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Optimization Design of Micro-Motor Rotor Core Feeding Mechanical System Based on Electrical Automation

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ABSTRACT

This study aims to present the optimization and design of micro-motor rotor core feeding mechanical system based on electrical automation. The methods of iron insulation treatment process for micro-motor rotor design and performance of the mechanical system are used for enhancing the performance. The performance of the micro-motor rotator is tested systematically through continuous operation tests under actual working conditions. To meet the requirements of fast feed and small volume, the results revealed that the feeding speed of the automatic feeding system needs to reach 300 pieces/h in the feeding process. The silver r16-5-500-570-0.05 lead screw is selected which should be 5 mm and the outer diameter of the screw should be 16 mm. The design effectively optimizes the feeding mechanical system of the micro-motor rotor iron core and improves the automation degree of the micro-motor rotor production process, which in turn improves the production efficiency and quality and reduces the cost. The present study revealed that in comparison with manual feeding and receiving, the micro-rotor saves labor, and if the optimization is enhanced effectively, it will be productive for future usage to meet contemporary demands.
***Index Terms*—**Automatic feeding, electrical automation, mechanical system design, PLC, rotor core.

I. INTRODUCTION

With the advancement of modern technology, demand for industrial products increases at fast pace. Therefore, to meet the demands, manufacturers have devised improved designs of electrical gadgets in terms of mechanical and electrical efficiency, besides intelligence and automation of product and production [1]. However, due to some important features of several types of micro-motor products such as fast product replacement, diversified parts specifications, small production demand of single specification products, and large total product demand, the standard general automatic production equipment cannot meet the needs of flexible production. The outsourcing of customized non-standard complete sets of automatic production lines and high costs eliminate the risk of real production problems. In order to solve this problem, this study aims to optimize the design of micro-motor rotor iron core feeding mechanical system based on electrical automation for high efficiency, quality, and productivity in order to meet the challenging demands of modern industrialization.

In view of this research problem, Liang, X. et al. believe that most foreign micro-motor manufacturers design fully automated production lines for motor rotors according to their own production needs, and the structure of such devices is complex, the design cycle is long, and the product is highly targeted [2]. Kano, Y. et al. believed that China's micro-motor manufacturers started manufacturing automation late and their manufacturing technology accumulation was weak; however, due to the low cost of human resources, most domestic enterprises adopt the production mode of combining standardized general equipment with manual operation and make up for the lack of automation in production [3]. Liu, Y., Ho, S. L. et al. believed that Chinese micro-motor enterprises gradually began to develop automatic equipment suitable for their own production, to cope with the increasing production capacity demand and manufacturing cost [4].

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Based on the current research, this study proposes the optimization and design of the micro-motor rotor iron core feeding mechanical system based on electrical automation [5]. Through the overall design of the mechanical system, because the feeding speed of the automatic feeding system needs to reach 300 pieces /h in the feeding process, therefore, the silver r16-5-500-570-0.05 lead screw is selected, with the lead is 5mm and the outer diameter of the screw is 16mm throughout the overall design of the mechanical system to meet the requirements of fast feed and small volume and effectively optimizes the design of the feeding mechanical system of the micro-motor rotor iron core [6]. Optimization is one of the key machine learning approaches, and algorithms are essential for enhancing the performance of the model. Compared to the other algorithms, Adam performs better [7]. To make fiber Bragg grating (FBG) responsive to changes in the external environment, the FBG section must be etched [8]. Usman et al. studied the threshold detection scheme based on parametric distribution fitting for optical fiber channels in a fiber optic channel, and the threshold value obtained by fitting a Rayleigh distribution to the received data results in error probability approaching zero [9].The first stage in converting an analog signal to a digital signal is sampling. A continuous-time signal is changed into a discrete-time signal by sampling. Amplitude modulation (AM) in the form of double sideband-suppressed carrier modulation suppresses the carrier component to increase power efficiency [10]. Predicting the closing price of a stock is extremely difficult. In this context, artificial neural networks (ANN) are good approximation methods. In the literature, a number of nature-inspired evolutionary optimization strategies are developed and applied to look for the best ANN-based forecasting model parameters [11]. Nayak and Ansar studied the cooperative optimization algorithm-based higher order neural networks for stock forecasting and revealed that the cooperative optimization algorithm approach enhances the prediction accuracy over individual algorithms, and it was found to be statistically significant by using the Deibold Mariano test. Hence, this approach can be used as a promising tool for stock market forecasting [12].

