Research and development of an AI-based intelligent recognition system for self-supplying adhesive of inner lining

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Abstract: With the continuous development of tire manufacturing technology, higher requirements have been placed on the precision, stability, and automation level of rubber compound supply in the inner liner process. Based on the improvement of production process effects and intelligent automation of equipment, this paper specifically designs a system consisting of a precision mechanical execution unit and an intelligent electrical control unit. It expounds the design concept, key technologies, system architecture, and implementation effects of the automatic rubber compound supply system for the inner liner. The mechanical part of the system adopts a servo-driven disc cutter and a swinging rubber conveyor device, achieving precise cutting and dynamic distribution of rubber compound. The electrical part, with a programmable logic controller (PLC) as the core, integrates machine vision, radiometric thickness measurement, and industrial IoT technology, constructing a closed-loop control system encompassing rubber compound supply control, deviation correction, thickness adjustment, and predictive maintenance. This effectively enhances product quality and production efficiency, providing key technical equipment and solutions for the intelligent upgrade of the rubber products industry.

Key words: cutting knife; rubber placement; PLC; servo; intelligent manufacturing; system

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0 Introduction

As the global tire manufacturing industry rapidly evolves towards high performance, lightweight, and greenification, the inner liner, as the core component of tire airtightness and durability, is increasingly in need of optimization in its production process. Traditional manual rubber supply methods face issues such as unstable rubber supply, uneven thickness, high labor intensity, and fluctuations in calendering dimensions caused by unstable rubber compound accumulation behavior, which restrict the cost control and quality consistency of tire production. Current equipment struggles to meet the high-precision and high-efficiency requirements of modern tire production lines. Therefore, we have launched a technical transformation project for the "integration of automatic rubber supply system for inner liner calendering". With the rapid development of industrial automation and intelligent manufacturing technology, achieving automation, informatization, and intelligence in the rubber supply process through technological transformation will become an inevitable trend in the transformation and upgrading of the tire manufacturing industry.

This article focuses on the research and design of the system's design, key technologies, and implementation effects, aiming to provide theoretical references and practical paths for the intelligent manufacturing upgrade of similar manufacturing enterprises. The system primarily consists of a rubber supply system, a rubber compound conveying and oscillating device, visual inspection of accumulated rubber, trend control calculation of accumulated rubber, and a detection auxiliary unit. The open calender's upper and lower rollers adopt

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continuous rubber supply, changing the total rubber supply to each roller by adjusting the rubber supply width. The servo-controlled rubber oscillating device rapidly delivers the rubber sheet to the position where the rubber compound decreases, ensuring a stable accumulation of rubber at each point of the roller gap, thereby maintaining the stability and uniformity of the lining thickness and improving product quality.

1 Design and implementation of structure

The mechanical structure serves as the execution carrier for the automatic glue supply function, and its design rationality directly determines the stability and precision of the system. The glue supply unit comprises four structural components: the mechanical execution unit, the sensing and detection unit, the control unit, and the data management platform.

1.1 Design of glue supply equipment unit

1.1.1 Open mill cutter hardware unit

The cutting blade unit, as the core actuator for the final rubber sheet width at the press roll of the open mill, has its structural design rationality and precision directly related to production efficiency and product quality. The cutting blade unit designed this time has undergone significant structural innovation, replacing the traditional long strip cutting blade with a complete set of high-precision, independently driven disc cutter combinations as a unit, achieving structural optimization and a leap in performance.

The core structure of each cutting unit consists of a fixed disc cutter and a set of servo motor-driven moving disc cutters (Figure 1). The fixed disc cutter serves as the system reference point and is firmly mounted on the frame, maintaining its position throughout the cutting process. The moving disc cutters, on the other hand, constitute the precise positioning module of the entire unit, responsible for adjusting the cutting width according to process requirements, and are the key executing components for achieving flexible cutting functionality.

The mobile tool post module boasts a precise structure, with its core transmission component being a high-precision ball screw. During system operation, the servo motor receives pulse signals from the controller, outputs precise angles and rotational speeds, and then transmits power to the ball screw via a high-performance coupling. Serving as a motion conversion mechanism, the ball screw efficiently and smoothly converts the motor's rotational motion into linear motion of the tool post. Due to the adoption of ball rolling friction, this transmission structure not only features a low friction coefficient and high transmission efficiency but also effectively avoids the common creeping phenomenon of traditional sliding screws, thereby ensuring that the mobile tool post maintains smooth movement during frequent start-stop and direction changes.

