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Research and Equipment Development of the Intelligent Distribution Car for Storage Cabinets

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Abstract: With the continuous development of automation and intelligence in the tobacco processing industry, the stability requirements for material transportation at various process points have increased significantly. Standard belt conveyors can no longer meet the long-term operational stability demands of production lines and require frequent maintenance. Therefore, this project draws from the structure of material transportation equipment in other industries and combines practical experience from our factory to develop an intelligent distribution car that offers automatic maintenance, simple operation, and self-sensing and self-control capabilities. The current distribution car used at the Wuhan Cigarette Factory has issues with frequent malfunctions, difficult maintenance, and insufficient intelligence. As a key auxiliary device, any malfunction in the distribution car could lead to major risks in production, quality, and safety, making it a critical weakness in the workshop. Through research and development of the storage cabinet distribution car and its intelligent upgrades, this project aims to create a device with real-time controllable operation, online monitoring of components, and automatic cleaning. The newly developed intelligent distribution car significantly reduces failure rates and maintenance difficulties. By using this car, the assurance of product quality has steadily improved. Currently, there is no clear research result on intelligent distribution cars for storage cabinets in the domestic silk production lines, making this project highly valuable for further research.

1. Introduction

With the development of modern industry, automated and intelligent production has become a mainstream trend. Storage cabinets, as critical components in industrial production for material storage and transportation, directly influence production efficiency and quality through their distribution efficiency. Therefore, it is of great significance to research and develop intelligent distribution cars for storage cabinets[1]. In today's industrial landscape, intelligent distribution car technology, with its unique advantages, has been widely applied in fields such as textiles, clothing, and warehousing, becoming a key device for improving the efficiency of modern production lines. The broad adoption of this technology not only highlights its remarkable impact on increasing production efficiency but also underscores its critical value in enhancing product quality.

As the manufacturing industry continues to advance, the technology of intelligent distribution cars for storage cabinets is continually being upgraded and optimized. In the context of increasing demands for production efficiency and quality, innovations in this technology effectively meet the market's needs for efficient, high-quality production, further promoting the transformation and upgrading of the manufacturing industry.

Looking ahead, the development trend of intelligent distribution car technology for storage cabinets will focus more on intelligence, automation, and efficiency. With the deeper integration of IoT, big data, and artificial intelligence, intelligent distribution cars will achieve more precise control and more efficient operations. These technological innovations will allow every step of the production process to be precisely controlled, thereby further improving production efficiency and quality.

The development of this technology will also emphasize environmental protection and sustainability. While pursuing high-efficiency production, reducing energy consumption, minimizing waste emissions, and realizing better resource recycling will become critical directions for the future development of intelligent distribution car technology for storage cabinets.

As an important device on modern production lines, intelligent distribution car technology has broad development prospects and immense potential. With continuous technological advancements and the expansion of its application fields, this technology will play an increasingly important role in the future of manufacturing.

