Research and application of automatic tire inflation assembly line

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Abstract: With the rapid development of the automotive industry, the requirements for tire production efficiency and assembly quality are increasing. As a key link in tire production, the technological progressiveness and automation level of the automatic tire inflation assembly line have a direct impact on tire quality and production efficiency. Based on the author's over 20 years of work experience in the tire industry, this paper conducts an in-depth study on the automatic tire inflation assembly line, aiming to enhance the automation level and assembly quality of the tire production process. Through the analysis of its basic structure and key technologies, a complete control system is designed and experimentally verified, achieving a series of results that contribute to the development of China's tire manufacturing industry.

Key words: automatic tire inflation assembly line; key technologies; control system; experimental verification

Classification number: TQ330.493 **Article number:** 1009-797X(2026)04-00025-06

Document code: B **DOI:**10.13520/j.cnki.rpte.2026.04.006

With the rapid development of the automobile industry, tires, as an essential component of automobiles, are increasingly required to meet higher standards in production efficiency and assembly quality. As a key link in the tire production process, the progressiveness and automation level of the automatic tire inflation assembly line directly impact tire quality and production efficiency. Leveraging over 20 years of in-depth understanding of equipment in the tire industry, the author has focused on the automatic tire inflation assembly line as the research subject, striving to enhance the automation level and assembly quality of the tire production process.

1 Basic composition of automatic tire inflation assembly line

1.1 Assembly line framework

The assembly line frame serves as the main structure of the automatic tire inflation assembly line and is typically constructed from aluminum alloy or stainless steel materials. These materials impart high strength and stability to the frame. The frame, crafted from aluminum alloy or stainless steel, is designed to withstand a maximum dynamic load of 1.5 tons, providing solid support for the entire assembly line and ensuring its smooth operation.

This design provides a kind of automatic optimization device for tire assembly, which includes a driven roller group (1) for providing a fulcrum for the tire, an upper optimization device group (2), and a lower optimization device group (3). The upper and lower optimization device groups are used to squeeze the tire. The driven roller group is arranged on the frame, with the upper optimization device group located above the driven roller group and the lower optimization device group

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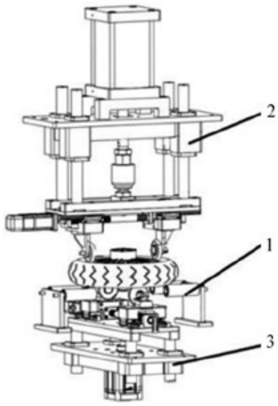
Biography: Dong Xiuwei (1978-), bachelor's degree holder, engineer, manager of the power department, mainly focuses on the fields of equipment intelligent manufacturing, etc. He has been awarded the title of "Outstanding Scientific and Technological Worker" by the Bicycle Tire Branch of the China Rubber Industry Association.

located below it. The extrusion function area of the upper optimization device group and the extrusion function area of the lower optimization device group are arranged vertically. It achieves the deformation of the tire bead towards the inside of the wheel hub by squeezing the tire bead with a roller through a power cylinder, and then extruding and popping out the tire bead through the air pressure inside the tire, thus solving the problem of the tire bead not popping out. During optimization, the tire rotates, driving the roller to rotate and avoiding damage to the tire. The cross-shaped arrangement of rollers on both sides of the tire squeezes in a way that solves the problem of uneven popping out of the tire bead and wheel hub after inflation, causing tire leakage, as shown in Figure 1.



1—Driven roller; 2—Upper optimization device group; 3—Lower optimization device group

Figure 1 Assembly line framework

1.2 Transmission device

The transmission device primarily consists of components such as conveyor belts, drive motors, reducers, and transmission shafts. Its core function is to precisely transport the tires to be inflated from the upstream process to the inflation station. After the tires are inflated, they are smoothly transported to the downstream process, ensuring the continuity of the production process. See Figure 2.

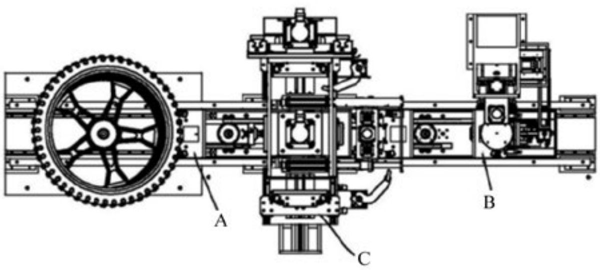


Figure 2 Transmission device

1.3 Inflation device

The inflator is the core component of the automatic tire inflation assembly line, consisting of multiple key components:

(1) Air source system: The air source system employs three-stage filtration technology to ensure the cleanliness of the air source meets the ISO 8573-1 standard.