II. METHODS

In induction motors, the calculation of losses is very important as it influences directly the temperature distribution and motor efficiency. Due to uncertainties, the prediction of losses is very difficult because of the problems associated with assigning losses and thermal coefficients. Therefore, the forecast of these losses is important for determining the efficiencies and temperature rise that affect the machine. Thus, the importance of stray load losses in induction machines illustrated that a small improvement of the average efficiency of the industrial motor would save energy [13, 14].

To prevent a short circuit between the coil and the iron core, insulation treatment should be carried out in the rotor iron core, winding slots, and the end face of the iron core during the production process of micro-motor rotor [15]. Alternating Current (AC) loss characteristics are reported to be affected by the ferromagnetic arrangement because magnetic penetration is altered [16]. As the AC loss characteristics directly affect the efficiency and feasibility of the HTS machines, it is important to measure the AC loss characteristics during the design stage [17]. Waldron MB and Waldron KJ. studied the time sequence of a complex mechanical system design, and hypotheses on the generation of sub-goals and the length of the conceptual design process are proposed for future research work in mechanical design theory and methods [18]. Chen and L. Cai J. used the vector projection method to assess the maintainability of mechanical system in the design review, and based on the definitions of maintenance and maintainability, an important tool of design for maintenance was developed. This provides a way to improve maintainability through design in terms of physical design, and a set of standard guidelines and maintainability factors in terms of physical design, logistics support, and ergonomics are identified. As a specific application of design review, vector projection method is developed to evaluate the maintainability of the mechanical system [19].

Experiments were carried out using lamination sheets fabricated through different manufacturing processes: insulation, laser cutting, electrical discharge machining (EDM), and thermal treatment. The best manufacturing processes were found to be bonding varnish insulation and EDM cutting [20].

A. Characteristics of Iron Insulation Treatment Process for Micro-Motor Rotor

In the production process of micro-motor rotors, in order to prevent short circuit between the coil and the iron core, insulation treatment should be carried out in the rotor iron core winding slots and the end face of the iron core [5]. Insulation of winding slot and end face is a key process in rotor production, which directly affects the performance of motor. Presently, a new process of electrostatic powder coating is used in micro-motor rotor Tiecang insulation. The paint film coated by this process has no pinhole, strong adhesion, good coverage, thickness, good mechanical properties, and many other characteristics. The main process parameters are shown in Fig. 1

B. Overall Design of Mechanical System

The function of the mechanical system of automatic feeding system for rotor core of micro-motor is to realize the mechanical action required for feeding and receiving function of rotor core. The overall design of the automatic feeding system adopts the design idea of initialization. Firstly, the whole mechanical system is divided into functional units according to the different functions required by the system, as shown in Table I.

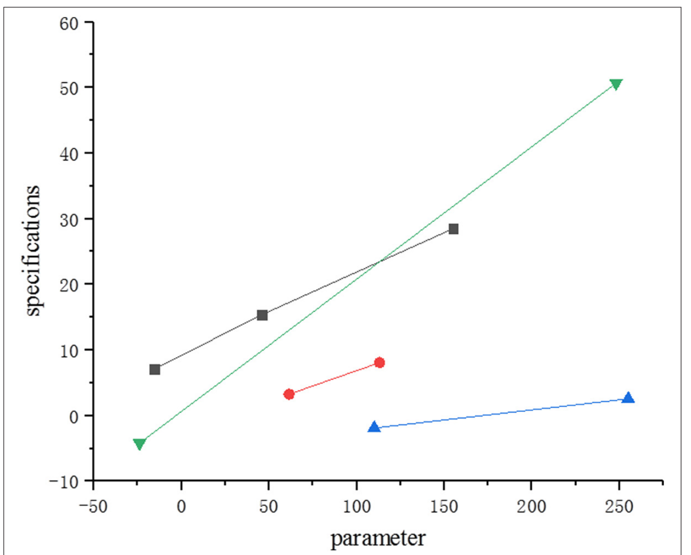

Fig. 1. Process parameters of coating machine.

