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Exploration into the Introduction of Visual Inspection Equipment and Electrical Management in Refrigeration Product Manufacturing

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Abstract: This article focuses on the manufacturing of refrigeration products and elaborates on the introduction and application of visual inspection equipment and electrical management systems. It introduces the principles of visual inspection technology, analyzes existing difficulties and corresponding solutions, and proposes measures for optimizing the architecture of electrical management systems. The practical effectiveness is verified through multidimensional indicators, operational data comparison, and testing. The current research still has limitations in adapting to low-temperature environments, and the integration of the industrial Internet of Things (IoT) and digital twin technology may become an important direction for future development.

Keywords: Manufacturing of refrigeration products; Visual inspection; Electrical management

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1. Introduction

The "14th Five-Year Plan for Intelligent Manufacturing Development" issued in 2021 highlights the need to continuously enhance the level of intelligence in the manufacturing industry. In the field of refrigeration product manufacturing, visual inspection technology that integrates image recognition algorithms, optical imaging systems, and deep learning can effectively identify defects in components. However, the application of such equipment still faces challenges, including installation and positioning deviation control, the influence of optical component performance under low-temperature conditions, and the need for synchronous triggering during image acquisition. By optimizing the architecture of electrical management systems, implementing IP protection standards, and carrying out energy-saving retrofits based on frequency converter parameter optimization, production stability and energy efficiency can be improved. Nevertheless, existing studies remain limited in their adaptability to low-temperature environments. In the future, the deep integration of the industrial IoT and digital twin technology is expected to further promote intelligent and efficient development in this industry.

2. Analysis of the application of visual inspection equipment in refrigeration product manufacturing

2.1. Basic principles of visual inspection technology

Visual inspection technology in refrigeration component surface inspection integrates principles such as image recognition algorithms, optical imaging systems, and deep learning. The optical imaging system converts surface information of refrigeration components into image information through lenses, light sources, and other equipment, clearly capturing detailed features on the component surface [1]. The image recognition algorithm processes the acquired images, extracting key features such as shape, size, and texture based on edge detection, morphological operations, etc., and compares them with preset standard models to determine whether the component has defects. Deep learning utilizes models such as convolutional neural networks, trained on a large amount of annotated refrigeration component image data, to enable the model to automatically learn component surface features and defect patterns, thus achieving more accurate and intelligent defect recognition. For example, in a compressor housing inspection project, technical parameters were selected based on the above principles, enabling the visual inspection equipment to effectively detect defects such as scratches and air holes on the housing surface, ensuring product quality.

2.2. Key technical difficulties in equipment introduction

Introducing visual inspection equipment into the manufacturing of refrigeration products presents numerous key technical challenges. Installation and positioning deviation control is a major challenge. The layout of equipment in the refrigeration product production line is complex, and even slight deviations in the installation of visual inspection equipment can affect detection accuracy. Therefore, high-precision positioning technology and advanced calibration methods must be employed to ensure accurate equipment installation [2]. In low-temperature environments, the performance of optical components is easily affected, such as frosting on lenses and changes in light refraction. This requires the selection of suitable low-temperature optical compensation devices to ensure imaging quality. Additionally, the synchronous triggering mechanism for image acquisition is crucial. The production speed of refrigeration products is fast, and if the image acquisition is not synchronized with the production pace, it can lead to missing or duplicate detection data. Therefore, a precise synchronous triggering system must be designed to ensure that image acquisition closely matches the pace of product production, thereby achieving efficient and accurate visual inspection.