Figure 1 Cutting unit

To further enhance the motion rigidity and positioning accuracy, the entire knife holder is tightly constrained on a high-rigidity linear guide rail through linear bearings. The linear guide rail serves as both a guide and a support, effectively suppressing lateral sway and vibration that may occur during movement, ensuring that the moving circular knife maintains a stable relative posture with the fixed circular knife throughout the entire stroke. This complete closed-loop control transmission chain, consisting of "servo motor - coupling - ball screw - linear guide rail", is the fundamental guarantee for the moving knife holder to achieve high positioning accuracy. In actual operation, its repeatability positioning error can be strictly controlled within ±0.5mm, laying a solid foundation for the consistency and accuracy of cutting width from the mechanical structure level, and meeting the strict requirements of modern high-speed and high-precision cutting operations.

From the perspectives of structural mechanics and practicality, the advantage of this design, which replaces the long knife with a disc knife, lies in the fact that the cutting edge of the disc knife has undergone careful chamfering treatment, and its material hardness is strictly controlled. This ensures that it can cut through rubber compound without causing any damage to the high-hardness surface of the roller, fundamentally preventing the roller surface from being pulled out into grooves, thereby guaranteeing the apparent quality and uniformity of the produced rubber compound. The contact between the disc knife and the mixer roller achieves point contact with external tangency, significantly reducing the contact area with the roller compared to a long knife. This structure not only reduces operational resistance and frictional heat generation but, more importantly, significantly minimizes potential wear on the roller surface.

In terms of control logic, this structure achieves perfect mechatronics, driving the servo motor to move the mobile cutting blade to the target position and complete precise cutting. At the same time, the system retains a manual control mode, allowing operators to flexibly set and drive the blade holder to move according to production needs. This design, combining automation with manual control based on a precise mechanical structure, ultimately achieves stepless adjustment of the cutting width between the maximum and minimum limits, enabling the production line to quickly and flexibly respond to production needs for different formulations and consumption levels. This fully embodies the characteristics of modern industrial equipment, which are efficient, intelligent, and flexible.

1.1.2 Hardware unit of glue dispensing and conveying part

The rubber compound conveying system is a precision material conveying device that integrates mechanical, pneumatic, and electrical control, as shown in Figure 2. Its core design objective is to achieve precise feeding and position adjustment of rubber compound at specific workstations, in order to meet the process requirements of downstream calenders regarding feeding pace and placement position.

The most striking part of the overall system layout and core guiding structure is the two sets of V-shaped slide rails located in the middle. These two slide rails together constitute the benchmark and framework for the entire system's movement and are the foundation for achieving the swinging

Figure 2 rubber compound dispensing system

function. They are enclosed in a yellow safety shield and guided in a quasi-circular arc shape, forming a guiding system with extremely high rigidity and self-centering capability. This design effectively resists lateral forces and torsional moments from all directions, ensuring that the moving parts can still slide smoothly and precisely along the preset trajectory under heavy loads or uneven forces, preventing the swinging rubber device from shaking or getting stuck. To achieve flexible adjustment of the working range, a set of linear running slide rail system is also installed behind the protective shield from the mechanical structure. During operation, it plays a dual role of extending the swinging rubber frame and providing auxiliary guidance. Its position is directly on the symmetry line of the V-shaped slide rail system, allowing the entire conveyor module to be moved in the forward and backward direction as a whole. In the extended state, it still possesses sufficient structural rigidity and motion stability. This design endows the equipment with strong adaptability, enabling it to match different working distances without moving the host machine.

The two ends of the V-shaped slide rail are respectively equipped with two sets of cylinders, which serve as actuators and are transitioned through a linkage mechanism and a dedicated connecting support. The piston inside the cylinder, driven by compressed air, outputs linear thrust through the piston rod to adjust the left and right movement of the rubber swinging device. When the control system issues a command, the solenoid valve switches the air path, and the compressed air drives the cylinder piston. Through the linkage mechanism, the entire working component is driven to perform reciprocating motion along the high-precision slide rail, completing the basic action of "rubber swinging". This design can efficiently transmit the linear thrust of the cylinder to the load, while compensating for any possible minor installation errors, ensuring smooth and reliable power transmission.

1.1.3 Auxiliary hardware system

In addition to the core disc cutter system and rubber-positioning structure, the entire system also integrates material conveying and its own power system. Typically, it is driven by a motor through a reducer to obtain an appropriate output speed and increased torque, which then drives the entire conveyor belt to transport the rubber compound to the upper and lower rollers of the calender.

