Optimization design of tire building machine press roller based on intelligent algorithm

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Abstract: This paper proposes a solution based on intelligent algorithms and structural optimization to address the issues of uneven pressure distribution, poor bonding effect, and low efficiency in the pressing process of tire building machine rollers. By establishing a multi-piece roller mechanical model, optimizing parameters with intelligent algorithms, and adopting a multi-piece roller (also known as a layered roller) structure, the structural parameters and pressure distribution strategy of the rollers are optimized, significantly improving the quality and efficiency of tire building. Experiments show that the optimized multi-piece roller system can enhance tire uniformity by 15% and reduce energy consumption by 20%, providing theoretical support for intelligent tire manufacturing.

Key words: tire building machine; multi-piece roller; mechanical model; intelligent algorithm; structural optimizationv

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0 Preface

The tire building machine referred to in this article specifically refers to the one-step three-drum building machine for all-steel radial tires. It is an advanced tire building equipment used to bond, press, and shape materials such as tire sidewalls, innerliners, carcass plies, bead fillers, belts, and treads on drums, ultimately forming tire blanks. It is mainly composed of a host machine system, a feeding system, a transmission system, a control system, and auxiliary devices. Its core components are three drums, including the carcass drum, belt drum, and building drum, which are responsible for bonding and shaping the carcass ply, belt, and tread, respectively. Tire building is the core process of tire manufacturing and a key procedure that directly affects the uniformity and service life of tires.

The tire building process has three essential elements: first, proper alignment; second, good jointing; and third, good compaction. The press roller, as a key executing component for good jointing and compaction, directly affects the quality of the tire. Traditional tire building machines often adopt a single-roller or dual-roller structure, typically using aluminum or steel press rollers to press and bond the tire, which presents the following issues:

(1) The metal roller is a hard roller, and the pressing trajectory is a straight line, which cannot conform to the curved surface of the joint area. The joint parts outside the pressing trajectory cannot be pressed, resulting in joint bubbles and loose splicing in these areas. This subsequently leads to tire defects such as joint cracking and sparse tire.

(2) Low bonding accuracy: Uneven pressure distribution of the pressure roller can easily lead to air bubbles or wrinkles between the layers of the tire body.

(3) Poor adaptability: Unable to dynamically adjust

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the pressing angle and pressure, making it difficult to handle complex curved surfaces.

(4) Efficiency bottleneck: The lamination of multiple layers of materials requires multiple repetitive operations, affecting production efficiency.

By optimizing the design of the press roller through intelligent algorithms, adopting a multi-piece press roller structure, and utilizing modular segmented design combined with intelligent control technology, the aforementioned issues can be effectively addressed. This approach simultaneously enhances molding efficiency and tire quality, meets the requirements of automotive tires for dynamic balance and uniformity, and aligns with the intelligentization demands for high-end equipment outlined in "Made in China 2025". It holds significant engineering application value.

1 Traditional pressure roller structure and problem modeling

The application of the press roller in the tire building machine mainly includes roller pressing during the lamination of the tire sidewall and inner liner, the bonding of the tire sidewall and inner liner, the roller pressing of the cord fabric and bead, the roller pressing of the pad rubber, and the roller pressing of the tread. Taking the roller pressing during the bonding of the tire sidewall and inner liner as an example: the tire sidewall and inner liner laminate on the tire carcass drum. Due to the different thicknesses of the two materials, the lengths around the drum are also different, making it impossible to achieve automatic jointing. This requires slightly stretching the thinner inner liner with higher pressure to achieve the same length as the tire sidewall, thus realizing automatic jointing of the laminate.

As shown in Figure 1, the rubber compound thickness varies in the four areas A, B, C, and D. If the same pressure is applied, the final material joints will be of different lengths and cannot be kept consistent.

Using multiple pressure rollers, like calculus, the rubber compound is divided into different areas, namely four distinct pressure zones, ensuring varying pressures in each area. This achieves different stretching lengths in areas of different thicknesses, ultimately achieving a perfect joint integration.