TABLE I. FUNCTIONAL UNIT DIVISION

Functional Unit Division	Cell Function
Rotor core feeding unit	Separates the single product rotor forbearance from the string bar and moves it to the preparation position for core removal
Rotor core moving position conversion unit	Realizes the automatic feeding of the string bar—the single rotor core, carries out the transfer between the functional units, and takes out the coated core.
Rotor core auxiliary tooling assembly and disassembly unit	Removes the auxiliary fixture from the coated single iron core and then, installs the auxiliary fixture on the uncoated iron core
Rotor core feeding unit	Puts the rotor iron safe coated with insulation layer on the finished tray and lays them in rows
Body unit	The installation platform and some auxiliary functions are provided for each functional unit and control system, and the whole system is connected with the conveyor belt of the coating machine to complete the supporting connection.

According to the different functions to be realized, the whole mechanical system is divided into five functional units and then, according to the unit function of each functional unit, the position layout and process design of each unit are carried out: Since the automatic feeding system needs to reach a feeding speed of 300 pieces/h during the feeding process, this requires a fast motion speed of the mechanical mechanism of the system, and in order to complete the rapid transfer of the rotor iron core among the functional units, the rotor core moving station conversion unit spans the entire automatic feeding system for fast transfer of the core between the units. The rotor core feeding unit and the rotor core receiving unit are respectively close to the core feeding end of the core conveyor belt and the core discharging end of the finished product after insulation treatment to shorten the distance and to reduce the motion time and vibration during positioning: As the system needs to install and disassemble auxiliary tooling for the iron core during automatic feeding and receiving, so W places the assembly and disassembly unit of the rotor core auxiliary tooling between the rotor core feeding unit and the rotor receiving unit, so that the transmission distance between the two units is the shortest. The main function of the body unit is to support each functional unit and connect the conveyor belt with the functional unit [6].

C. Overall design of PIC control system

The function of the control system of the micro-motor rotor core automatic feeding system is to realize the automatic control of the mechanical action required by the feeding and receiving function of the rotor core. The overall technical requirements of automatic feeding control system are as follows:

(1) It should fully realize the automatic control of the system, automatically complete the mechanical action required by all functions, respond quickly to sudden faults and anomalies, and realize the simple automatic fault diagnosis function.
(2) It should have a friendly man–machine interface and simple and easy to operate.
(3) Manual mode and automatic mode can be converted to each other and are easy to debug and troubleshoot.
(4) The control program can be erasable and the structure is simple, which is convenient for later modification and adaptation of the program.
(5) The control system circuit is simple and clear, the components are easy to replace and convenient to maintain, and the cost is moderate.

Based on the overall design requirements of the control system, the control system is designed to choose the commonly used industrial Programmable logic controller (PLC) control system. The PLC controller is the core of the whole system, and the touch screen is used as the man–machine interaction interface, a plurality of solenoid valves as action controllers, and a variety of cylinders as action actuators with cylinder position sensors and metal proximity sensors, and the closed-loop control system of the automatic feeding system as shown in Fig. 2 is composed of the reflection photoelectric sensor and other sensors such as motion and state sensors [21].