3. Construction of electrical management system for production equipment

3.1. System architecture design optimization strategy

To optimize the electrical management system architecture of refrigeration product manufacturing equipment, multiple approaches can be taken. In terms of PLC controllers, a deep analysis of the complex start-stop logic of refrigeration equipment can be conducted, and combined with the characteristics of production line takt time, the program can be refined to enhance control accuracy and response speed, ensuring that equipment start-stop operations closely align with the production line rhythm and avoiding energy waste and production delays caused by improper control [3]. For industrial communication networks, high-speed and stable communication protocols are adopted to enhance the real-time and reliability of data transmission between devices at all levels, achieving efficient collaboration among various parts of the electrical system. For energy consumption monitoring modules, the data acquisition algorithm is optimized to accurately capture energy consumption information of refrigeration equipment during different operating stages, providing accurate basis for energy consumption analysis and energy-saving strategy formulation, and helping enterprises achieve cost reduction, efficiency improvement, and green production goals.

3.2. Safety protection and energy efficiency improvement measures

In the manufacturing of refrigeration products, it is crucial to strictly implement IP protection standards for high-humidity production environments. It is necessary to select the appropriate IP protection level based on the actual usage scenario and humidity conditions of the equipment, and to perform sealing and moisture-proof treatment on visual inspection equipment and related electrical components to ensure stable operation of the equipment in harsh environments [4]. At the same time, energy-saving retrofits of injection molding machine power systems based on frequency converter parameter optimization can effectively improve energy efficiency. By precisely adjusting key parameters such as frequency and voltage of the frequency converter, the operation of the injection molding machine motor can be better matched to production needs, avoiding waste of electrical energy. For example, in a refrigeration product manufacturing workshop, optimizing the parameters of the injection molding machine's frequency converter reduced the overall energy consumption of the equipment and improved production efficiency. This dual approach of safety protection and energy efficiency improvement lays a solid foundation for efficient and stable production in refrigeration product manufacturing.

4. Equipment integration and system integration solutions

4.1. Equipment collaborative control technology

4.1.1. Visual signal triggering mechanism

In the manufacturing of refrigeration products, a visual signal triggering mechanism is crucial for the automatic sorting of defective parts in evaporator pipelines. A linkage control system between visual inspection results and assembly robots, built on the OPC UA protocol, acquires image information of evaporator pipeline parts through visual inspection equipment. The visual inspection system analyzes and processes the images based on preset defect determination criteria, and generates a visual signal when a defective part is detected [5]. This signal serves as a triggering command and is transmitted in real-time to the assembly robot control system through the OPC UA protocol. Upon receiving the signal, the assembly robot responds quickly and accurately grasps and sorts out the defective part according to a pre-set action program, thus achieving automated collaborative operation of the entire system. This effectively improves the efficiency and accuracy of sorting defective parts in the manufacturing process of refrigeration products, ensuring product quality.

4.1.2. Development of data interaction interface

In the equipment integration and system integration solution for the introduction of visual inspection equipment and electrical management in refrigeration product manufacturing, the development of data interaction interfaces is crucial. Designing an intelligent gateway device compatible with Modbus TCP and Profinet protocols can effectively solve the data interaction problem between visual inspection equipment and MES systems. The Modbus TCP protocol has a wide application base and is easy to implement for simple and fast data communication between devices; the Profinet protocol excels in the field of industrial Ethernet and is suitable for data transmission scenarios with high real-time requirements. Through the intelligent gateway, the detection data collected by the visual inspection equipment can be accurately and real-time transmitted to the MES system for analysis and processing, ensuring efficient monitoring and management of the production process, and realizing the intelligence and informatization of the refrigeration product manufacturing process [6].

4.2. Application of intelligent surveillance technology

4.2.1. Construction of fault prediction model

In the manufacturing of refrigeration products, establishing a compressor motor bearing life prediction model based on vibration spectrum analysis is a crucial step in achieving fault prediction. The vibration spectrum can reflect rich information about the operating state of the motor bearing, and through in-depth analysis, potential fault signs of the bearing can be accurately captured. By collecting a large amount of vibration spectrum data of compressor motors under different operating conditions and utilizing machine learning algorithms for feature extraction and model training, a prediction model that fits the actual operating conditions can be constructed. In the meantime, combined with edge computing units, the model can be deployed on the device side close to the data source to achieve real-time data analysis. In this way, early warnings can be given quickly when faults occur, avoiding the expansion of faults and causing greater losses [7]. This integration of equipment and technology provides an effective approach for intelligent monitoring and fault prevention in the manufacturing of refrigeration products.

