate aluminum shell 9-core module to verify the effectiveness of the proposed method.

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2. Significance of Intelligent Positioning and Automatic Correction Strategies

The production process of stacking aluminium shell lithium-ion battery packs is shown in Figure 1: Firstly, the MES system of the production line assigns production tasks. After the PLC system receives the assigned tasks, the three-dimensional warehouse works to transport the required battery cells to the corresponding production line. The production line performs QR code scanning and OCV testing on the incoming battery cells. The data of the qualified battery cells is uploaded to the MES and stored in the database. Transport the required battery cells for production to the corresponding production line. Afterwards, the system controls the production line to perform plasma cleaning and glue coating on qualified cells, arranges and stacks them in series and parallel according to the dispatch requirements. Finally, the production line welds the stacked cells.

In theory, after the module is stacked and pressurized, the ends of the module side plates should be tightly attached to both sides of the end plate, with a distance of 3-5mm from the end face of the end plate, to ensure that the reserved weld position coincides with the welding trajectory of the welding robot. In actual production, due to the positioning error of the module stacking table fixture and the cumulative deviation of the battery cell thickness, the deviation range of the reserved welding seam of the module exceeds the welding trajectory range of the robot, causing welding defects such as welding deviation, high excess height, and porosity, which affect the subsequent production processes such as busbar electrode welding and PACK box insertion, and even cause unstable performance of the battery module, leading to module scrapping, disassembly, and increased production costs. This design proposes a laser positioning and automatic correction measure, which enables the welding system to use laser sensors to measure the distance between the side and end plates, accurately locate the welding position based on the distance measurement jump, and automatically correct the welding trajectory of the welding robot to complete the welding work, effectively solving the welding quality problem caused by the deviation of the reserved position of the weld seam.

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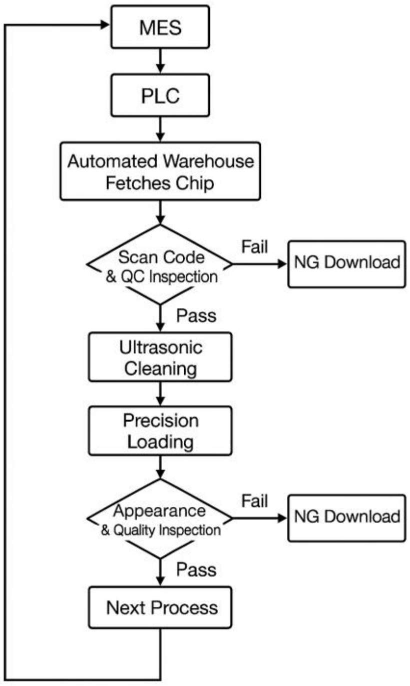

Figure 1 Production Process Flow Chart

3. Design of Automatic Positioning and Correction Strategy System Scheme

The automatic positioning and correction system of welding robots mainly consists of three parts: detection system, control system, and execution system. Before module welding, the detection system detects the distance data between the module side plate and end plate. And transmits the detection data to the control system. The control system processes the data to determine the position of the weld seam, and the welding system corrects the trajectory according to the weld seam position to achieve automatic positioning and correction of the module weld seam position, ensuring stable and reliable module welding quality. The control system block diagram is shown in Figure 2.

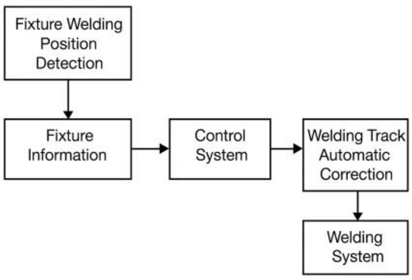

Figure 2 Control System Diagram

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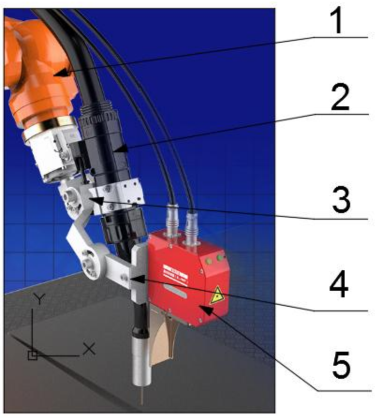
a. Design of Detection System

The detection system will complete the inspection of the reserved position of the module weld after pressurization. The detection system needs to inspect the reserved positions of different types of module welds during the production process. In this design, the detection system considers using laser displacement sensors to detect the distance between the side plate and end plate, and installing the sensor and welding gun together on the sixth section of the welding robot. The laser displacement sensor will move with the welding gun to a safe position before welding, and perform distance detection on each weld seam separately. The detection data will be fed back to the control system during the production process. The structural diagram is shown in Figure 3.



