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Intelligent Transformation and Industrial Application of Motor Rotor Magnet Insertion Equipment in the Context of High-End Manufacturing

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Abstract

Magnet steel assembly of motor rotor is a key process in the manufacture of permanent magnet motor. Its slot posture, assembly position and compaction state are related to the machining organization and quality control of the subsequent rotor assembly. Traditional magnet insertion equipment relies on manual operation, single serial and decentralized setting, which is easily disturbed by personnel skills, magnet steel characteristics and model change, and it is difficult to meet the requirements of high-end manufacturing for stability, coordinated beat and data traceability. In this paper, aiming at the magnet insertion equipment of motor rotor, combined with the functional relationship of its core mechanism, a modular intelligent transformation scheme is proposed. The research focuses on equipment layout, material grabbing, station interlocking and data management, and forms the automatic operation logic driven by process state. This scheme retains the necessary manual operation links, and hands over the highly repetitive and strict positioning procedures to the automatic mechanism for execution, which provides a reference for upgrading the existing motor assembly equipment.

Keywords

High-end Manufacturing; Motor Rotor; Magnet Steel Insertion; Intelligent Transformation; Industrial Robot.

1. Introduction

Permanent magnet motor has the characteristics of high power density, high operating efficiency and compact structure. With the development of motor products to high speed, light weight and serialization, rotor assembly needs to deal with more specification differences and stricter process constraints [1]. Magnet steel, as the core component of rotor magnetic field, its size, polarity direction and assembly position must accurately correspond to the slot position of iron core [2]. "magnet insertion" is an assembly process in which magnet steel is put into the slots of rotor core according to the specified posture and compacted and fixed after all slots are completed.

Traditional operations rely on manual pick-and-place and single-machine execution, which are easily affected by the adsorption characteristics of magnet steel, the proficiency of personnel and the cooperation of equipment [3]. This will lead to material taking deviation, rhythm fluctuation and unstable process connection. High-end manufacturing requires magnet insertion equipment to have structural optimization, process control and data management capabilities [4]. The investment in rebuilding the whole production line is high, so it is more in line with the needs of manufacturing enterprises to implement modular transformation based on existing equipment. Based on the

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equipment structure and operation process, this paper studies the function reorganization, mechanism connection and control methods.

2. Process Characteristics and Transformation Requirements of Magnet Insertion

2.1 Process Objects and Job Constraints

The rotor core is usually provided with a plurality of magnet steel slots along the circumference, and the magnet insertion of each slot needs to be completed according to the process sequence during assembly. Magnet steel is brittle, and its surface may be coated [5]. Collision, scraping and local impact should be avoided during grabbing and pushing. Magnet steel will be affected by magnetic force, notch clearance and iron core structure after entering the notch, and it may get stuck at the entrance if the insertion attitude is slightly deviated. The device needs to control the grasping position, end posture, insertion path and release opportunity.

Magnet steel needs to keep the distance between clamps and spacers to avoid overlapping suction and overturning. The feeding system should take into account the requirements of continuous transportation and product replacement, and ensure that the single magnet steel can reach the grasping position stably.

2.2 Main Problems of Traditional Equipment

The problem of traditional equipment is first reflected in the process connection. Feeding, feeding, separating, grabbing, slotting and compacting are undertaken by different institutions [6]. If the control relationship mainly depends on time delay, it is difficult for each mechanism to judge whether the pre-sequence action is really completed. When magnet steel does not reach the grasping position, the turntable is not accurately indexed or the iron core clamping is abnormal, the subsequent actions may still be triggered, which will increase the downtime and manual intervention.

Changing models often relies on personnel to readjust the stop, cylinder stroke and robot coordinates. The parameters are scattered in different control units, which is prone to inconsistent settings [7]. Some equipment lacks a unified man-machine interface, so it is difficult for operators to intuitively grasp the current station, magnet steel allowance and alarm position [8]. After the equipment is abnormal, the maintenance personnel need to check the sensor and actuator section by section.

Core model, magnet insertion program, alarm record and equipment status are usually not related, so it is difficult to trace the specific process after assembly. Therefore, the intelligent transformation needs to solve the problems of mechanism coordination, parameter unification, abnormality diagnosis and data recording at the same time, so that the equipment can be transformed from local automatic action to a working unit with complete process logic[9].

3. Overall Scheme of Intelligent Transformation

3.1 Equipment Structure and Function Partition

The reformed equipment consists of magnet steel feeding area, robot magnet insertion area and core transfer compaction area. The overall structure is shown in Figure 1. On the right side of the equipment, multiple layers of magnet steel clamps and clamp switching mechanisms are arranged, and the feeding mechanism pushes the magnet steel in the selected material clamp to the separation unit. The separation mechanism of magnet steel in the middle is responsible for releasing the combination relationship between magnet steel and spacer, and sending the single magnet steel to the grab position of the mechanical arm. The left side is provided with a magnet insertion manipulator and a magnet insertion station, and the front part is provided with a loading and unloading turntable, an iron core loading and unloading station and a magnet insertion compaction mechanism.