III. RESULTS AND ANALYSIS

A. Mechanical Mechanism Design and Action Realization

The analysis of the function of the sub-core feeding unit and the design of its basic function can be done, and after that, the mechanical mechanism of the rotor core feeding unit can be designed. The design requirements of the mechanical mechanism of the feeding unit of the rotor iron core should be as follows:

(1) Consistent with its basic function and action, the mechanical mechanism of the rotor core feeding unit is divided into the following H parts for design: the core string material supply part, the separate part of single-product iron crazy string material, and the feeding part of single product iron core handling.
(2) The iron grip string supply part needs to use the structural feature that is a certain blank string rod end at both ends of the string to achieve the translation transmission of the string and set the iron core detection sensor to monitor the state of the string.
(3) The separation mechanism of single iron core and string material can hold and fix the string material rod. A variety of adjustable strokes can carry out uniform and stable straight-line motion, and with stable thrust W, there will be a variety of specifications for single iron core from the string of material rod separation. The mechanism is set with a limit protection switch to prevent fault. After the separation action is completed, the holding device of the string bar will discharge the empty string bar.
(4) The feeding part of single core handling can provide the separated single core of various specifications to the core handling preparation position continuously and flexibly and set the detection sensor in the product removal position to monitor the preparation state of the single iron core.
(5) In the design of each part, the movement distance of the iron core should be minimized, the action time should be shortened, and the equipment size should be compressed to reduce the cost.

In accordance with the above design requirements, the design of mechanical mechanism is framed in accordance with the direction of iron transmission design. Firstly, the design of iron crazy string

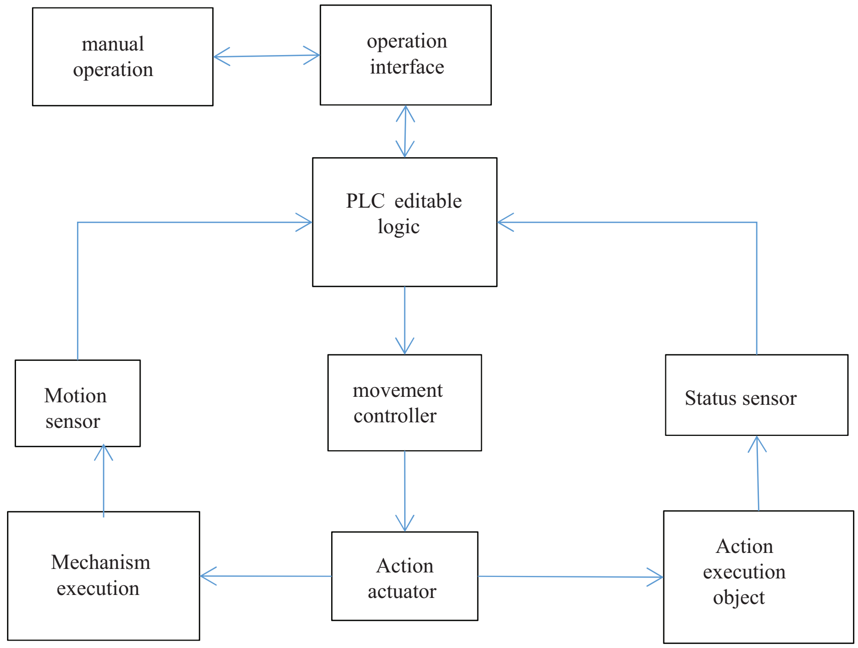

Fig. 2. Composition of closed-loop control system.

material supply part of the mechanical structure should be molded according to the design requirements using movable tooth plate alternately up and down. The mechanical mechanism design of the core string material supply and the string material was placed on the string material rack, the movable tooth plate moves up and down as the linear guide column moves up, and the movable tooth plate moves forward and backward after the linear guide rail moves forward to the top of the V-shaped guide plate. After the string is detected by the sensor above the string, the movable tooth plate moves down to place the first string on the V-shaped guide plate and the subsequent string is moved forward by a tooth groove distance. The movable tooth plate moves down and back to the initial position to prepare for the next string supply, and the core string supply action is completed. After the core feeding action is completed, the string material is located on the V-shaped guide plate, and the string rod-clamping device will clamp the string rod head at one end of the string material. After receiving the feeding signal, the screw drive motor starts to rotate the screw, and the screw sleeve drives the iron core pushing plate to move at different distances to the end of the screw based on different product specifications separating the single iron core of various specifications from the string rod and pushing it into the V-shaped transition feeding guide plate of the material handling part of the single iron core to complete the separation action of single iron core and string material. After all the iron cores on the string material are pushed out, the holding device of the string material rod is loosened, and the empty string material rod is discharged to complete the core separation of the whole single product. In the design process, we need to calculate the type of lead screw driving motor. The lead screw is r16-5-500-570-0.05, the lead is 5 mm, and the outer diameter of the screw is 16 mm to meet the requirements of fast feed and small volume according to the parameters of the screw and load. The selection calculation of the screw drive motor is shown in Table II.

