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Application Research on an Automatic Painting Production Line for the Formation of Locks

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Abstract: *This article addresses the painting process in the lock manufacturing process and designs a dedicated automatic painting production line for locks. By applying this automatic painting system, it can significantly improve the painting process in lock production, enhance product quality and production efficiency, and ensure the health and safety of operators. This has a positive impact on promoting the development of the lock manufacturing industry.*

Keywords: *lock production; automatic painting; drying system; control system*

1. Introduction

With the development of the Chinese economy, China has become the world's largest producer and consumer of locks, and locks are closely related to people's lives. According to experts, the lock market in China is expected to continue growing at a rate of over 20% annually in the future [1]. Although the quantity of lock production in China is rapidly increasing, there is a significant gap in traditional processing techniques and equipment in the lock industry compared to international advanced levels. The traditional manual painting method for lock body coating remains prevalent, leading to inefficiency, severe pollution, and adverse effects on the health of production workers. Therefore, the research presented in this project plays a crucial role in promoting the rapid development of locks and enhancing the competitiveness of the lock production industry.

A certain enterprise primarily produces various types of locks, including copper and iron padlocks, hanging locks, lateral locks, steel ball locks, ball locks, lever locks, and more, totaling over 70 specifications across six major series. The products not only sell well throughout China but are also exported to Southeast Asia, Australia, Europe, and the Americas, making the enterprise a leading lock industry production base. Although the production technology of the enterprise's locks has gradually improved with its growth, the painting and forming process, as an essential step in lock production, lags behind in technology. It mainly relies on manual labor, and the quality of lock body painting is heavily influenced by the skills, responsibility, and professional ethics of the operators. This not only fails to guarantee the consistency of lock product quality but also results in significant paint loss and low production efficiency. Moreover, painting operations involve toxic and harmful special tasks, posing a serious threat to the health of operators. The tools used in the painting process may generate sparks, and since paint is flammable, there is a risk of fire and explosion. The mixing of paint may involve fire hazards or spark generation, leading to potential fire or explosion risks. Additionally, paint contains toxic substances such as benzene, which may volatilize or disperse into the air, causing severe occupational health diseases when inhaled. Therefore, the painting and forming process in lock production seriously constrains product quality, cost, and production efficiency. To improve product quality and stability, reduce paint and energy consumption, increase labor productivity, meet market needs, enhance economic benefits, and improve the production environment, researching an automatic painting production line for lock production is of great practical significance.

2. Current Development Status and Trends of Relevant Technologies at Home and Abroad

Spraying is a processing method that uses a spray gun to atomize paint onto the surface of objects to be coated. It can be divided into air spraying, airless spraying, electrostatic spraying, and other spraying methods derived from basic spraying. The four main types of thermal spraying processes widely applied are arc spraying, flame spraying, plasma spraying, explosion spraying, and supersonic spraying technology, among others [2]. Through the application of spraying technology, coatings with wear resistance, corrosion resistance, thermal insulation, conductivity, insulation, sealing, lubrication, and

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other special mechanical and chemical properties can be obtained on various locks. The scope of application is very broad, involving various sectors of the national economy.

The development of spraying technology abroad is rapid, especially in the application of automated production lines for spraying, covering areas such as the home appliance industry, metal products, electronic products, and the automotive production industry. Intelligent spraying robots have been introduced in spraying production lines [3]. In China, large and medium-sized enterprises have undergone transformations towards automated painting production, and many enterprises have conducted research on the production of automatic painting machines. However, the application of automatic painting to products like locks, which are diverse, small-sized, and irregularly shaped, is relatively limited. Therefore, there is significant potential for development in this area.

3. System Hardware Design

Painting operation is an indispensable and crucial process in the lock manufacturing process, playing a significant role in lock production. However, painting operations involve toxic and harmful tasks, posing potential risks to the health of operators. Additionally, the quality of painting operations is influenced by various factors such as the skill level and responsibility of operators, making it challenging to ensure the stability of product quality. Therefore, manual hand spraying is not ideal, especially considering that manual spraying is mainly applied to the post-treatment of defective products after automated spraying. This project explores how to achieve fully automated spraying on lock bodies, focusing on the application of industrial robot technology, PLC technology, sensor technology, intelligent instrument technology, stepper motor control technology (or servo control technology), and touchscreen technology in practical production.