2. Technical Route and Research Content

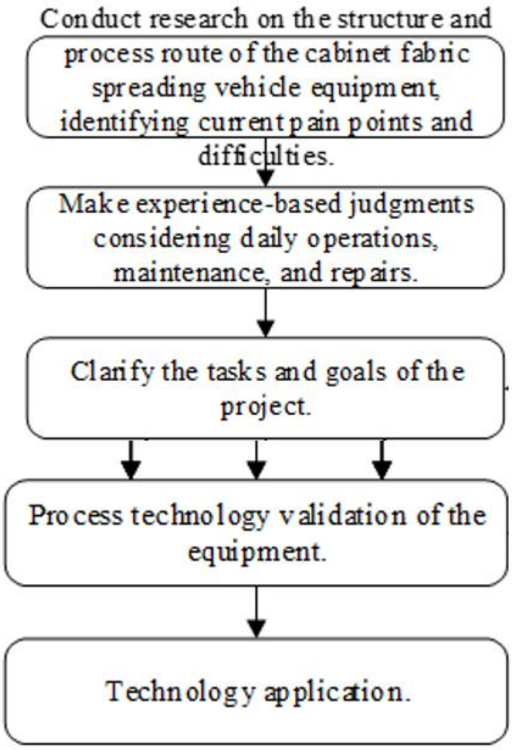

Figure 1: Technical Roadmap

By studying the development status of various distribution cars in the industrial sector and considering the characteristics of the tobacco industry, this project builds on the extensive application of storage cabinet distribution cars in the Wuhan Cigarette Factory. Through the analysis and identification of pain points and challenges in existing storage cabinet distribution cars, the design is re-engineered with intelligent enhancements to achieve precise and reliable control over the entire machine, ensure steady progress in product quality assurance, and reduce the failure rate and maintenance difficulties of the distribution car. The overall technical roadmap, based on practicality, feasibility, economic efficiency, and ease of maintenance, as shown in Figure 1:

The main research areas include:

Research on the driving mechanism of the distribution car

Design of the side plate structure

Research on the cleaning roller design

Wheel structure design

Development of a deviation-correction device

Design of the cleaning system

Slip monitoring system

Design of maintenance access points

Wireless transmission of signals and electrical usage

3. Establishment of a Finite Element Model

The intelligent distribution car mainly consists of the car frame, material transportation system, motor, and control system. Among these, the car frame serves as the supporting structure, and its rigidity and stability significantly influence the overall performance of the equipment. The material transportation system is responsible for automatic material transport, and its operational performance and precision directly affect the quality and efficiency of material distribution. The motor and control system drive and monitor the entire device's operation, ensuring that it follows the predetermined program. As shown in Figure 2:

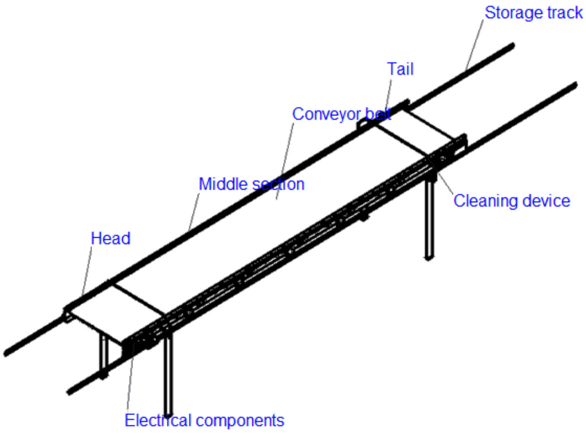

Figure 2: Intelligent distribution car

3.1 Geometric Modeling

First, it is necessary to use CAD software or related tools to create a geometric model of the intelligent distribution car. The modeling process must consider the connections and dimensional accuracy of each part to ensure the geometric model closely matches the actual equipment. CAD (Computer-Aided Design) software is the primary tool for geometric modeling of the intelligent distribution car[2]. These tools provide a wealth of modeling functions and precise drawing capabilities, allowing for the creation of a detailed 3D model. In the process, it is crucial to accurately represent all components, connections, and dimensions. Parametric modeling techniques can be employed to adjust and modify the model efficiently, generating various configurations of intelligent distribution cars by adjusting parameters.

3.2 Mesh Generation

The geometric model is then divided into a series of elements and nodes. The quality of the mesh significantly affects the accuracy and computational efficiency of finite element analysis, so selecting an appropriate mesh density and type is crucial. Before mesh generation, it is important to thoroughly analyze the structure of the intelligent distribution car, including understanding its main components, connection methods, and load distribution to focus mesh generation in key areas.

3.2.1 Geometry Cleaning and Simplification

The geometric model should be cleaned and simplified to remove unnecessary details and features, reducing the number of mesh elements and improving computational efficiency. However, the simplified model should still accurately reflect the real structure.