The number of working pulses is shown in (1).

$$A = \frac{s}{p} \cdot \frac{360}{\theta_s} = 20000 \tag{1}$$

The pulse frequency of uniform operation is shown in (2).

$$f = \frac{A - f_2 t_1}{t - t_1} = 2666Hz \tag{2}$$

The speed of uniform motion is shown in (3).

$$N = \frac{\theta_S}{360°} \cdot f \cdot 60 = 800r/m \tag{3}$$

TABLE II. SELECTION OF LEAD SCREW DRIVE MOTOR

Model	**Data**
Quality of work pieces and worktables	M = 8 kg
Friction coefficient of screw nut	$\mu_0 = 0.3$
Silk waste trunnion	D = 12 mm
Filament density	$\rho = 7.9 \times 10^3$ kg/m^3
Designed to distinguish	1 = 0.05 mm
Tilt angle	$\theta = 0°$
Coefficient of friction of sliding surface	$\mu = 0.05$
The efficiency of screw	$\eta = 0.9$
Silk waste length	L=570 mm
Lead a ball screw	P = 5 mm
Step from the angle of θ_s:	$\theta_s = \frac{360 \cdot l}{p} = 3.6\theta_s = 3.6°$

The load in the direction of motion is shown in (4).

$$F = Mg\mu = 3.92N \tag{4}$$

The preload is shown in (5).

$$F_0 = \frac{F}{3} = 1.3N \tag{5}$$

The load torque is shown in (6).

$$T_L = \frac{F \cdot P}{2\pi \cdot \eta} + \frac{\mu_0 \cdot F_0 P}{2\pi} = 0.038N \cdot m \tag{6}$$

The moment of inertia of the lead screw is shown in (7).

$$J_n = \frac{\pi}{32} \cdot \rho \cdot L \cdot D^4 = 0.09 \times 10^{-4} kg \cdot m^3 \tag{7}$$

The moment of inertia of the table is shown in (8).

$$J_T = m\left(\frac{P}{2\pi}\right)^2 = 0.05 \times 10^{-4} kg \cdot m^3 \tag{8}$$

The moment of inertia of load is shown in (9).

$$J_L = J_T + J_N = 0.14 \times 10^{-4} kg \cdot m^3 \tag{9}$$

The acceleration torque is shown in (10).

$$T_a = \frac{J_0 + J_L}{9.55} \cdot \frac{N}{t_1} = 0.3 \times 10^{-3} N \cdot m \tag{10}$$

$J_0 = 0.162 \times 10^{-4}$ Moment of inertia of motor rotor

The required torque is shown in (11).