1. Welding robot; 2 welding guns; 3 Welding gun fixing bracket; 4 Sensor fixing bracket; 5 Laser Displacement Sensor

Figure 3 Structure diagram of the detection system

b. Control System Design

The control system is the core of the automatic correction system. The control system will process the detection data, determine the critical points of the side plate and end plate positions through data jump variables, and determine the position of the reserved weld seam based on the upper and lower critical points of each weld seam during the welding process. Then, the welding system compares and corrects the robot's welding trajectory to ensure that the welding trajectory coincides with the reserved position of the weld seam. The control system consists of Siemens PLC and the welding robot central processing unit.

The Siemens S7-1500 PLC adopts a new type of backplane bus technology, which uses the high baud rate and high transmission protocol to make its signal processing speed faster [17]. The Siemens S7-1500 comes with up to 3 PROFINET interfaces [18,19]. Among them, two ports have the same IP address and are suitable for on-site communication. The third port has an independent IP address and can be integrated into the company network [19]. At the same

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time, the Siemens S7-1500 can be seamlessly integrated into TIA BoZhong, significantly improving the efficiency of engineering configuration [20].

c. Execution System Design

The execution system mainly consists of welding robots, welding workbenches, and welding machines. The control system issues execution instructions, and upon receiving the execution signal, the welding system compensates for deviations in the welding trajectory to ensure that the actual welding trajectory coincides with the reserved position of the weld seam, thereby guaranteeing the welding quality of the module weld seam.

4. Software Design of Automatic Addressing Strategy System

a. Software Architecture Design

According to the production plan, operators issue orders in the MES system. After the control system receives the dispatch information, PLC control equipment completes the tasks of cell cleaning, glueing, stacking, etc. The stacked modules are sent to the welding station. At the same time, the PLC sends corresponding instructions to the welding system based on the module information, and the welding system selects the corresponding program to execute the welding task. Before welding, the sensor measures the distance of the weld seam position and uploads the data to the control system. The control system completes the reserved weld seam position positioning and automatic correction. And executes the welding task. The data related to module welding can be displayed on the HMI interface throughout the entire welding process and transmitted by PLC to the MES system for database storage, facilitating the establishment of a module lifecycle ledger. The control system architecture is shown in Figure 4.

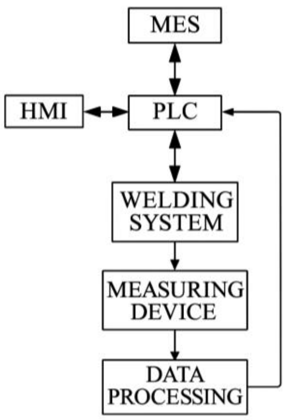

Figure 4 Schematic diagram of system architecture

b. Software Program Design

In order to improve the convenience of debugging and porting the automatic positioning and correction system program, the program in this design adopts a modular programming method. The entire program module includes MES-PLC communication module, cell scanning module,

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OCV detection module, cell stacking module, data processing module, HMI display module, and automatic positioning welding module. The program flowchart of the control system is shown in Figure 5.

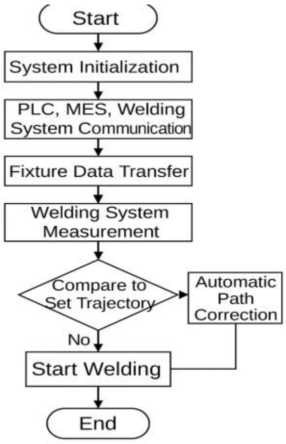

Figure 5 Program flowchart

The automatic positioning welding module is the core module of this design, which measures the distance of the module's weld seam position through a data acquisition system. Each weld seam of the module adopts a two-point measurement method, measuring the upper and lower positions of the reserved weld seam respectively. Use the measured distance jump position to determine the position of the two points above and below the reserved weld seam, and the line where the two points are located is the position of the weld seam. The program flowchart of this module is shown in Figure 6.

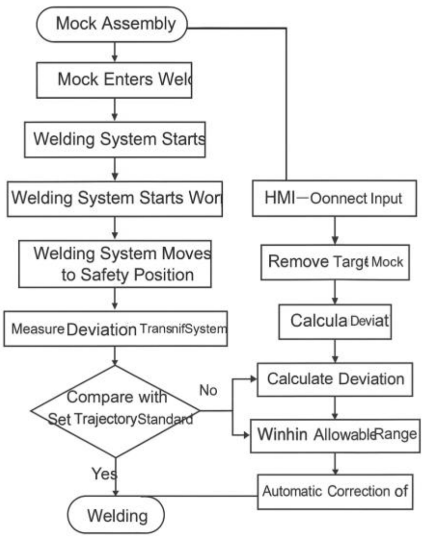

Figure 6 Process of automatic positioning and correction module

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In the system operation, the central control PLC communicates with the welding unit to transmit module information to the welding room PLC. The welding system obtains the parameters of the current module, selects the welding parameters and trajectory that match the current module, and the welding robot enters the working state. The welding robot reaches the safe positions outside the four reserved weld seams according to the calibration trajectory. It performs laser scanning on the upper and lower parts of each weld seam. Transfer the scanned data to the control system, and the control system compares and calculates the jump variables of the measured data to obtain the offset of each weld seam. The robot then performs supplementary welding on the welding trajectory to ensure stable and reliable weld seam quality.