3.2.2 Mesh Type Selection

Based on the structure and analysis needs of the intelligent distribution car, an appropriate mesh type should be selected[3]. Common types include tetrahedral and hexahedral meshes. Tetrahedral meshes are faster to generate but have lower accuracy, while hexahedral meshes provide higher accuracy but are more complex to generate.

3.2.3 Mesh Density Control

Mesh density is a key factor affecting analysis accuracy and computational efficiency. In critical and stress-concentrated areas, mesh density should be increased for greater precision, while less critical areas can have sparser meshes to reduce computational load. Reasonable mesh density control ensures analysis accuracy while improving computational efficiency.

3.2.4 Boundary Condition Handling

Special attention must be given to handling boundary conditions during mesh generation. Boundary conditions significantly impact analysis results, so ensuring correct representation of boundary constraints, such as fixed supports or displacement boundaries, is essential.

4. Description and Working Principle of the Intelligent Distribution Car

The DZHB-type intelligent distribution car operates by reciprocating along a track installed on the top of the cabinet. A guide rail is mounted along the entire length of the cabinet, allowing the fabric carriage to move back and forth. The fabric distribution across the width of the cabinet (i.e., the cabinet's horizontal dimension) is managed by another inching motor that runs along the cabinet's width direction, which is external to the storage cabinet. The operation, stopping, and reversing of the DZHB-type intelligent distribution cars are controlled through laser rangefinders or proximity switches. As shown in Figure 3:

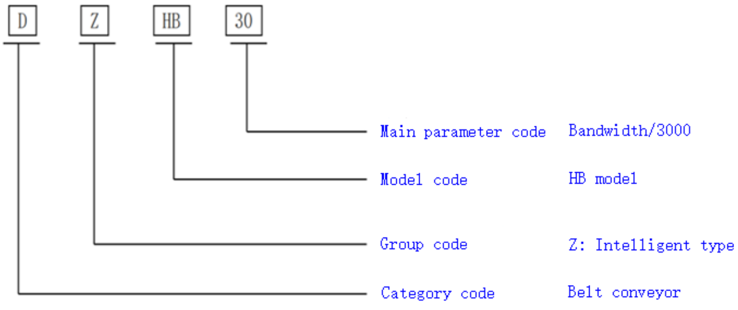

Figure 3: Control Signal Diagram

The working principle of the DZHB-type intelligent distribution cars involves moving back and forth along the track installed on the cabinet top, driven by a transmission device. It spreads the incoming material in a linear, layer-by-layer manner onto the conveyor belt inside the storage cabinet. The horizontal fabric distribution across the width of the cabinet is achieved by a separate DM inching motor that runs along the cabinet width direction, which is external to the storage cabinet. The conveyor's operation, stopping, and reversing are controlled via proximity switches, allowing the DZHB-type intelligent distribution cars to move reciprocally between the two ends of the storage cabinet.

For uniform fabric distribution and easy belt adjustment, two separate reduction gears drive the carriage and the belt. When the storage cabinet is half-full, the fabric belt moves slowly in the same direction as the fabric carriage. When controlled by the laser rangefinder or proximity switches, the carriage reverses direction, and while the carriage moves in the opposite direction, the belt continues moving in the original direction at a higher speed. This allows the carriage to reciprocate over half the cabinet's distance, distributing fabric evenly in the forward section. The DM carriage performs inching movements across the width of the fabric carriage, advancing or retreating a set distance each time the fabric carriage completes a round trip. The material is fed into the cabinet in strips, and as the DM inching conveyor moves, the fabric carriage feeds material strip by strip into the cabinet.

When the DM inching conveyor reaches the sides of the cabinet, a layer of material will have been fully spread inside the cabinet. When the DM conveyor reverses, the process begins again for a second layer. This repeats, and layer by layer, the material fills the cabinet. When the material covers the high-positioned photoelectric switch A1, it indicates that the cabinet is full, and the upstream feeding equipment stops.