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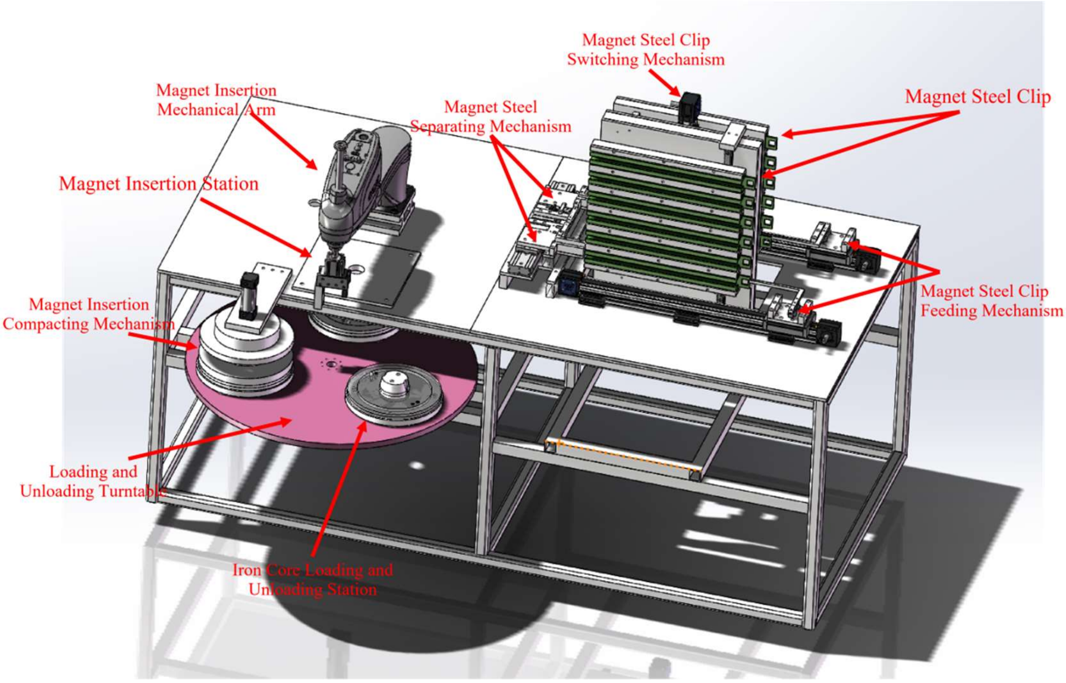

Figure 1. overall structure of magnet insertion equipment for motor rotor

This layout shortens the movement distance of the manipulator and is convenient for manual loading and unloading and equipment maintenance. The multi-station turntable is responsible for the conversion of iron core between loading and unloading, magnet insertion and compaction stations.

The mechanism design should adopt independent modules and standard interfaces. The magnet steel fixture, the feeding module and the separation mechanism constitute the feeding module, the mechanical arm and the end fixture constitute the magnet insertion module, and the turntable and the compaction unit constitute the core processing module. The modules are connected by fixed coordinates, in-place signals and task handshakes. When the product is changed, the fixture and end fixture can be replaced first and the corresponding program can be called to reduce the repeated adjustment of the whole machine structure.

3.2 Control System Reconfiguration

The equipment control system adopts a programmable controller as the main control unit. The robotic arm controller is responsible for trajectory and end effector actions. The two exchange task numbers, workstation status, and completion signals through an industrial communication interface. The human-machine interface is used to display the operating mode, product formula, magnet steel remaining amount, and alarm information, and to reserve a communication interface for connection with the workshop management system.

The control program replaces simple sequential delays with state machines. Each workstation is set with standby, preparation, execution, completion, and abnormal states, and subsequent actions are only allowed after the preceding conditions are met.. Driven by state conditions, actions can make the shutdown position and recovery path more clear.

The device is set to automatic, manual, and maintenance modes. Automatic mode is continuously executed according to the formula, manual mode is used for single mechanism jog, and maintenance mode is used for sensor inspection, coordinate calibration, and component maintenance. Key parameters should have permissions and modification records set to prevent accidental operations from affecting subsequent production.