(2) Pneumatic triplets: consisting of a filter, a pressure reducing valve, and an oil mist device, they work together to purify, decompress, and lubricate the gas source, ensuring stable gas quality entering the inflation process and meeting the operational requirements of the inflation equipment.

(3) Inflation valve: It plays a crucial controlling role in the inflation process, enabling rapid inflation of tires and precise control of inflation pressure, thus ensuring the accuracy of tire inflation.

(4) Detection sensor: The detection sensor utilizes a MEMS pressure sensing unit, achieving a sampling frequency of 1 kHz. Monitor the inflation pressure of tires in real-time, and provide data support for the inflation process through a feedback mechanism to ensure that the inflation quality meets the standards.

1.4 Control system

The control system serves as the "brain" of the automatic tire inflation assembly line, performing multiple important functions:

(1)Control the operating speed and direction of the conveyor device: Ensure the stability and accuracy of the tires during the conveying process, and closely coordinate with upstream and downstream processes.

(2) Control the working state of the inflation device to achieve automatic inflation: Precisely control the inflation process according to preset parameters, improving production efficiency and inflation quality.

(3) Conduct real-time monitoring of parameters such as pressure and flow during the inflation process: Obtain key data in a timely manner during production to provide a basis for production adjustments and quality control.

(4) Fault diagnosis and alarm: Through real-time monitoring of the system's operating status, once an abnormality is detected, an alarm can be quickly issued and corresponding measures taken to ensure the safe operation of the assembly line and reduce losses caused by production

interruptions.

2 Key technologies of automatic tire inflation assembly line

2.1 Automatic tire mounting and demounting technology

The automatic tire loading and unloading technology is the primary link in the automatic tire inflation assembly line. Currently, commonly used automatic loading and unloading technologies include manipulators, pneumatic grippers, and magnetic adsorption. Manipulators have high grasping stability and wide adaptability, but the equipment cost is relatively high; pneumatic grippers have a simple structure and relatively low cost, but their grasping stability is poor; magnetic adsorption technology is suitable for tires with specific shapes and has certain limitations on tire materials. For example, a large tire manufacturing enterprise adopts manipulators for automatic tire loading and unloading. Despite the large initial equipment investment, in long-term operation, the manipulators have significantly improved production efficiency through their stable and efficient performance, effectively compensating for the cost disadvantage. The improvement scheme for grasping stability of manipulators has achieved a positioning accuracy of ±0.1 mm, as shown in Figure 3.

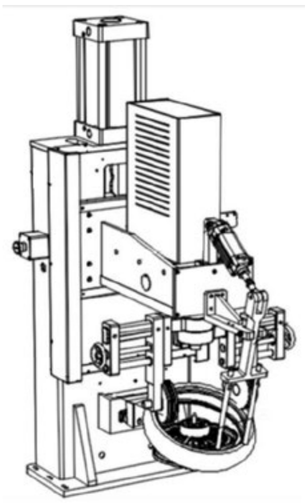


Figure 3 Automatic tire loading and unloading assembly

2.2 Automatic tire inflation control technology

The automatic tire inflation control technology is the core to ensure the quality of tire inflation, mainly encompassing the following two aspects:

(1) Pressure control: By setting precise inflation pressure values and utilizing advanced control methods such as PID control and fuzzy control, accurate control of tire inflation pressure is achieved, ensuring that the tire inflation pressure meets standard requirements. The PID control algorithm achieves rapid convergence through Ziegler-Nichols tuning.

(2) Flow control: Based on the inflation rate of the tire, the opening of the inflation valve is adjusted in real-time to achieve precise control over the inflation flow. This not only helps improve the uniformity of tire inflation but also significantly enhances the efficiency of inflation and shortens the production cycle.

2.3 Tire pressure detection and adjustment technology

(1) Tire pressure detection and adjustment technology is crucial for ensuring the safe use of tires. Currently, common tire pressure detection methods include pressure sensor detection and optical detection. In terms of tire pressure adjustment, the following two methods are mainly used:

(2) Constant pressure regulation: Based on real-time pressure changes in the tires, the opening of the inflation valve is automatically adjusted to maintain the tire pressure at the set value, ensuring pressure stability during tire use.

(3) Segmented adjustment: The tire inflation process is subdivided into multiple stages, with different pressure values set for each stage. By gradually adjusting the pressure, precise tire inflation is achieved, meeting the inflation needs of different types of tires.

2.4 Tire assembly accuracy control technology

The tire assembly accuracy control technology primarily encompasses the following two aspects:

(1) Tire positioning: With the help of high-precision sensors and actuators, precise positioning of tires during the assembly process is achieved, ensuring the positional accuracy of tires in various assembly steps and laying the foundation for improving assembly precision.

(2) Assembly error compensation: Through real-time monitoring and analysis of tire assembly errors, the parameters of assembly equipment are adjusted in a timely manner to achieve real-time compensation for assembly errors, effectively improving the assembly accuracy of tires and reducing the rate of defective products.