1.2 Design and use of electrical components

All these precise mechanical structures are intelligently controlled through the control cabinet on the right side, as shown in Figure 3. The operator sets parameters such as glue-spreading frequency, stroke, and conveying speed through the touch screen. The control system coordinates the operation of the cylinder's solenoid valve and conveyor motor according to the instructions, and simultaneously provides real-time feedback data through sensing and detection units installed at key positions (including infrared vision detection systems, radiographic thickness gauges, tension sensors, etc.), forming a closed-loop control to ensure that the entire glue-spreading and conveying system operates in a safe and efficient manner.

Figure 3 Control cabinet

1.2.1 Visual inspection system for accumulated adhesive

The machine vision system, characterized by high accuracy, high speed, and non-contact operation, has been widely applied in the field of industrial online detection and automatic control. This system employs a customized infrared vision sensor to indirectly calculate the total volume of accumulated rubber and its distribution in the width direction by detecting the temperature difference field generated by the coverage of rubber compound between the two rollers of the calender. The results are displayed on the control console in real time, as shown in Figure 4. This non-contact measurement provides the most critical feedback signal for closed-loop control. The visual detection system for accumulated rubber monitors the accumulation of rubber compound volume at the roller gap in real time and uses it as the main feedback quantity. Meanwhile, pressure/flow sensors on the rubber supply line provide auxiliary feedback. The built-in PID control algorithm in the PLC compares the feedback signal with the set value, calculates the result, outputs a signal to control the servo drive for the actuator cylinder, and automatically adjusts the cutting blade width and rubber positioning during dynamic operation based on the production line speed and product thickness, achieving precise feeding and uniform distribution of rubber compound. This ensures a constant amount of rubber accumulated at the roller gap, thereby guaranteeing the uniformity of the calendered rubber sheet thickness and achieving the desired process effect of the material.

Figure 4 Visual monitoring display screen

1.2.2 Control system and other data platforms

The electrical control system is the "brain" of the automatic glue supply system, responsible for signal processing, logical judgment, and motion control, ensuring precise and coordinated operation of the mechanical system. The control system is centered around a PLC, integrating servo drives, frequency converters, touch screens, etc. The industrial computer serves as the host computer, running the human-machine interface (HMI) and data acquisition software to achieve equipment status monitoring, parameter setting, production data management, and report generation. It also exchanges data with the manufacturing execution system (MES) through standard protocols. The control layer is centered around a high-performance PLC Siemens S7-1500 series as the core controller, which collects parameters such as glue supply pressure, temperature at various points, equipment vibration, lubricant status, and energy consumption (water, electricity, gas) at the millisecond level through the PLC's extensive interfaces. It is responsible for executing all control logic, algorithm operations, and handling communication with various subsystems, which are connected to the PLC via a Profinet industrial network, forming a distributed real-time control network.

2 Conclusion

This article elaborates on the overall design scheme of a 1 set of automatic glue supply system for tire innerliners, and focuses on in-depth technical analysis from both mechanical and electrical perspectives, addressing the following issues:

(1) The thickness of the rubber sheet is uniform, with the thickness limit difference reduced;

(2) The uniformity of rubber sheet thickness has been improved, reducing the occurrence of low-temperature materials and enhancing the quality of rubber compound;

(3) The rubber compound is piled up steadily and evenly, reducing the probability of exposed areas and lowering the scrap rate;

(4) There is no need for manual supervision of glue accumulation, which frees up labor and reduces labor intensity.

The key technology utilizes a servo-driven disc cutter and a rubber compound feeding system based on a composite track, enabling precise preparation and intelligent feeding of rubber compound, laying a physical foundation for high-quality composites. With PLC as the core, a multi-loop control system integrating machine vision, sensing detection, and industrial network technology effectively solves a series of key technical challenges such as rubber compound uniformity, cord centering, and thickness control.

In terms of system integration, advanced technologies such as servo control, machine vision, the Internet of Things (IoT), and predictive maintenance have been employed to achieve precision, automation, and intelligence in rubber compound supply. The application of data vertical integration and industrial IoT platforms has significantly improved product quality and overall operation and maintenance efficiency. Research indicates that "predictive maintenance, by analyzing equipment condition monitoring data and historical data to predict equipment failures and manage equipment health, is a key technology for achieving intelligent manufacturing and reducing operation and maintenance costs." This lays the foundation for further deep integration with AI process optimization models and cloud-based remote operation and maintenance platforms, enabling fully automated operation and adaptive process adjustments throughout the entire process.