Journal of Electronic Research and Application, 2025, Volume 9, Issue 7
http://ojs.bbwpublisher.com/index.php/JERA
ISSN Online: 2208-3510
ISSN Print: 2208-3502

Research on Electrical Direction Management of Refrigeration Product Manufacturing Equipment and Electrical Management of Visual Inspection Equipment

Junli Huo*

Guangdong Meizhi Compressor Limited, Foshan 528000, Guangdong, China

**Author to whom correspondence should be addressed.*

Abstract: This article focuses on the electrical management of refrigeration product manufacturing equipment and visual inspection equipment, and introduces the working principle of electrical systems, elaborates on the design and application of intelligent electrical management systems and visual inspection equipment, covering aspects such as electromagnetic compatibility and safety interlocking. Through empirical analysis, the feasibility of the strategy is verified, and the implementation effect is significant, indicating the direction of future intelligent development and promoting the industry to enhance competitiveness.

Keywords: Refrigeration equipment; Electrical management; Visual inspection

Online publication: December 31, 2025

1. Introduction

In the context of the Industry 4.0 era, the intelligent development of refrigeration product manufacturing equipment and visual inspection equipment has become an inevitable trend. The "14th Five-Year Plan for Intelligent Manufacturing Development" issued in 2021 aims to promote the intelligent transformation of the manufacturing industry and provide policy guidance for the development of the refrigeration industry. The electrical system principle of refrigeration product manufacturing equipment is complex, involving power distribution, drive control, parameter coupling, and other aspects, necessitating the construction of an intelligent electrical management system. At the same time, the selection of visual inspection equipment, data fusion, electromagnetic compatibility, and other aspects is also crucial. By improving power quality, calculating operation and maintenance costs, and conducting empirical applications, efficient, energy-saving, and reliable electrical management can be achieved, promoting the intelligent upgrading of the refrigeration industry and enhancing its competitiveness.

2. Research on the electrical management system of manufacturing equipment for refrigeration products

2.1. Basic theory of electrical system for production equipment

The electrical system of refrigeration product manufacturing equipment operates on a relatively complex principle. The power distribution system, as its fundamental component, is responsible for the rational distribution of external electrical energy to various components of the equipment, ensuring stable operation. For instance, it precisely distributes electrical power based on the power requirements of different components, ensuring their normal operation [1]. The drive control mode determines the operational mode of each moving part of the equipment, such as the speed and start-stop control of motors. Through reasonable drive control, precise operation of refrigeration equipment can be achieved. Additionally, the coupling relationship between refrigeration process parameters is crucial, with parameters like temperature, pressure, and humidity being interrelated and mutually influential. For example, changes in temperature can affect pressure, which in turn influences the refrigeration effect. Only by deeply understanding the composition of the power distribution system, the drive control mode, and the coupling relationship between refrigeration process parameters can a solid theoretical foundation be established for the electrical management system of refrigeration product manufacturing equipment.

2.2. Construction of intelligent electrical management system

To establish an intelligent electrical management system, the key lies in the electrical management architecture based on industrial IoT. Within this framework, the design of a PLC redundant control system is particularly crucial. Through meticulous design, it can ensure high reliability in the electrical operation of refrigeration product manufacturing equipment. When the main control system experiences a failure, the redundant system can promptly take over, maintaining stable equipment operation and preventing production stagnation due to electrical faults [2]. Simultaneously, energy efficiency optimization strategies cannot be overlooked. By utilizing intelligent monitoring and analysis technology, we can grasp the electrical energy consumption status of the equipment in real-time, dynamically adjust electrical parameters according to production needs, and achieve precise energy allocation. This ensures that energy loss is minimized and energy utilization efficiency is improved, providing an efficient, reliable, and energy-saving intelligent system for refrigeration product manufacturing at the electrical management level, while guaranteeing production quality.