3.1 Industrial Robots

Currently, there are numerous industrial robot brands both domestically and internationally, each with its own characteristics [4]. They can meet the requirements of tasks such as transporting locks on the production line, installing locks, transporting lock painting racks, and installing lock painting racks. Due to the simplicity of the tasks, mainly involving the movement and handling of locks, this system adopts a small six-axis robot. Two different fixtures are designed to achieve functions such as picking up and placing locks, transporting locks, and transporting lock painting racks. The robot fixtures use pneumatic control technology, including cylinders or vacuum generators, suction cups, solenoid valves, sensors, and mechanical components. The fixture for picking up locks is designed with suction cups for easier handling, while the fixture for transporting lock painting racks is designed with a gripper for easier installation on the painting rack conveyor chain.

3.2 Lock Conveyor Belt

A dedicated conveyor belt for lock transport is designed based on the characteristics of locks. Lock positioning platforms are added to the conveyor belt, and motion and stop functions are achieved using stepper motor control technology (or servo control technology). The platform facilitates the oriented placement of locks. The conveyor belt support and the conveyor belt itself are designed with sensors to identify locks. When a lock is detected, the sensor sends a signal to the PLC, which controls the conveyor belt to stop. Lock ejection cylinders are added, and when a lock reaches a specified position, the sensor sends a signal to the PLC. The PLC, upon receiving the signal, controls the electromagnetic valve of the lock ejection cylinder to push the lock to the designated position. Once the ejection is complete, the PLC sends a signal to the industrial robot, which then performs the relevant actions for lock handling and placement.

3.3 Lock Painting Rack

The design of the lock painting rack focuses on meeting the requirements of hanging locks, facilitating automatic painting in the later stages, and being easy for the robot to grip and place. This necessitates special design considerations for the structure and specific material requirements for the lock painting rack.

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3.4 Touchscreen Technology Intelligent Control

The system control interface is designed on a touchscreen, utilizing touchscreen technology to achieve remote operation and control. The interface design includes feeding systems, conveyor systems, spraying systems, drying systems, control systems, safety protection systems, cleaning and environmental protection systems, remote monitoring systems, fault diagnosis and warning systems, and operation control systems. Each system incorporates relevant functional controls to display the operating status of equipment, atomizer rotation speed, paint flow rate, air pressure, and other parameters, ensuring precise control of the equipment and maintaining the stability and consistency of the spraying effect. A user-friendly touchscreen interface is provided, allowing operators to start, stop, and adjust the speed of the equipment through the touchscreen interface.

3.5 PLC Technology

The control system utilizes PLC (Programmable Logic Controller) for control, serving as the core of the entire lock automatic painting production line control system. It coordinates the work of various processes such as lock transport, automatic lock installation, rack transport, spraying, and drying. The Mitsubishi FX3U series PLC is selected, representing the pinnacle of small PLC products. It has significantly improved basic performance, with three independently positioned axes within the basic unit, reaching a maximum of 100 kHz. It also adds new positioning instructions, enhancing the positioning control function and providing greater convenience. The FX3U series PLC is a micro programmable controller with a large capacity of up to 64K of RAM, high-speed processing at 0.065μS/basic instruction, and a control scale of 16 to 384 points for input and output (including CC-LINK I/O). It features an expandable control CC-Link network with a maximum of 84 points (including remote I/O). The series also allows monitoring, testing, setting the clock, and other functions for software components on application modules. The FX3U series can have its display module installed on the control cabinet panel.