5. Analysis of Experimental Results

The test object of the automatic positioning and correction system for module welding in this design is a 9-cell module of ternary aluminum shell lithium battery. The experimental period is one week, with two shifts per day. The MES system records the number of single module groups, qualified and unqualified, and the number of repair welding modules and disassembly modules caused by welding seam problems.

After the battery module is stacked, the module enters the welding room fixing table with the stacking trolley. When the trolley is in place, the positioning cylinder of the trolley automatically extends to position the trolley on the welding workbench. The welding robot starts to move from the origin to a safe position outside the reserved weld seam. And measures the position of the four reserved weld seams of the module in sequence. The system calculates the deviation and automatically corrects it during the welding process. The automatic welding process and the module after welding of photos are shown in Figure 7. The parameters of module information and welding system can be displayed in real-time on the HMI interface throughout the entire welding process.

(a) Welding system welding

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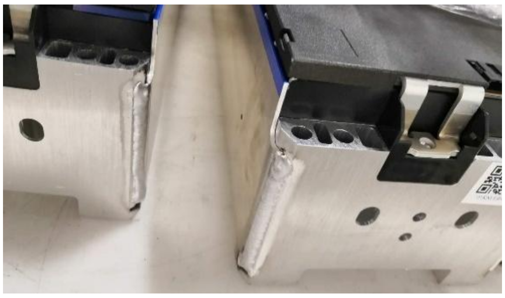
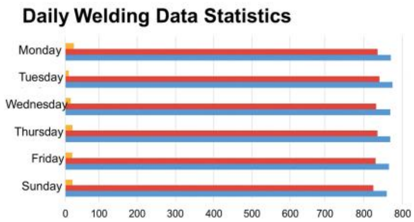


(b) After welding, the module weld seam is completed

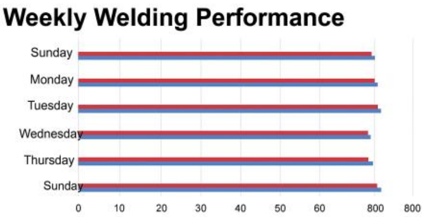
Figure 7 Module welding and module status after welding completion

Figure 8 shows a bar chart of the production-related data measured during the experiment. This bar chart records the number of single module units dispatched, the number of qualified welding modules, the number of modules that need to be repaired, and the number of NG modules due to non-conforming welds on the production line every day during the one week experiment.



	Monday	Tue	Wedne	Thur	Frid	Sat	Sund	Sunday
Fixture Misalignment	5	3	23	6	7	4	3	3
Rework Failures	21	23	67	63	60	28	23	23
Pass Count	669	23	670	673	668	680	682	702
MES Orders	695	70	680	688	680	682	702	701

(a) Pre-implementation status of automatic correction system



	Ficuring	Tue	Wed	Thur	Frid	Sun	Sunday
Fixture Clamp Gun and Wire	0	0	0	0	0	0	0
Displacement Misalignment Count	0	3	5	5	5	4	4
Welding Rework Failures	4	4	4	4	5	5	5
Pass Count	40	4	64	67	711	702	708
MES Orders	720	694	687	711	702	708	703

(b) Status after implementation of the automatic correction system

Figure 8 Module Production Status Information

As shown in Figure 8, after adopting the automatic addressing correction system, the welding quality of the module has been effectively improved, and the one-time welding qualification

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rate of the module can reach over 99%. Due to the deviation of the welding seam, the number of welding gun wire blockages has been reduced to zero, which minimises the disassembly of the module caused by unqualified welding seams and saves production costs.

Although the automatic positioning and correction system has added a weld seam scanning and positioning process, which increases the welding time of a single module by 3-4 seconds, the welding process takes less time than the previous module stacking process for the entire production line, so it does not affect the production capacity of the production line. At the same time, the use of this system has improved the equipment shutdown problem caused by excessive deviation of module welds during the module welding process, which helps to increase production line capacity.

6. Conclusion

The laser positioning and automatic correction system for lithium-ion battery module welding in this design effectively solves the problem of unstable weld quality caused by cumulative errors in fixtures and cell size deviations by detecting and locating the position of the module weld seam and automatically correcting the welding trajectory during the welding process. The welding system automatically corrects the deviation between the reserved position of the weld seam and the system calibration trajectory, improving the first pass rate of module welding during the welding process. In addition, the reserved weld deviation over travel alarm function solves the problem of wire blockage caused by excessive reserved weld deviation in the welding system, reduces the TPRR of the equipment, and improves the OEE of the equipment. Therefore, the system has high industrial application value.

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