The operating conditions are as shown in Table 1:

Table 1: Usage Status Table

Energy conditions	Power supply	3N-50HZ/TN-S,380V ±38V,50Hz ±1Hz
Process requirements	Conveying material	All kinds of leaves, leaf silk, stem, stem silk, mixed, recycled tobacco, etc
	Feed moisture content	
Environmental requirements	Altitude above sea level	No higher than 2000m
	Ambient temperature	10℃~40℃
	Relative humidity	No more than 80%

The machine's noise emission complies with the relevant regulations in YC/T86.2-2006, with measured on-site noise levels not exceeding 85 dB(A).

5. Load and Constraints

The material properties of the finite element model are as follows: density of 7800 kg/m^3, elastic modulus of 2.1×10^{11} Pa, and Poisson's ratio of 0.3. The finite element model uses a unit system based on mm, kg, and s. The value of gravitational acceleration is 9.8 m/s^2. The beam extends 36 meters, and the belt runs at 20 m/min, transporting 80 m^3 of crops per hour. For common crops with a density of 2500 kg/m^3, the belt holds approximately 2.4 m^3 of crops at any given time.

5.1 Constraints of the Intelligent Distribution Cars

5.1.1 Motion Constraints

During operation, the intelligent fabric carriage must adhere to predetermined tracks and speeds, requiring motion constraints[4]. These constraints include path planning and speed control, ensuring that the fabric carriage can accurately and stably complete its material distribution tasks.

5.1.2 Boundary Constraints

Within its working area, the intelligent distribution cars must observe certain boundary constraints to prevent collisions with other equipment or obstacles[5]. These boundary constraints can be achieved by setting up physical barriers or using sensors to detect surroundings, ensuring safe operation within defined limits.

5.1.3 Fixed Constraints

The frame and critical components of the intelligent distribution cars must have fixed constraints to ensure structural stability and stiffness[6]. These fixed constraints can be implemented through bolted connections or welding to prevent loosening or deformation during operation.

6. Computational Control of the Intelligent Distribution Car

To enable intelligent management and autonomous operation of the fabric carriage, a targeted path planning model must first be established. This model takes into account various factors in the carriage's actual working environment, such as terrain features, obstacle distribution, and specific task requirements, ensuring that the fabric carriage can autonomously navigate and optimize paths in complex, changing work areas. With this model, the fabric carriage can intelligently select the optimal path, improving work efficiency while minimizing unnecessary energy consumption and wear.

To precisely describe the fabric carriage's motion state, a detailed kinematic equation is established based on its mechanical structure and movement characteristics. These equations accurately reflect the carriage's position, speed, and acceleration under different motion states, laying a solid foundation for subsequent trajectory tracking and precision operation.

A high-efficiency trajectory tracking algorithm can be designed to achieve precise material distribution operations. This algorithm continuously acquires the fabric carriage's current position and motion state, compares and adjusts them against the preset trajectory. By constantly optimizing algorithm parameters and adjusting control strategies, the fabric carriage can successfully track the preset trajectory with precision, ensuring accuracy and stability during material distribution.

By integrating the path planning model, kinematic equations, and trajectory tracking algorithm, the intelligent management and autonomous operation of the fabric carriage can be successfully realized. This not only improves the efficiency and quality of material distribution but also reduces the difficulty and risk of manual operations.

In the current field of industrial automation, achieving adaptive control and optimization of the fabric carriage is a key technical challenge. The application of fuzzy control algorithms in this field provides an effective solution to this challenge. Based on the fabric carriage's real-time motion state and environmental information, the algorithm flexibly adjusts control strategies through fuzzy processing, achieving adaptive control. This control method not only adapts to complex and changing work environments but also significantly improves the carriage's operational efficiency and reduces energy consumption. Neural network control algorithms also provide precise learning and prediction capabilities for the carriage's motion. By simulating the connection and transmission methods of neurons in the human brain, the algorithm extracts motion patterns from large volumes of historical data, enabling accurate predictions and control. This not only enhances control precision but also improves the stability of the carriage, allowing it to maintain excellent performance in high-speed, high-precision work scenarios.