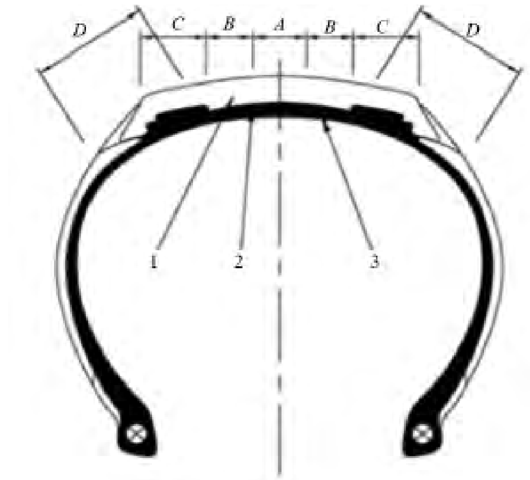

Figure 1 Cross-sectional view of tire

In addition, due to the very thin thickness of the roller sheets of the multi-sheet press roller, it can ensure that the rubber compound in each area is compacted without bubbles, achieving high-quality bonding of materials within the entire pressing range.

2 Mechanical structure design of multi-piece pressure roller

2.1 Operating principle of multi-plate press roller

As shown in Figure 2, the multi-roller press consists of a square roller cylinder, a cover plate, a piston, and roller segments. The cylinder body features a cylinder piston hole and a partitioned air circuit. The small pistons move up and down within the cylinder body, with each controlling the vertical movement of a respective roller segment. Through the control of electromagnetic proportional valves, each air path independently controls the vertical movement of each set of roller segments via the small pistons, thereby pressing the tire rubber compound. Simultaneously, different pressures are applied to achieve segmented rolling in different sections. Its core functions include:

(1) Flexible fitting: It adapts to material surfaces with different curvatures through independent movement of individual segments.

(2) Pressure equalization: Real-time adjustment of pressure on each segment based on sensor feedback, allowing for the application of different pressures to the edges, center, or

local areas of the material.

(3) Quick switching: Supports preset parameter calling to accommodate the production needs of multiple tire specifications. By adjusting the air pressure parameters, it can adapt to materials of different thicknesses, hardnesses, or widths.

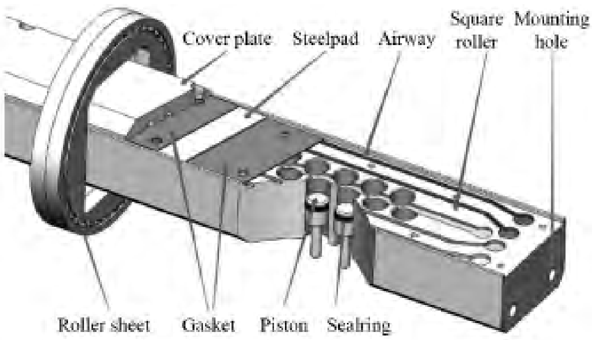

Figure 2 Internal structure diagram

2.2 Key structural design

2.2.1 Sharding module design

Establish a mechanical model for a multi-piece pressure roller, consisting of a square roller cylinder, a piston, and roller pieces. The roller pieces are numerous and independently arranged along the axial direction of the square shaft. The roller pieces are composed of plastic sheets with a fixed thickness, typically 8 millimeters. Each roller piece can move up and down independently, allowing it to conform to the irregular material's contour in contact with the multi-piece pressure roller in a calculus-like manner. The outer ring of the roller piece can rotate with the material, maintaining rolling contact with the inner ring through steel balls. The inner ring of the roller piece generally only moves up and down on the square shaft along with the control piston, without rolling with the outer ring.

The roller blade is made of modified engineering plastic according to the working conditions, featuring self-lubrication, low friction, high mechanical strength, wear resistance and toughness, non-stickiness to materials, and minimal deformation. The roller blade can be knurled on the surface according to the working conditions to increase the friction with the material during rolling. The diameter and stroke of the roller blade vary according to different usage parts and functions. See Table 1 for the technical parameters of the roller blade.

Table 1 Technical Parameters of Roller Sheets

Roller plate outer diameter (mm)	65	100	110	120	140
Roller plate stroke/mm	12	20	22	26	40
Roller surface requirements	Smooth surface or knurled surface				
Work pressure range	0-8 bar				

2.2.2 Overall layout optimization

The application positions of multiple pressure rollers on the molding machine vary, and the widths of the material components differ, resulting in varying overall widths of the multiple pressure rollers, ranging from 6 to 200 pieces. Taking the 54-piece pressure roller as an example, refer to Figure 3 for the structural diagram of the multiple pressure roller.

