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Exploration of Control Technology for Stator and Rotor Equipment of Flat Wire Motor Based on Automation

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Abstract: The manufacturing processes of flat wire motor stators and rotors are highly specialized and demand advanced automation and control technologies. Automation control plays a critical role in flat wire motor manufacturing equipment and is typically implemented using a three-layer system architecture. Key technologies such as multi-axis coordinated motion control, flat wire tension regulation, and optimized path planning are employed to ensure efficient and high-precision equipment operation. Through the application of diverse control strategies, production quality and manufacturing efficiency are significantly enhanced. Looking ahead, the integration of digital twin and artificial intelligence technologies is expected to further promote high-quality development in industrial manufacturing.

Keywords: Flat wire motor; Automation control technology; Smart manufacturing

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1. Introduction

With the promulgation of the new energy vehicle industry development plan (2021–2035) in October 2020, the development of the new energy vehicle industry has ushered in a new opportunity, and the flat wire motor, as a key component, has attracted much attention. Its stator and rotor manufacturing process is unique, and it has strict requirements for the control technology of automatic equipment. The application value of automatic control in flat wire motor equipment system is significant, and it can improve the production quality and efficiency through all links. The control technology based on automation adopts a three-tier system architecture, integrating multiple strategies such as multi-axis coordination and tension control, covering assembly, integration and other aspects. The technology has been verified by practical application, which can significantly improve the production efficiency and product qualification rate. In the future, the combination of digital twins, artificial intelligence and other technologies will promote the high-quality development of flat wire motor industry.

2. Overview of flat wire motor equipment control technology

2.1. Manufacturing process characteristics of flat wire motor stator and rotor

In the manufacture of flat wire motor stator, the winding uses flat wire, and its technology has high requirements for equipment. The shape characteristics of the flat wire greatly improve the winding density, which requires the winding equipment to have higher accuracy and stability to ensure that the flat wire is closely and regularly arranged to achieve efficient electromagnetic conversion [1]. At the same time, in order to ensure good heat dissipation performance, the stator manufacturing needs to accurately control the insulation treatment and structural design, and the manufacturing equipment should be able to accurately implement the relevant processes. In terms of rotor manufacturing, the pressure, position and other parameters of the rotor press mounting process should be strictly controlled. The automatic equipment should have the ability of high-precision positioning and pressure control to ensure that the components of the rotor core are firmly assembled and have high concentricity, so as to avoid affecting the motor performance due to assembly problems. In short, the uniqueness of the manufacturing process of flat wire motor stator and rotor determines that it has strict requirements for high precision and high stability of automation equipment control technology.

2.2. Application value of automation control in equipment system

Automatic control has significant application value in flat wire motor equipment system. In terms of process stability, automatic control can accurately adjust various parameters, ensure the stable operation of all links in the production process of flat wire motor stator and rotor, avoid fluctuations that may be caused by manual operation, so as to improve the stability of product quality [2]. In terms of production beat, automatic control can quickly and efficiently complete a series of production actions according to the preset program, greatly improving production efficiency and meeting the needs of large-scale production. Through the precise operation of automation, the quality consistency of different batches of products can be guaranteed, and the defective rate can be reduced, making the flat wire motor products more competitive in the market. Automatic control runs through all links of the flat wire motor equipment system, from winding to iron core assembly, and comprehensively improves the stability, efficiency and quality of production, which plays a vital role in promoting the development of the flat wire motor industry.

3. Design architecture of equipment automatic control system

3.1. Overall design of modular control system

Based on the automatic control technology of flat wire motor stator and rotor equipment, a three-tier system architecture including motion control module, quality detection module and data management module is adopted. The motion control module is responsible for accurately regulating the operation of various parts of the equipment, ensuring the accurate position and speed of the stator and rotor in the process of processing and assembly, and meeting the requirements of the production process. The quality detection module monitors the products in the production process in real time, judges the product quality according to the preset standards, finds defects in time, and prevents defective products from flowing into the next link. The data management module collects, stores and analyzes the data from the motion control and quality detection module to provide the basis for production optimization. Each module cooperates closely through a specific information interaction mechanism. The motion control module transmits the operating parameters to the data management module. The quality detection module synchronizes the detection results to the data management module. The data management module adjusts the

motion control module according to the analysis results, so as to achieve efficient, stable and intelligent automatic control of the equipment [3].

3.2. Multi-axis cooperative motion control strategy

In the control technology of flat wire motor stator and rotor equipment based on automation, multi-axis cooperative motion control strategy is very important. The distributed control scheme based on EtherCAT bus provides the basic support for multi-axis cooperation. It has the ability of high-speed and real-time data transmission to ensure the timeliness and accuracy of information interaction between the axes. The multi-axis linkage mathematical model for flat wire winding process is the core of achieving precise cooperative motion. By accurately modeling the motion trajectory, velocity, acceleration and other parameters of each axis in the process of flat wire winding, the complex winding process is decomposed into the cooperative action of each axis. For example, according to the shape of the flat wire, the size of the stator and rotor and the winding requirements, the model can accurately calculate the motion parameters of each axis at different stages, so that each axis can cooperate to realize the uniform and tight winding of the flat wire on the stator and rotor. This strategy combines advanced control bus technology and accurate mathematical model to provide a strong guarantee for the efficient and accurate operation of flat wire motor stator and rotor equipment [4].