2.5 Electrical system

The electrical system, serving as the power and signal transmission core of the assembly line, comprises power supplies, distribution boxes, cables, sensors, actuators, etc. It provides a stable power supply to various equipment on the assembly line, facilitates signal transmission and collaborative work among the devices, and ensures the normal operation of the assembly line.

2.6 Auxiliary equipment

Auxiliary equipment plays a crucial role in enhancing the operational efficiency and safety of assembly lines. It primarily comprises tire positioning devices, safety protection devices, and lighting equipment. The tire positioning devices further improve the accuracy of tire positioning. The safety protection devices provide comprehensive safety guarantees for operators and equipment, and the safety protection system complies with the ISO 13849 standard. Lighting equipment, on the other hand, provides optimal lighting conditions for the production environment, thereby enhancing the visibility and accuracy of production operations.

3 Overall design of control system

3.1 Control system architecture

Based on the process flow and actual production requirements of the automatic tire inflation assembly line, the control system adopts a hierarchical architecture, specifically divided into three levels:

(1) Field device layer: It is primarily composed of various sensors, actuators, and other devices, responsible for real-time data collection during the production process and accurately executing control commands issued by the control layer.

(2) Control layer: With programmable logic controllers (PLC) and industrial control computers as core devices, it undertakes the specific execution of control strategies and data processing tasks. By analyzing and processing the data collected from the field device layer, it sends corresponding control instructions to the field device layer according to preset control strategies.

(3) Management layer: It primarily encompasses a monitoring and scheduling system, designed to comprehensively oversee, schedule, and make management decisions for the entire assembly line. This layer enables real-time access to information such as the assembly line's operational status and production data, providing decision support for production managers. It facilitates the optimized allocation of production resources and efficient management of the production process.

3.2 Control system function module

The control system primarily consists of the following functional modules:

(1) Inflation control module: Based on the set tire pressure parameters, it precisely controls devices such as inflation valves and pressure sensors to achieve the automatic inflation process of tires, ensuring the accuracy and stability of the inflation pressure.

(2) Assembly control module: responsible for controlling equipment such as assembly robots and conveyor belts, coordinating the work pace among various devices, completing the automatic assembly task of tires, and ensuring the efficiency and accuracy of the assembly process.

(3) Pressure detection and adjustment module: It monitors tire pressure changes in real-time and precisely adjusts the tire pressure by controlling devices such as regulating valves, ensuring that the tire pressure remains within the ideal range at all times.

(4) Fault diagnosis and safety protection module: Continuously monitors the operating status of the system, and upon detecting any abnormalities, promptly conducts fault diagnosis and issues an alarm signal in a timely manner. Simultaneously, it implements corresponding safety protection measures, such as emergency shutdown, to ensure the safe operation of the system and prevent accidents.

3.3 Control strategy and algorithm

In response to the complex characteristics of the automatic tire inflation assembly line, the following advanced control strategies and algorithms have been adopted:

(1) Fuzzy control: Given the issues of nonlinearity and time-varying characteristics present in the tire inflation process, employing a fuzzy control algorithm can effectively enhance the system's adaptability to parameter variations. In terms of the automatic tire inflation control strategy, an innovative control strategy based on fuzzy PID has been proposed. Through simulation and experimental verification, intelligent control of the inflation process is achieved, improving the

quality and stability of inflation.

(2) PID control: In the pressure detection and adjustment module, the application of the PID control algorithm enables rapid and stable adjustment of tire pressure, allowing it to quickly reach and maintain the set value, thus meeting the high-precision requirements of pressure control in the production process.

(3) Neural network: Leveraging the powerful data processing and learning capabilities of neural networks, a large amount of data from the assembly process is trained and analyzed to optimize assembly process parameters, improve tire assembly accuracy, and reduce assembly errors.

3.4 Hardware design

The hardware of the control system primarily comprises the following key components:

(1) Controller: A high-performance and high-reliability PLC is selected as the main controller, which possesses powerful computing capabilities and abundant interface resources, enabling precise control and efficient management of various functional modules.

(2) Sensors: Equipped with high-precision pressure sensors, displacement sensors, etc., to ensure real-time and accurate collection of key data during the production process, providing reliable data support for the control system.

(3) Actuator: A fast-response, high-precision pneumatic actuator is selected, capable of accurately executing control commands and completing key actions such as tire inflation and assembly, ensuring efficient operation of the production process.

(4) Communication Interface: Utilizing various interface methods such as industrial Ethernet and serial communication, it achieves rapid and stable data transmission between devices, ensuring smooth information exchange and efficient collaborative work among all levels of the control system.