4. Automatic Painting System Design

To address this issue, a dedicated lock automatic painting system has been designed and developed, comprising ten major systems, including the feeding system, conveyor system, spraying system, drying system, control system, safety protection system, cleaning and environmental protection system, remote monitoring system, fault diagnosis and warning system, and operation control system [5]. The process flow is illustrated in Figure 1, realizing automated production, enhancing product quality and stability in the painting process of lock production, reducing paint and energy consumption, minimizing harm to human health during the painting process, and improving labor production safety and economic efficiency.

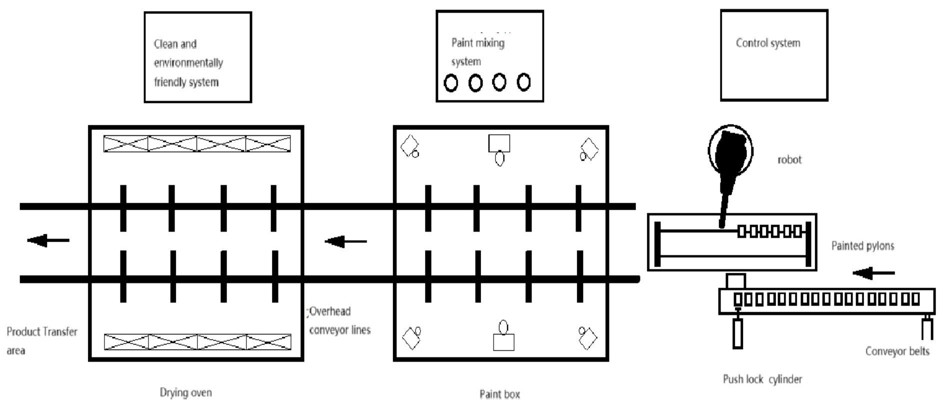

Figure 1: Process flow of automatic lock painting

4.1 Feeding System

This includes the lock body conveyor transport system and the system for the automatic installation of locks on painting racks. After the lock bodies are produced, they are systematically transported to

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designated positions through the conveyor system. The robot then places them onto lock painting racks according to a specified pattern. Each lock painting rack is divided into two rows, each accommodating 20 lock bodies, totaling 40 lock bodies. Once the robot fills a lock painting rack with lock bodies, it places the fully loaded lock painting rack onto the conveyor system, which transports it to the painting booth for the painting process.

4.2 Conveyor System

The conveyor system adopts a hanging chain structure, where the racks filled with lock bodies move horizontally in a hanging manner at a constant speed. The system eliminates the rotating axis commonly used in manual painting to ensure that the position of the hung lock painting rack remains fixed without rotation. When the lock painting rack reaches the designated position in the painting booth, the conveyor belt stops, and the painting process begins.[6]

4.3 Spraying System

The system employs a DISK pneumatic turbine high-speed atomizer vertically fixed on a lifting rod. The atomization process is achieved through reciprocating up-and-down motion. The pneumatic motor, driven by compressed air, reaches a high speed of 40,000 rpm/min. An alloy disk (atomization disk) is mounted on the rotating shaft. Paint is transported to the high-speed rotating atomization disk through a precision gear pump via a paint pipe. The paint is then atomized into fine droplets as it is transported from the high-speed rotating atomization disk. The atomized paint particles, negatively charged due to the high-voltage electrostatic field (0-120kV), uniformly disperse, and, under the influence of electrostatic forces, fly towards the well-grounded workpiece. The paint particles are adsorbed onto the work surface, forming a bright and firm coating [7].

4.4 Drying System

After painting, the locks are directly guided to the drying system by two hanging conveyor devices. The drying system consists of a direct oil heating system, a hot air circulation system, a drying control system, and a housing. The advanced direct oil heating technology in this drying system quickly dries the moisture on the paint surface while ensuring no damage to the lock material. The hot air circulation system promptly exhausts the waste gas generated during the drying process, ensuring a fresh drying environment. The drying control system utilizes PID automatic temperature control to adjust the drying time and temperature automatically based on different lock materials and paint types, achieving precise control. This process realizes automatic control, unmanned operation, reduces manual intervention and errors, and improves production efficiency and product quality. Additionally, the system enables short drying times, occupies a small area, is not affected by weather conditions, and operates efficiently.