4. Research on key technology of stator and rotor production

4.1. PIN wire forming control technology

4.1.1. Adaptive control of flat wire tension

In the winding process of flat wire motor stator, the accurate control of flat wire tension is very important. In order to realize the adaptive control of flat wire tension, the key measure is to develop a closed-loop PID control algorithm integrating the feedback of tension sensor. By installing a high-precision tension sensor on the winding equipment, the tension data of flat wire can be collected in real time. These data are fed back to the control system, which uses PID control algorithm to calculate the corresponding control quantity according to the deviation between the preset tension value and the actual collected value. The algorithm enables dynamic tension compensation for flat wires of varying diameters. When diameter changes cause tension fluctuations, the algorithm rapidly adjusts to ensure the flat wire maintains optimal tension throughout the drawing process. This prevents dimensional issues during PIN wire cutting caused by uneven tension—such as non-compliant dimensions, inadequate stripping length, or residual coating—thereby effectively enhancing the quality and stability of PIN wire forming [5].

4.1.2. PIN wire forming planning

In the PIN wire forming control technology for flat wire motors, 2D/3D forming path planning is of paramount importance. Firstly, a PIN wire dimensional chain must be established to provide a foundational framework for path planning. Building upon this, the bending motion trajectory undergoes dynamic optimisation, precisely controlling the velocity curve at each transition point for every bend angle. This enhances the consistency and efficiency of PIN wire forming [6]. Leveraging extensive data support, AI technology enables the automatic calculation of optimal bending and 3D forming parameters for copper wires of varying materials and dimensions. These parameters encompass bending angles, die pressure, transition positions, and more, thereby substantially reducing debugging time and changeover durations.

4.2. Rotor precision assembly technology

4.2.1. Vision-guided positioning system

In the process of rotor precision assembly, the positioning accuracy of silicon steel lamination is very important to the motor performance. Therefore, a dual camera stereo vision detection system is constructed to solve the micron level positioning problem. The system uses two cameras to shoot the rotor silicon steel sheet from different angles to obtain its image information [7]. Through image processing and analysis, the spatial position and posture of silicon steel sheet can be accurately calculated. With the help of advanced algorithms, it can quickly identify and accurately measure the position deviation of silicon steel sheet, and provide accurate positioning guidance for subsequent assembly operations. This enables each silicon steel sheet to be accurately placed in the predetermined position with micron precision when the silicon steel sheet of the rotor is stacked, which greatly improves the assembly quality of the rotor, ensures the stability and reliability of the performance of the flat wire motor, and provides a key support for the control technology of the stator and rotor equipment of the flat wire motor based on automation.

4.2.2. Press mounting force closed-loop control

In the closed-loop control of pressing force during the precision assembly of flat-wire motor rotors, the design of a servo system incorporating an electric cylinder with pressure feedback is pivotal. This system employs pressure sensors to capture real-time, precise pressure data throughout the pressing process, feeding this information back to the control system. Based on pre-set pressing process parameters, the control system dynamically adjusts the servo system's output pressure, thereby achieving precise control over the pressing force. At the same time, it is also very important to establish the database of press mounting displacement pressure characteristic curve. In the actual press mounting process, the corresponding data of displacement and pressure of rotors with different specifications during press mounting are collected to build the characteristic curve database [8]. The database not only provides data support for the optimization of the press mounting process, but also in the subsequent production, by comparing the real-time press mounting curve with the standard curve in the database, it can find the abnormal conditions in the press mounting process in a timely manner, ensure the stability and consistency of the rotor press mounting quality, and improve the overall production level of the stator and rotor of the flat wire motor.

5. System implementation and production verification

5.1. Equipment integration and commissioning

5.1.1. Development of electromechanical cooperative control system

The deep integration of PLC and servo drive based on TwinCAT platform is the key to the development of electromechanical cooperative control system. Through this platform, the logic control function of PLC can be deeply integrated with the precise motion control of servo drive, which greatly improves the overall performance of the system [9]. Based on this, the modular programming of the control program is completed, and the complex control tasks are divided into independent functional modules, each module is responsible for specific control functions, such as motor speed regulation, position control, etc. This modular programming method is not only convenient for program writing, debugging and maintenance, but also enhances the reusability of the program and improves the development efficiency. After integration and programming, the system is fully debugged to ensure that the electromechanical components work together accurately, laying a solid foundation for the stable operation of flat wire motor stator and rotor equipment in actual production.