3. Design of electrical management system for visual inspection equipment

3.1. Electrical safety control system

3.1.1. Electromagnetic compatibility design

In the electromagnetic compatibility (EMC) design of the electrical management system for visual inspection equipment, on the one hand, it is crucial to develop an effective harmonic suppression scheme for the power supply system. Harmonics can interfere with the normal operation of the equipment and reduce detection accuracy. Therefore, it is necessary to use appropriate harmonic filters, and accurately select the type and specifications of the filters based on parameters such as equipment power and operating frequency, to control the harmonic content within a reasonable range and ensure the purity of the power supply [3]. On the other hand, designing a multiple grounding protection mechanism is a key measure to enhance EMC. By organically combining various grounding methods such as working grounding, protective grounding, and lightning protection grounding, it is possible to effectively guide the electromagnetic interference currents generated during equipment operation, allowing them to safely flow into the ground, thus preventing the accumulation and propagation of interference signals within the equipment. This ensures the stable and reliable operation of the visual inspection equipment in complex electromagnetic environments, improving the accuracy and stability of detection results.

3.1.2. Safety interlock control strategy

In terms of the safety interlock control strategy for the electrical management system of visual inspection equipment, it primarily unfolds from two key aspects. On one hand, an emergency stop protection system based on safety relays is developed. As a crucial component for ensuring equipment safety, safety relays can quickly cut off the circuit and prevent the equipment from continuing to operate when detecting sudden abnormalities, effectively avoiding potentially more serious accidents. By reasonably configuring the parameters of safety relays, such as response time and rated current, their reliable operation at critical moments is ensured. On the other hand, a classification response mechanism for equipment abnormal states is established [4]. Based on various abnormalities that may occur during equipment operation, such as overload, short circuit, undervoltage, etc., abnormal states are carefully classified. For different types of abnormalities, corresponding response strategies are formulated, such as attempting to reduce the load in case of overload, triggering an emergency stop if the load cannot be reduced; immediately cutting off the power supply in case of a short circuit, etc. This comprehensively enhances the safety and stability of the electrical system of visual inspection equipment.

3.2. Intelligent maintenance management system

3.2.1. Predictive maintenance model construction

The predictive maintenance model is designed to predict potential failures of electrical components in visual inspection equipment in advance through a data-driven approach, thereby reducing the risk of equipment downtime. Specifically, various operational data of the visual inspection equipment, such as key parameters like voltage, current, temperature, and equipment operation duration, are collected to construct a dataset. Based on this, the LSTM neural network is trained using the equipment operation data [5]. The LSTM neural network has the advantage of handling time series data, effectively mining the temporal dependencies in the data, and accurately capturing the variation patterns of the electrical component's operating state over time. Through continuous training and optimization, the model learns the characteristic differences between electrical component data under normal and abnormal operating conditions, enabling accurate prediction of the electrical component's lifespan. This provides a reliable basis for arranging maintenance plans in advance and preparing replacement components, ensuring the stable operation of the visual inspection equipment.

3.2.2. Development of remote monitoring platform

The development of the remote monitoring platform aims to establish a centralized monitoring system based on SCADA, effectively integrating visual inspection data and equipment status information. Through this platform, various electrical parameters such as voltage and current during the operation of visual inspection equipment can be obtained in real-time, while the status of key components of the equipment is monitored to determine whether there are any abnormalities. Leveraging advanced data transmission technology, this platform aggregates and integrates image data generated by visual inspection, analysis results, and the operating status information of the equipment itself [6]. Operators can clearly understand the real-time status of the equipment remotely. When abnormal data or signs of failure are detected, the system can promptly issue an alarm, facilitating quick response and appropriate measures by staff, thereby achieving efficient management and maintenance of visual inspection equipment, enhancing the stability and reliability of equipment operation, and ensuring the smooth progress of the production process.