4.5 Control System

The control system uses a PLC (Programmable Logic Controller) for control, serving as the core of the entire lock automatic painting production line control system. It coordinates the work of various processes such as lock transport, automatic lock installation, rack transport, spraying, and drying. The system can operate both manually and automatically, with manual control mainly used for equipment debugging and automatic operation for production. In automatic mode, operators can set parameters such as conveyor belt speed, precise control of paint thickness and uniformity, and the start and end times of painting. The PLC also monitors the overall system operation status and can stop the system promptly and raise alarms in case of a malfunction, ensuring safe equipment operation.

4.6 Safety Protection System

To ensure the safety of operators, the system is equipped with a safety protection system. This system includes a series of sensors and safety valves to detect the working status of paint cans and atomizers, as well as parameters such as the pressure and flow rate of compressed air. If any of these parameters deviate from normal, the safety protection system automatically stops the operation and raises an alarm to ensure operator safety.

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4.7 Cleaning and Environmental Protection System

The cleaning system includes a cleaning tank and a cleaning pump, used to clean components such as paint cans, atomizers, and material pipes. Operators only need to place the components into the cleaning tank and start the cleaning pump to complete the cleaning process, significantly reducing the workload for operators. The environmental protection system comprises waste gas treatment devices and waste liquid collection devices to handle and collect the waste gas and liquid generated during the painting process. The waste gas treatment device employs methods such as activated carbon adsorption, catalytic combustion, or condensation recovery. The waste liquid collection device collects the waste liquid into designated containers for centralized treatment, ensuring minimal impact on the environment.

4.8 Remote Monitoring System

The remote monitoring system includes one or more cameras, sensors, and data collectors to monitor parameters such as equipment operation status, paint flow, and exhaust emissions. It transmits this data to a remote computer or cloud platform. Operators can use the remote monitoring system to understand the real-time operation status and paint usage of the equipment, make timely adjustments to parameters, and perform maintenance, thereby improving equipment efficiency and production quality.

4.9 Fault Diagnosis and Warning System

To promptly identify and address equipment faults, the system is equipped with a fault diagnosis and warning system. This system monitors various parts of the equipment in real-time using sensors and monitoring devices to detect anomalies and issues warnings through various means such as sound, light, and displays. Additionally, the system records and analyzes the historical operational data of the equipment, predicts potential problems, and enables proactive maintenance and replacement to prevent downtime or malfunctions during production, ensuring smooth production.

4.10 Operation Control System

To facilitate the use of operators, the system is equipped with an operation control system. The operation control system adopts a touchscreen interface, displaying parameters such as equipment operation status, atomizer rotation speed, paint flow, and air pressure. This allows for precise control of the equipment, ensuring the stability and consistency of the painting effect. It also provides a simple and user-friendly interface, allowing operators to start, stop, and adjust the speed of the equipment through the interface.

5. Conclusion

This paper presents an applied research on an automatic painting production line for locks. Through the conceptual design of the automatic lock painting production line, the overall layout is determined, and various hardware systems within the line are developed. The control system of the automatic lock painting production line is studied, considering the hardware selection for devices such as PLC, touchscreen, and industrial robots. The application design of lock painting racks and bases, as well as the lock conveyor belt, is explored. The process design for the automatic lock painting production line achieves the expected results.

The automatic lock painting production line is well-equipped, operates in a streamlined manner, provides uniform and delicate painting with full and even coatings. It can realize an efficient, safe, environmentally friendly, and reliable production process. Through validation by enterprises, the adoption of this automated production line significantly enhances product quality and production efficiency. The use of the spraying system is conducive to saving paint consumption. It effectively controls the volatile release of toxic substances such as benzene from the paint into the air, reducing inhalation by operators and minimizing harm to their health. This system reduces the amount of hazardous waste generated, alleviating environmental pollution. Simultaneously, it effectively controls the risk of fire and explosion during the painting process, which may arise from sparks produced by the tools used. This makes it an ideal painting solution for lock manufacturing enterprises.

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