4.2.2. Development of digital twin system

In the manufacturing of refrigeration products, taking the refrigerator foam production line as an example, the development of digital twin systems achieves the application of intelligent monitoring technology by constructing a virtual-to-real mapping model. Advanced sensor technology is utilized to collect real-time operational data and process parameters of the refrigerator foam production line, such as temperature, pressure, and flow rate. These data are transmitted to the cloud via the IoT, and modeling and simulation techniques are employed to create virtual models that closely match the physical entities. Through virtual-to-real mapping, the operational status of equipment can be visually presented, potential issues can be identified in a timely manner, and equipment failures can be predicted [8]. Simultaneously, based on the virtual model, process parameters are simulated and optimized, and parameters such as the amount of foam agent and foaming time are adjusted to enhance product quality and production efficiency. This achieves the dual goals of equipment status monitoring and process parameter optimization, providing a more efficient and precise intelligent management solution for refrigeration product manufacturing.

5. Empirical research and effect verification

5.1. Test platform setup

5.1.1. Experimental environment configuration

In the construction of the test platform for a refrigeration valve production line renovation project, the experimental environment configuration needs to be comprehensive and precise. In terms of equipment layout, visual inspection equipment and related electrical management devices are reasonably arranged according to the production line process to ensure efficient collaboration between devices. For example, the visual inspection equipment is placed at key nodes of valve assembly to capture production defects in a timely manner. In terms of sensor network deployment, suitable sensors such as pressure sensors and temperature sensors are selected according to the production characteristics of refrigeration valves, distributed across various production links, accurately collecting temperature, pressure, and other data, and ensuring stable sensor communication [9]. The data acquisition system architecture adopts a layered design, with the bottom layer responsible for data collection from various sensors, the middle layer responsible for data preprocessing and transmission, and the upper layer responsible for data storage and analysis. Each layer is connected through a high-speed network to ensure real-time and accurate data collection and transmission, laying a solid foundation for subsequent empirical research and effect verification.

5.1.2. Evaluation index system

In the evaluation index system for the introduction and electrical management of visual inspection equipment in refrigeration product manufacturing, Overall Equipment Effectiveness (OEE) measures the overall efficiency of equipment from three aspects: time utilization, performance efficiency, and quality pass rate. A high OEE indicates stable and efficient operation of the equipment. Detection accuracy is related to the visual inspection equipment's ability to accurately identify defects and electrical parameters of refrigeration products, directly affecting product quality. Energy consumption per unit of product reflects the effectiveness of electrical management, indicating the relationship between the energy consumed by the visual inspection equipment and the quantity of products produced during the manufacturing process of refrigeration products. Through these multi-dimensional verification standards, the actual effects of introducing visual inspection equipment and electrical management in refrigeration product manufacturing can be comprehensively and objectively evaluated, providing a quantitative basis for subsequent optimization and improvement [10]. This helps enterprises enhance production efficiency, ensure product quality, and reduce energy consumption.

5.2. Comparative analysis of operational data

5.2.1. Improvement in quality inspection efficiency

After the introduction of visual inspection equipment in the manufacturing of refrigeration products, the efficiency of quality inspection has been significantly improved. Through comparative analysis of operational data before and after implementation, it can be seen that before the introduction of visual inspection equipment, the detection rate of condenser fin defects through manual inspection was only 92.3%, and the inspection speed was slow and susceptible to human factors. After the introduction of visual inspection equipment, its high-resolution image acquisition and accurate algorithm recognition significantly increased the detection rate of condenser fin defects to 99.6%. This not only greatly reduces the probability of defective products entering the market, but also enables the equipment to perform inspection quickly and continuously. Compared to manual inspection, it significantly shortens the inspection time for individual products and improves overall production efficiency. This quantitative effect intuitively reflects the excellent role of visual inspection equipment in the quality inspection process of refrigeration product manufacturing, effectively verifying the positive impact of introducing this equipment on improving quality inspection efficiency.