Genetic algorithms play an important role in optimizing control parameters to further improve the carriage's operational efficiency and performance. By simulating the processes of inheritance, mutation, and selection in biological evolution, genetic algorithms search for optimal control strategies in large parameter spaces. This optimization method avoids the local optimum problem found in traditional methods and can achieve satisfactory optimization results in a short time.

The combined application of fuzzy control algorithms, neural network control algorithms, and genetic algorithm optimization provides strong technical support for improving the carriage's adaptability, control precision, stability, and operational efficiency. The integration of these algorithms is expected to advance fabric carriage control technology towards greater intelligence and efficiency.

7. Finite Element Calculation and Simulation

Using finite element software to solve the above model allows for obtaining the stress distribution and deformation[7]. The displacements and stresses are calculated, with displacement units in millimeters (mm) and stress units in kilopascals (kPa).

Here, I will take the short axle head and long axle head of the fabric cart as examples. Let's first look at the short axle head. Based on the part drawing of the short axle head, I conducted a finite element analysis, selecting the appropriate material based on the stress analysis. The material selected for the short axle head is 45 high-quality carbon steel, and it was applied accordingly. Next, the fixtures were fixed by selecting the geometry. After securing the fixtures, a torque of 50N was applied. After completing this series of operations, the mesh was generated. As shown in Figure 4:

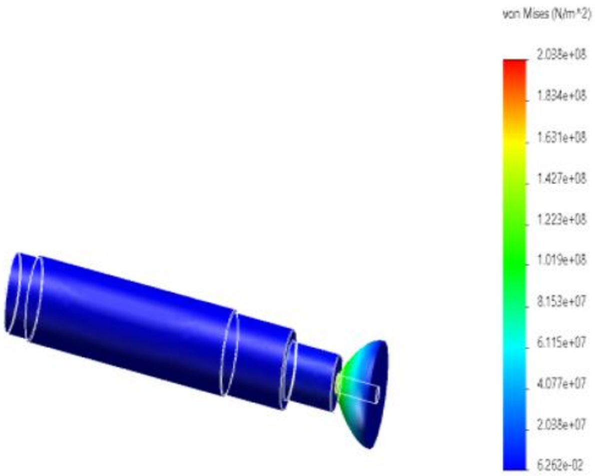

Figure 4: Finite Element Simulation Diagram

From the figure, it can be seen that the stress increases from bottom to top, with a maximum stress of 2.038e ×10^8 N/m ², which is less than the yield strength.

The displacement is shown in the figure 5 below:

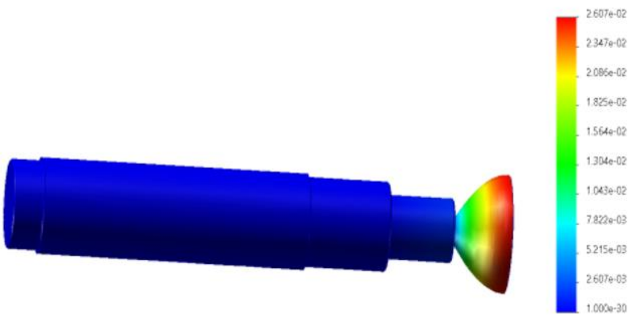

Figure 5: Finite Element Simulation Diagram

As seen in the figure, the displacement at the far right end changes significantly, while the displacement in the left half does not change much.