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4. Key Mechanism and its Collaborative Design

4.1 Switching, Feeding and Separation of Magnet Steel Fixture

Magnet steel fixture undertakes the functions of batch storage and direction constraint. Guide grooves matching the shape of magnet steel can be set inside the fixture, and the spacing between adjacent magnet steels can be controlled by spacers. The fixture switching mechanism selects the material channel according to the product formula and moves the designated fixture to the feeding reference position. After the switch is completed, the position sensor will confirm the number and locking state of the material holder, so as to avoid the feeding mechanism from exerting force on the misaligned fixture. Feeding mechanism can use servo electric cylinder or air cylinder with linear guide rail to push magnet steel and spacer to separation mechanism step by step. The separation mechanism needs to keep the posture of magnet steel, guide the magnet steel and the spacer to different positions respectively, and then send the single magnet steel to a fixed grasping point.

4.2 Mechanical Arm Grasping and Entering Groove

The mechanical arm is connected with the feeding module and the iron core station. The end effector should give consideration to both clamping stability and surface protection. According to the size and surface state of magnet steel, pneumatic gripper, vacuum adsorption or special coated fixture can be used. The clamping surface should be provided with flexible materials. The slot entry trajectory is established based on the core positioning datum. The number of iron core slots, angular distribution, material taking position, insertion depth and robot program number are saved in the product formula. After the mechanical arm completes a piece of magnet steel assembly, the system updates the slot number, and then performs the next material fetching. It is advisable to adopt sectional speed control in the insertion process, reduce the speed when approaching the notch, continue to descend after entering the guide area, and release and exit after reaching the depth. Under abnormal conditions, the mechanical arm returns to a safe position and retains the current slot status.

4.3 Turntable Indexing and Magnet Insertion Compaction

The loading and unloading turntable is responsible for the conversion of iron core between stations. The operator first places the unmagnetized insertion iron core at the upper and lower feeding stations. After the fixture is centered and fixed, the turntable sends it to the magnet insertion station. After all the magnet steel assembly is completed, the turntable continues to index and send the iron core to the compaction mechanism. After compaction, the workpiece returns to the loading and unloading position. The turntable needs stable indexing positioning and mechanical locking. It is difficult to ensure the repeatability of the station for a long time only by the stop position of the motor, so positioning pins or end-face clamping structures can be set at each working position. Before rotating, the system checks whether the mechanical arm, pressure head and feeding mechanism leave the interference area; After it is in place and locked, the station action is allowed. The compaction mechanism is used to unify the final position of magnet steel in the groove. Its pressure head should be adapted to the distribution of rotor end face and magnet steel, and the stroke limit should be set to prevent overvoltage from damaging the workpiece.

5. Work Flow and Intelligent Control Method

5.1 Continuous Homework Process

The equipment operation flow is shown in Figure 2. The operator first places the core to be loaded at the core loading and unloading station and confirms that the fixture is locked. After the turntable is indexed, the iron core enters the magnet insertion station. At the same time, the operator will install magnet steel into magnet insertion steel fixture, and the control system will select the corresponding material holder according to the formula. The feeding mechanism pushes the magnet steel into the separating mechanism, and the separating mechanism removes the spacer and sends the single magnet steel to the grabbing position. After the mechanical arm obtains the permission signal, it grabs magnet steel, and then inserts it into the iron core slot according to the preset trajectory.

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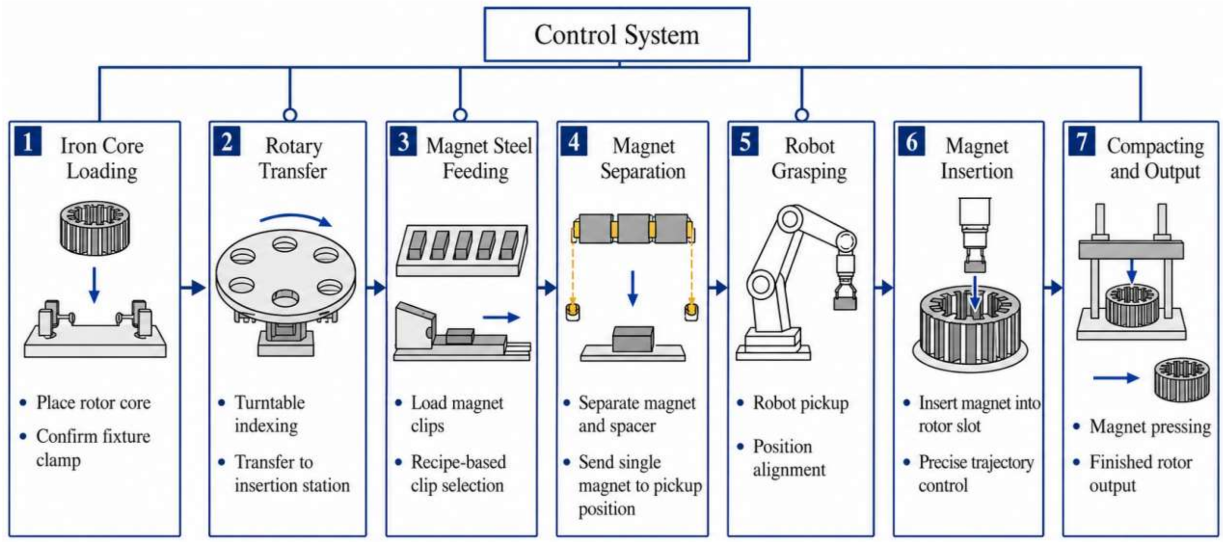