5.2.2. Comparison of energy consumption

In the manufacturing of refrigeration products, to verify the impact of the introduction of visual inspection equipment and electrical management optimization on energy consumption, an in-depth analysis was conducted based on quarterly data recorded by the SCADA system. It is clearly evident from the data that after the introduction of visual inspection equipment and the implementation of electrical optimization schemes, there was a significant change in energy consumption at the compressor testing station. Specifically, compared to before the optimization was implemented, energy consumption at the compressor testing station decreased by 18.7%. This data strongly demonstrates that the electrical optimization scheme achieved considerable energy-saving results at the compressor testing station. Through such comparative analysis of operational data, the positive effects of the introduction of visual inspection equipment and electrical management strategies on energy consumption are visually presented, providing a reliable practical basis and data support for the refrigeration product manufacturing industry in energy management.

5.3. System stability verification

5.3.1. Equipment joint debugging and testing

In the manufacturing of refrigeration products, equipment joint debugging tests were conducted to verify the system stability after the introduction of visual inspection equipment. Through a 72-hour continuous operation test, the focus was on verifying the synchronous control stability between the visual inspection equipment and the injection molding machine. This test simulated continuous operation scenarios in actual production, closely monitoring various operating parameters and synchronous control conditions of the equipment. The test results showed that the mean time between failures (MTBF) of the equipment reached 1500 hours. This indicates that the visual inspection equipment and the injection molding machine exhibit high stability in synchronous control, meeting the requirement for long-term stable operation in the manufacturing process of refrigeration products. This provides a strong empirical basis for subsequent large-scale production applications, ensuring that the visual inspection equipment and the injection molding machine can work stably and efficiently after joint debugging in actual production.

5.3.2. Simulation of abnormal operating conditions

In the manufacturing of refrigeration products, to verify the stability of the system under the introduction of visual inspection equipment and electrical management, abnormal operating conditions are simulated. A simulated grid fluctuation scenario is set up, with a voltage sag of 15%, to observe whether the inspection equipment can operate normally. This tests the system's anti-interference capability during abnormal voltage changes, ensuring that even in the event of significant fluctuations in grid voltage, the inspection equipment can still operate stably without misjudgment or missed inspections. Simultaneously, a simulated mechanical impact scenario is conducted, replicating the mechanical vibrations, collisions, and other situations that may be encountered during the manufacturing process of refrigeration products. This tests whether the system's detection accuracy and stability are affected by mechanical impacts, and determines whether the visual inspection equipment and electrical management system can maintain normal operation under complex operating conditions, thereby ensuring the reliability and accuracy of visual inspection during the manufacturing process of refrigeration products.

6. Conclusion

In the manufacturing of refrigeration products, the introduction of visual inspection equipment and electrical management are crucial. By refining the key points of visual inspection equipment selection and configuration, as well as the methodology for optimizing electrical systems, this provides key guidance for industry practice. However, current research has limitations in terms of adaptability to low temperature environments, which means that under extreme low temperature conditions, the stable operation and accurate detection of equipment still face challenges. In the future, the deep integration of industrial IoT and digital twin technology will be an important development direction. With the help of industrial IoT to achieve real-time monitoring and remote operation and maintenance of equipment, combined with digital twins to construct virtual models for optimizing design and predictive maintenance, it is expected to break through existing limitations, improve the performance and electrical management efficiency of visual inspection equipment in refrigeration product manufacturing, and promote the refrigeration product manufacturing industry to a new stage of intelligent and efficient development.

Disclosure statement

The author declares no conflict of interest.

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