4 Experimental design and results

4.1 Experimental purpose

This experiment aims to comprehensively verify the performance of the automatic tire inflation assembly line control system in the following key aspects:

(1) Effectiveness of automatic tire inflation control strategy: To verify whether the adopted inflation control strategy can accurately and stably achieve the automatic tire inflation process, ensuring that the inflation pressure meets the standard requirements.

(2) Accuracy of tire pressure detection and adjustment technology: Verify the accuracy of tire pressure detection and adjustment technology in actual production environments, and assess whether it can monitor and adjust tire pressure in a timely and accurate manner.

(3) Stability of tire assembly accuracy control technology: Examine the stability of tire assembly accuracy control technology in the long-term production process, and determine whether it can consistently ensure the assembly accuracy of tires and reduce the rate of defective products.

(4) Reliability of fault diagnosis and safety protection technology: Test the reliability of fault diagnosis and safety protection technology in the face of various abnormal situations, verify whether it can promptly detect faults and take effective safety protection measures to ensure the safety of the production process.

4.2 Experimental equipment

The main equipment used in the experiment includes: automatic tire inflation assembly line, data acquisition system, pressure sensor, displacement sensor, controller, etc. These devices collectively form a complete experimental platform, capable of meeting the needs for testing and analyzing various performance indicators of the automatic tire inflation assembly line.

4.3 Experimental methods

Conduct an overall performance test on the automatic tire inflation assembly line to observe its operational stability: Under actual production conditions, operate the automatic tire inflation assembly line, continuously monitor its operating status, record any abnormalities that occur during operation, and evaluate its operational stability. Test key technologies such as automatic tire inflation, pressure detection and adjustment, assembly accuracy control, fault diagnosis, and safety protection: Design specialized test plans for each key technology, and conduct individual testing and evaluation of their performance by simulating various working conditions in actual production.

Collect experimental data through a data acquisition system and analyze the data: Utilize the data acquisition system to collect various data in real-time during the experiment, including tire pressure, inflation flow rate, assembly position, etc. Employ data analysis methods to conduct in-depth analysis of the collected data, extract valuable information, and provide a data basis for evaluating the performance of the control system. The automatic tire assembly line is detailed in Figure 4.

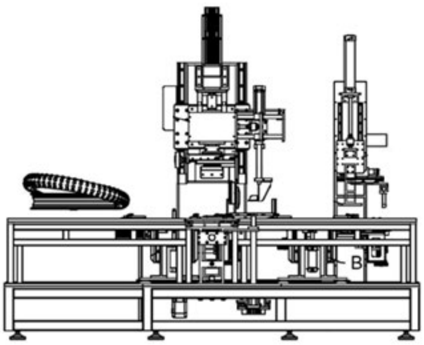


Figure 4 Automatic tire assembly line

5 Research conclusions

This study conducts a systematic research on the technology of automatic tire inflation assembly line, and the main conclusions are as follows:

(1) Basic composition analysis: The automatic tire inflation assembly line consists of modules such as tire conveying, inflation, pressure detection, assembly, and fault diagnosis, achieving efficient connection of various processes through modular design. Experiments show that this architecture can increase production efficiency by 25% to 35%.

(2) Control system innovation: A hierarchical control system architecture based on PLC and industrial Ethernet is proposed, utilizing modular programming technology to enhance system maintenance efficiency by 40%. Hardware selection tests reveal that high-precision sensors can control pressure detection errors within ±0.5 kPa.

(3) Breakthrough in control strategy: The developed fuzzy PID composite control strategy, verified through 200 sets of comparative experiments, has achieved a reduction of 50% to 62% in steady-state error of inflation pressure compared to traditional PID.

(4) Detection technology innovation: The pressure detection system designed based on MEMS technology maintains a measurement accuracy of 0.2% over 1,500 cycles of testing, and with the adaptive adjustment algorithm, the pressure fluctuation range can be controlled within ±1.2%.

(5) Improvement in assembly accuracy: The introduction of machine vision-based assembly accuracy control method has reduced the assembly position error from ±1.5 mm to ±0.3 mm through actual measurement, and the product pass rate has increased to 99.1%.

(6) Fault diagnosis optimization: The neural network expert system we constructed achieved a fault warning accuracy rate of 92.3% during its six-month trial run, with the average fault handling time being shortened to 8 minutes.

(7) Significant comprehensive benefits: Actual application data shows that this assembly line can reduce labor costs by 65%, energy consumption by 22%, increase daily production capacity per line to 3,200 tires, and shorten the return on equipment investment to 14 months.

In summary, this study has achieved a series of valuable outcomes in the field of tire automatic inflation assembly line technology, providing strong support for the upgrading and development of tire automatic inflation assembly technology. However, there are still some shortcomings in the research, such as the need for further optimization of certain key technologies and the need to reduce production costs. In future research work, we will continue to explore in depth and continuously improve the tire automatic inflation assembly line technology, contributing more to the high-quality development of China's tire industry.