$$T_M = (T_L + T_a) S_f = 0.077N \cdot m, \quad S_f = 2 \tag{11}$$

After the implementation of the system cylinder and iron Qiao key monitoring sensors are completed, the C control system can be designed. PLC control system is composed of man–machine interface, PLC controller, and action controller. Firstly, the number of input ports of the PLC controller is determined by the number of feedback signals of the sensor feedback system, according to the PLC controller, to control the execution of gas rainbow and motor signal number, to determine the PLC controller output port number, and to determine the need to choose the PLC controller model and input and output expansion unit model. According to the design of the sensor feedback system, the sensor feedback system has a total of 59 sensor feedback signals that need to monitor the core position and motion and then, it can be determined that the C controller needs to have at least 64 input ports for feedback signals. According to the number of actuating cylinders and the number of driving motor signals required by the Tiaqiao automatic feeding system, 41 necessary action control signals of the whole system can be obtained and it can be determined that the PLC stabbing controller needs to have at least 48 points W on the control of the execution of pneumatic rainbow and motor control signal output port. For determining the terminal n points required for input feedback signal and output actuator control signal of PLC controller obtained by root pendulum, it is decided to adopt PLC master controller and input and output extension unit to form C controller. Omron CP-X40DT-D type NX control host connected to evaluation of 1W-40EDT type INPUT and output expansion module 1, Cp1w-20 mansion T type I/O expansion module 2, PLC controller host, and I/O module are connected by supporting data line, together, the PLC controller is formed, and the combined PLC controller has a total of smart input ports and 48 output ports, meeting the control needs of the system [22]. Omron NB7W touch screen is used as the man–machine interface for PLC controller. After completing the design of C controller, all the sensor feedback signals of the sensor feedback system are connected to the feedback signal input port of the PLC controller to allocate the signal input port, and similarly, all the PLC controller needs to control the action control signal of the jins and the PLC controller's clever signal output port corresponding to the distribution of the output end n of the clever signal.

IV. DISCUSSION

The basic function of the study depends on the design of the rotator. The mechanical mechanism of the rotor core feeding unit is divided into different parts; besides, there will be a variety of specifications for a single iron core from the string of material rod separation. In the design process, the lead screw is r16-5-500-570-0.05, the lead is 5 mm, and the outer diameter of the screw is 16 mm to meet the requirements of fast feed and small volume according to the parameters of the screw and load. There is much to consider at the design stage; a designer should be provided with simple and logical measures qualitatively or quantitatively to evaluate and calculate the maintainability. Prediction enables an early assessment of the maintainability of the design and enables decisions concerning the compatibility of a proposed design [19]. The analysis of the function of the sub-core feeding unit and the design of its basic function can be done, and after that, the mechanical mechanism of the rotor core feeding unit can be designed. By means of probabilistic models for the uncertainties related to geometry, loads, and material properties, several studies were made on the reliability-based analysis and optimum design of structures and mechanical systems [23]. Generally, normal distribution is assumed for describing the probabilistic behavior of the uncertain parameters. The reliability-based optimum design requires a quantitative assessment of all engineering uncertainty. When past data are available, Bayesian statistical decision theory can be used to include professional information and past data in achieving an optimal design [24]. In the design process, calculations of the type of lead screw driving motor are important. Rao, S.S. developed a fuzzy set methodology for the description of uncertain mechanical systems and illustrated its application for the optimum design of four-bar mechanisms. Apart from the methods based on fuzzy theory, probabilistic approaches were also applied for the analysis and design of uncertain engineering systems [25]. Nakagiri, S. presented a stochastic finite element method to perform the uncertain Eigenvalue analysis of composite plates [26].

V. CONCLUSION

This present study observes the optimization and design of the feeding mechanical system of micro-motor rotor iron core based on electrical automation. This method tested systematically the overall design of the mechanical system, the design and action of the mechanical mechanism, and the performance of the automatic feeding system for rotor core of micro motor. The micro-rotor core automatic feeding system recognizes the full automatic feeding and receiving function of the rotor iron core. The experimental results reach the production capacity requirement of 300 pieces/h, in the average time of 12 seconds/piece, in order to meet the design of functional requirements. Compared with manual feeding and receiving, the micro-rotor iron expansion automatic feeding system can reduce the reject rate caused by feeding and receiving to zero. It also saves the labor cost of two operators in each rotor iron core production line and understands the design purpose of improving the automation degree of micro-motor rotor production process, besides improving production efficiency and production quality and reducing the human cost, if the design of the functional requirements is enhanced further in the future, the production capacity increases with an increase in efficiency and costs and will be molded according to the requirements. If the distance of the iron core can be minimized, the action time should be shortened, and the equipment size should be compressed which in turn helps to reduce the cost. The components of the proposed design are easy to replace and easy to maintain. The automatic control of the system automatically controls the mechanical action and responds promptly to sudden faults besides having a friendly man–machine interface. Therefore, if these characters are further improved, in the future, it becomes a novel device.

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