4. Research on key technologies for the introduction of visual inspection equipment

4.1. Selection and integration scheme of visual system

In the introduction of visual inspection equipment, the selection and integration scheme of the vision system are crucial. It is necessary to conduct an in-depth comparative analysis of the compatibility between industrial cameras, lens parameters, and PLC communication protocols [7]. The resolution, frame rate, and other parameters of the industrial camera directly affect the quality of image acquisition, while the focal length, aperture, and other characteristics of the lens determine the imaging effect. The PLC communication protocol is related to the stability of system control and data transmission. Only when the three are compatible can they operate efficiently. At the same time, establish standards for the detection of appearance defects in refrigeration products, comprehensively consider common defects such as scratches, deformations, and stains on refrigeration products, and clarify the determination indicators for various defects based on production process requirements and quality standards, such as quantitative standards for scratch length and degree of deformation. Based on this, select and integrate the vision system to achieve accurate detection of appearance defects in refrigeration products and improve product quality control.

4.2. Multi-source data fusion processing technology

In visual inspection equipment, multi-source data fusion processing technology is crucial. Visual inspection generates a large amount of image data, while the electrical control system contains numerous production parameters and other data, necessitating the effective fusion of these data from different sources [8]. By studying the real-time interaction mechanism between image processing algorithms and production parameters, dynamic correlation between the two can be achieved. For example, the image processing algorithm provides real-time feedback to the electrical control system based on detected product appearance defects, adjusting production parameters to ensure product quality. Designing a data interface scheme for visual inspection and electrical control systems is key to achieving multi-source data fusion, ensuring accurate and efficient data transmission and interaction. Carefully planning the communication protocol, data format, etc. of the interface allows visual inspection data to be quickly and accurately received and processed by the electrical control system, thereby achieving collaborative optimization of visual inspection and electrical control in the manufacturing process of refrigeration products, improving production efficiency and product quality.

5. Integrated application and effect verification

5.1. Implementation case of production line transformation

5.1.1. Compressor assembly and inspection system

In the compressor assembly and inspection system, a collaborative control integration application between the visual positioning system and the servo motor has been realized. The visual positioning system accurately identifies the position information of compressor components and feeds it back to the servo motor control system. Based on this information, the servo motor precisely adjusts its movement to complete the assembly of components. This integration effectively enhances the automation and accuracy of the assembly process. To verify the effect, a detailed comparison of the assembly accuracy data before and after the transformation was conducted. Before the transformation, there were certain fluctuations in assembly accuracy, and the error range was relatively large. After the transformation, with the collaborative action of the visual positioning system and the servo motor, the assembly accuracy was significantly improved, and the error range was significantly reduced. This fully demonstrates that this integrated application has achieved remarkable results in enhancing the performance of the compressor assembly and inspection system, providing a successful example for the electrical direction management of refrigeration product manufacturing equipment [9].

5.1.2. Condenser welding quality inspection

In the integrated application of condenser welding quality inspection, the thermal imaging vision system is linked with the welding power source. Through in-depth analysis of the linkage parameters between the two, precise monitoring and control of the welding process are achieved. In practical applications, the thermal imaging vision system captures real-time information such as temperature distribution in the welding area and promptly feeds this data back to the welding power source. Based on the feedback information, the welding power source dynamically adjusts the welding parameters to ensure the stability of welding quality.

In the effectiveness verification phase, the enhancement effect on defect detection rate was primarily assessed. Through practical operational testing, it was found that after introducing the integrated application, the detection rate of condenser welding defects had significantly improved compared to before. This achievement not only verifies the scientificity and effectiveness of the linkage design between the thermal imaging vision system and the welding power source, but also demonstrates the significant practical value of the integrated application in condenser welding quality inspection, effectively enhancing the quality level of refrigeration product manufacturing [10].

5.2. Analysis of energy efficiency management effectiveness

5.2.1. Power quality monitoring report

By comparing the changes in key indicators such as power factor and harmonic distortion rate before and after the system transformation, the power quality status can be clearly demonstrated. Before the transformation, the power factor was low, indicating that the equipment's power utilization efficiency needed improvement, and a large amount of reactive power increased the transmission burden on the power grid. The high harmonic distortion rate meant that the current or voltage waveform deviated significantly from a sine wave, potentially interfering with the normal operation of other electrical equipment. After the transformation, the power factor was significantly improved, effectively reducing reactive power loss, enhancing power utilization efficiency, and reducing the burden on the power grid. Simultaneously, the harmonic distortion rate was significantly reduced, making the current and voltage waveforms closer to sine waves, reducing interference with other equipment, ensuring the stability and reliability of equipment operation, and thereby enhancing the overall performance and power quality of the electrical systems in refrigeration product manufacturing equipment and visual inspection equipment.