Figure 2. Motor rotor magnet insertion operation process

Every time the mechanical arm enters the slot, the system updates the installed slot position and judges whether the current iron core is completed. If the position is still to be installed, request magnet steel to supply again. After all magnet steel assembly are completed, the mechanical arm returns to the safe position, and the turntable moves the iron core to the compaction station. The compaction mechanism completes the pressing and resetting, and the turntable sends the workpiece back to the loading and unloading station, and the operator takes it out and puts it into the next iron core.

This process keeps artificial iron core loading and unloading and magnet steel feeding, which is suitable for production conditions with large batch and specification changes. For scenes with higher beat requirements, truss manipulators, conveyor lines or automatic handling equipment can be added on the basis of existing interfaces. During the transformation, it is helpful to control the complexity of the system by first establishing the closed loop of the internal action of the equipment and then gradually expanding the peripheral automation.

5.2 Interlocking, Exception Handling and Formula Management

Equipment safety is jointly guaranteed by hardware, control and program interlocking. Emergency stop, emergency door switch and grating directly limit dangerous actions, the control layer limits the execution conditions according to the status of the station, and the program layer judges the action timeout, sensor contradiction and communication interruption. After the safety protection is triggered, the equipment stops its automatic action; It is necessary to reconfirm the positions of the mechanical arm, turntable and compaction mechanism before recovery.

When giving an alarm, the system records the product model, slot serial number, actuator status and trigger signal. After troubleshooting, you can choose to restore from the current step, return to a safe state or end the current workpiece according to the actual situation. The man-machine interface should display the alarm position and inspection prompt, so that the problems of feeding, robot and turntable can be quickly distinguished.

Formula management is used to support multi-model production. Each set of formula includes fixture number, feeding step, robot program, slot number, insertion depth and compaction stroke. When changing the model, the operator selects the product number, and the system automatically issues relevant parameters and checks whether the fixture matches the program. The upper and lower limits of parameters related to mechanical position are set, and version records are kept for recipe modification to reduce human setting errors.

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6. Industrial Application and Equipment Management

6.1 Production Site Integration

The physical layout of the transformation equipment is shown in Figure 3. The mechanical arm, magnet steel feeding module, turntable, compaction mechanism and man-machine interface are installed in the same work unit, forming a compact assembly area. The motion range of the robot should be provided with a fence or a closed cover, and the manual loading and unloading position needs to be equipped with safety detection.

Figure 3. Physical layout of intelligent magnet insertion equipment

The equipment interface should be coordinated with the upstream core processing and downstream rotor processing procedures. When manual logistics is adopted, product information can be transmitted through tooling trays and bar codes; When accessing the automatic conveying line, it is necessary to unify the pallet positioning reference and the station handshake signal. After receiving the task, the equipment calls the product formula, returns to the workpiece state after completing the magnet insertion, and sends waiting information to the production line when there is a shortage of materials or an alarm.

6.2 Data Traceability and Operation And Maintenance

The equipment shall record two kinds of data: workpiece and equipment. Workpiece data includes model, operation time, formula used, finished slot and exception handling. Equipment data includes feeding times, turntable cycle, alarm type and maintenance information of key components. Data collection should focus on quality traceability, fault analysis and maintenance plan to select the necessary fields.

The equipment can be connected with the manufacturing execution system through the industrial network, and the system will issue work orders and product information, and the equipment will return the process status and abnormal codes.

The magnet steel separation mechanism, the end of the mechanical arm and the positioning part of the turntable belong to high-frequency action units, and maintenance reminders should be set according to the action times and running time. The control system provides input and output monitoring, single-step debugging and alarm history query functions.

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7. Conclusion

Combined with the actual equipment structure and operation process, this paper puts forward the modular intelligent transformation scheme of motor rotor magnet insertion equipment. The reformed work unit consists of magnet steel fixture switching, feeding and separating module, manipulator magnet insertion module, and turntable transfer and compaction module, which are coordinated by a unified control system. State machine control defines the preconditions and completion conditions of each station, and recipe management provides support for multi-model program calling and parameter switching.

In industrial implementation, the closed-loop operation, abnormal interlocking and parameter unification of equipment can be completed first, and then the product identification, data recording and manufacturing execution system can be gradually connected. This path can make use of the existing equipment foundation and reduce the implementation pressure brought by one-time reconstruction.

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