The safety factor is shown in the figure 6 below:

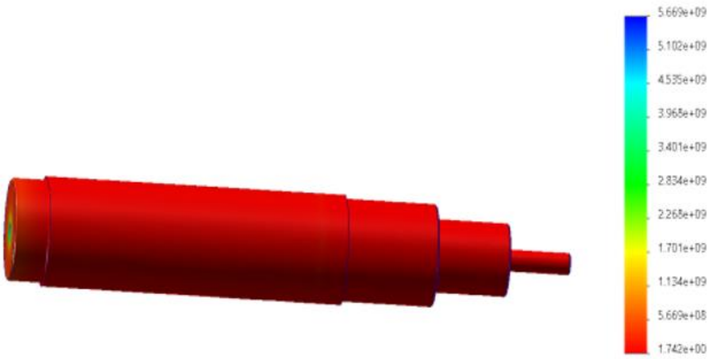

Figure 6: Finite Element Simulation Diagram

The minimum safety factor is 1.7. The minimum safety factor for ordinary axle steel is 1.5, so the safety factor is acceptable.

Next, we examine the long axle head of the fabric cart. Based on the part drawing of the long axle head, I conducted a finite element analysis and selected the appropriate material based on the stress analysis. The material for the long axle head is also 45 high-quality carbon steel. The fixtures were fixed by selecting the geometry. After securing the fixtures, a torque of 50N was applied. After completing this series of operations, the mesh was generated. As shown in the figure 7 below:

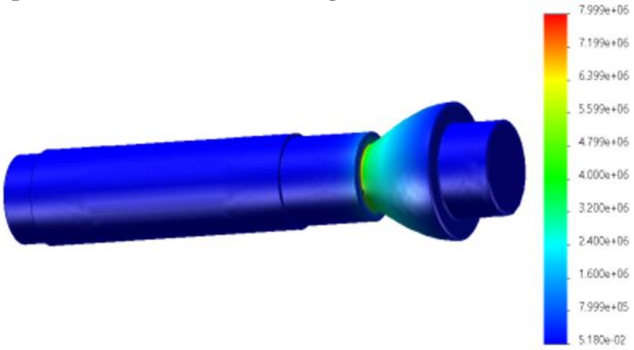

Figure 7: Finite Element Simulation Diagram

From the figure, it can be seen that the stress increases from bottom to top, with a maximum stress of 7.999e ×10^6 N/m ², which is less than the yield strength.

The displacement is shown in the figure 8 below:

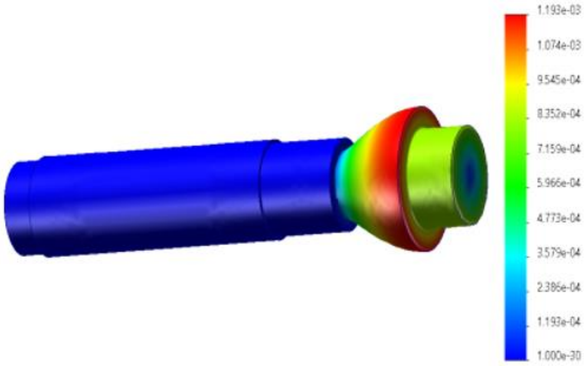

Figure 8: Finite Element Simulation Diagram

As seen in the figure, the displacement at the far right end is moderate, but the middle portion of the far right end shows a significant displacement change, while the displacement in the left half does not change much.

The safety factor is shown in the figure 9 below:

Figure 9: Finite Element Simulation Diagram

The minimum safety factor is 44. The minimum safety factor for ordinary axle steel is 1.5, so the safety factor is acceptable.

8. Conclusion

The research and development of intelligent distribution cars for storage tanks have significant importance in improving industrial production efficiency and quality. Through in-depth research and exploration, we can continuously optimize the performance and functions of intelligent distribution cars, providing more efficient, stable, and reliable material distribution solutions for industrial production. In the future, with continuous technological advancements and the expansion of application scenarios, intelligent distribution cars for storage tanks will play a more critical role in the industrial field, supporting the sustainable development and innovation of industrial production.

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