5.1.2. Human-computer interaction interface design

The purpose of human-computer interface design is to develop HMI system that supports visual configuration of process parameters and realize real-time monitoring of equipment status. The interface will present various key process parameters of the flat wire motor stator and rotor equipment, such as winding speed, turns, current, etc., in a simple and intuitive layout. The operator can easily configure these parameters visually to reduce manual input errors. At the same time, through the real-time data acquisition and transmission technology, the operation status of the equipment, such as equipment start-up and stop, fault alarm and other information are fed back to the interface in real time, so that the operator can grasp the equipment status in time and make rapid response. In addition, the interface design pays attention to the convenience and humanization of operation, and sets function buttons and navigation bar to facilitate the operator to switch different function modules. Through this design, it provides operators with efficient, accurate and humanized operation experience, and ensures the stable operation of flat wire motor stator and rotor equipment [10].

5.2. Intelligent transformation of production line

5.2.1. Manufacturing execution system integration

The integration of manufacturing execution system achieves automatic collection of production data by establishing OPC UA communication interface between equipment layer and MES system. This communication interface builds a bridge between the equipment and the MES system, and all kinds of key data such as equipment operation parameters and production progress can be transmitted to the MES system in real time and automatically. On one hand, it makes the production process transparent, so that managers can timely grasp the production dynamics and make rapid decisions and adjustments for emergencies. On the other hand, these automatically collected data provide the basis for production analysis and quality traceability. For example, according to the collected processing accuracy data, it can be traced back to specific equipment, operators, etc., so as to continuously optimize the production process, lay a solid foundation for the intelligent production of flat wire motor stator and rotor equipment, and improve the overall production efficiency and product quality.

5.2.2. Adaptive process optimization

In the process of adaptive process optimization in the intelligent transformation of the production line, the key is to build a process knowledge base with the help of big data analysis technology. By collecting a large number of process data of flat wire motor stator and rotor equipment under different working conditions, such as processing speed, temperature, pressure, etc., and using big data analysis means, the potential relationship and laws between the data are deeply excavated, and these valuable information is integrated into a process knowledge base. At the same time, a self-learning parameter adjustment algorithm is developed, which can automatically identify the deviation based on the comparison between the real-time production data and the standard data in the knowledge base, and adjust the equipment parameters adaptively based on the deviation. With the continuous production, the algorithm constantly learns new production data, optimizes its own logic, and keeps the process parameters of the equipment in the best state, so as to effectively improve the production quality and efficiency of the stator and rotor of the flat wire motor, and realize the adaptive process optimization of the production line.

5.3. Analysis of practical application effect

5.3.1. Comparison of production efficiency

In the practical application of the automatic control technology for the stator and rotor equipment of flat wire

motor, the equipment movement rate and beat time are the key indicators to measure the production efficiency. Taking the traditional equipment without automatic control technology as a reference, after the introduction of automatic control technology, the equipment utilization rate was significantly improved. This is because the automation system reduces the downtime caused by equipment failure time and manual intervention, so that the equipment can run stably for a longer time. From the perspective of beat time, automatic control realizes precise process connection and action execution, and effectively shortens the production cycle of a single product. After quantitative evaluation, the production efficiency has been increased by 5% compared with the traditional way after the adoption of automatic control technology, which has greatly increased the product output per unit time, which strongly proves the remarkable effect of the control technology of flat wire motor stator and rotor equipment based on automation in improving the production efficiency.

5.3.2. Product qualification rate verification

In the practical application of flat wire motor stator and rotor equipment control technology, it is very important to verify the product qualification rate. The change trend of key quality data, such as the qualified rate of winding size and rotor balance, can directly reflect the product quality status. For the winding size, accurately measure and calculate the proportion of qualified size. If the qualified rate is increased, it shows that the automatic control technology can accurately control the winding size and ensure the stator performance. For rotor balance, professional equipment is used to detect different batches of rotors. When the number of qualified products increases, it shows that the control technology has effectively reduced rotor imbalance. Continuous monitoring of these key quality data can not only verify the effectiveness of automatic control technology in improving the product qualification rate, but also provide a reliable basis for subsequent technical optimization to ensure the stability and reliability of the stator and rotor product quality of flat wire motor.

6. Conclusion

Automation control technology has shown many innovative application achievements in the stator and rotor equipment of flat wire motor. By means of automation, the precise control of equipment operation is realized, the efficiency and quality of flat wire motor production are improved, and the labor cost and production error are effectively reduced. The stability and reliability of automatic control provide a solid guarantee for product performance in key processes such as winding and wire embedding. Looking forward to the future, digital twin technology is expected to be deeply applied in the intelligent manufacturing field of flat wire motor. With the help of digital model to simulate the real production process, potential problems can be found in advance and the scheme can be optimized to achieve more efficient production planning and management. Artificial intelligence technology will also play a greater role, for example, based on machine learning algorithm to achieve equipment fault prediction and intelligent maintenance, and improve the continuity and stability of equipment operation. The integration and expansion of these technologies will promote the manufacturing of flat wire motors to be intelligent and efficient, and help the industry achieve higher quality development.

Disclosure statement

The author declares no conflict of interest.

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