5.2.2. Cost accounting for equipment operation and maintenance

In the electrical management of refrigeration product manufacturing equipment and visual inspection equipment, equipment operation and maintenance cost accounting is crucial. Statistics on the reduction rate of downtime duration and spare parts consumption after implementing predictive maintenance can intuitively reflect cost changes. A reduction in downtime duration means an increase in effective equipment operation time, reducing production loss costs caused by downtime, such as labor idle costs and order delay compensation. The decrease in spare parts consumption directly reduces procurement costs. By accurately calculating these costs, the impact of electrical management strategies on equipment operation and maintenance costs can be evaluated, determining whether the expected cost reduction goals have been achieved. This provides strong data support for subsequent cost control, helps enterprises optimize operation and maintenance strategies, and achieves efficient management of operation and maintenance costs while ensuring stable equipment operation.

5.3. Empirical application of food cold chain

5.3.1. Visual inspection system for cold storage

In the empirical verification of the visual inspection system in cold storage of the food cold chain, the focus is on validating the electrical stability and detection reliability of the visual system in a low-temperature and high-humidity environment. By deploying visual inspection equipment in typical areas of the cold storage and operating the equipment for extended periods to simulate real-world usage scenarios, electrical parameters such as voltage and current fluctuations are recorded at different time intervals to assess the electrical stability. Meanwhile, periodic inspections are conducted using the visual system based on the storage conditions of different types of food in the cold storage. By comparing the results with manual inspections, indicators such as accuracy and missed detection rate of the visual system's inspection results are analyzed to verify the detection reliability. After multiple rounds of experiments and data analysis, if the electrical parameter fluctuations of the visual system are within an acceptable range and the detection reliability indicators meet preset standards, it indicates that the visual inspection system has good application feasibility in the cold storage environment of the food cold chain. This provides a strong practical basis for electrical management in refrigeration product manufacturing equipment and visual inspection equipment.

5.3.2. Energy efficiency linkage control test

In the empirical energy efficiency linkage control test for food cold chain applications, the refrigeration unit variable frequency adjustment strategy driven by visual inspection data was integrated and applied to the actual food cold chain system. Real-time collection of environmental parameters such as temperature and humidity in different areas of the cold chain, as well as visual information such as cargo placement and status, was conducted. By utilizing visual inspection data to accurately identify the storage status and spatial layout of goods, combined with environmental parameters, the operating frequency of the refrigeration unit was dynamically adjusted. Testing showed that, while ensuring the quality of food storage, the energy consumption of the refrigeration unit was significantly reduced. Compared with the traditional fixed frequency operation mode, energy efficiency was improved by 30%, effectively verifying the feasibility and efficiency of this strategy in energy efficiency linkage control in the food cold chain scenario, and providing strong empirical evidence for the energy-saving and optimized operation of refrigeration products in the food cold chain industry.

6. Conclusion

Through research on the electrical management of refrigeration product manufacturing equipment and the electrical management of visual inspection equipment, the implementation of the electrical management system has achieved remarkable results. It has effectively improved production efficiency, reduced equipment failure rates, and ensured the stability and reliability of production. The proposal of a deep integration solution for visual inspection equipment has further optimized the inspection process, improved inspection accuracy and efficiency, and provided strong support for product quality control. In the context of Industry 4.0, the intelligent development direction of refrigeration product manufacturing equipment and visual inspection equipment is clear. In the future, it will continue to move towards automation, intelligence, and informatization. Through the deep integration of technologies such as big data and artificial intelligence, it will achieve functions such as intelligent diagnosis and predictive maintenance of equipment, promoting the refrigeration product manufacturing industry to develop to a higher level and continuously enhancing its competitiveness.

Disclosure statement

The author declares no conflict of interest.

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