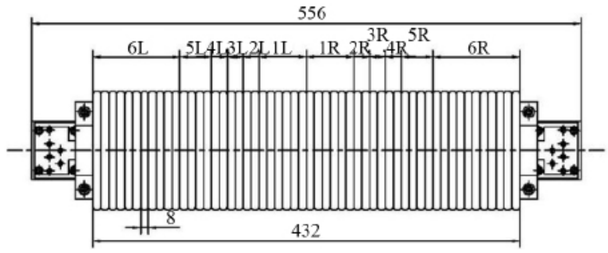

Figure 3 Structural diagram of multi-piece pressure roller

Figure 4 Outline drawing of multi-piece pressure roller

Each kind of multi-piece pressure roller is controlled by multiple air path zones on the square roller cylinder. Each zone consists of multiple roller pieces, and each set of pressure roller components is driven by a small piston to press the material. The piston holes of the small piston are formed by air path slots of different lengths on the square shaft cylinder to achieve grouping, which is then controlled by a precision proportional valve. Different pressures are achieved through air paths with different pressures, and different zones are controlled separately. Moreover, the range of high-pressure and low-pressure zones can be adjusted by adjusting the control area of the proportional valve (controlled by the on and off of the air path) to accommodate the width of different materials. The overall appearance is shown in Figure 4.

3 Automated control system for multi-piece pressure rollers

3.1 Control system architecture

A two-level control architecture consisting of "PLC + motion controller" is adopted.

(1) Upper computer: As the "intelligent hub" of the building machine, the upper computer performs process parameter setting, data monitoring, and fault diagnosis through high-precision control, data fusion, and algorithm optimization. The multi-piece pressure roller is controlled by a precision proportional valve. By adjusting the control area of the proportional valve and controlling the on and off states of the air circuit, the range of high-pressure and low-pressure areas can be adjusted to generate width formulas for different rubber compounds, which are then downloaded to the lower computer.

(2) Lower-level machine: Real-time control of the position, pressure, and inclination of each segment, enabling different pressure rolling in different areas of the pressure roller, while ensuring smooth trajectory transitions.

3.2 Core intelligent algorithm design

The panel of the square roller cylinder features an air path partition, typically divided into two zones: left and right (L, R). Each zone is equipped with 6-8 air inlet holes. Each air path is controlled by an electromagnetic proportional valve, and each set of plies is pressed against the tire rubber compound through a small piston. Simultaneously, different pressures are applied to achieve segmented rolling in different zones.

Taking the case of using multiple pressure rollers with three pressure values as an example, as shown in Figure 5: the combination of three proportional valves and a valve manifold distributes the three pressure values to eight pressure zones. By driving the square shaft cylinder with compressed air and using precision proportional valves for control and feedback, it is possible to ensure pressure fluctuations of ≤±0.5% and positional repeatability of ±0.1mm.

Upper computer formula setting, automatic switching of pressure formula upon changing specifications.

By adjusting the control area of the proportional valve and controlling the on and off states of the gas path, the ranges of the high-pressure area and low-pressure area can be adjusted, as shown in Figure 6.

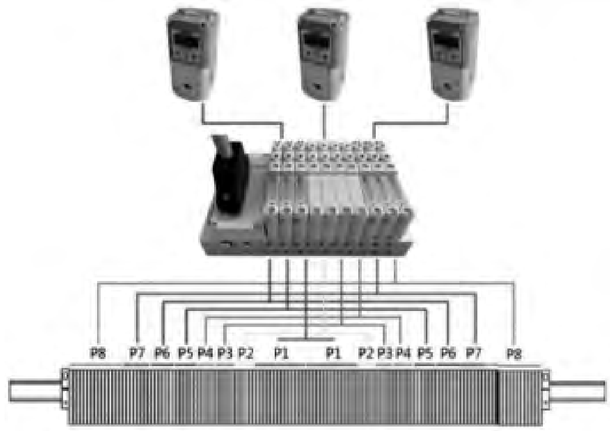

Figure 5 Schematic diagram of proportional valve control

Proportional Valve / Pressure Zone	I		II		III	
P1	Normally Open		X		X	
P2	V2.1 OFF		V2.1 ON		X	
P3	V3.1 OFF	V3.2 OFF	V3.1 ON	V3.2 OFF		V3.2 ON
P4	V4.1 OFF	V4.2 OFF	V4.1 ON	V4.2 OFF		V4.2 ON
P5	V5.1 OFF	V5.2 OFF	V5.1 ON	V5.2 OFF		V5.2 ON
P6	V6.1 OFF	V6.2 OFF	V6.1 ON	V6.2 OFF		V6.2 ON
P7	X			V7.2 OFF		V7.2 ON
P8	X		X		Normally Open	

Figure 6 Schematic diagram of pressure adjustment

In summary, the multi-piece pressure roller, with its modular and segmented design combined with intelligent control technology, possesses the following advantages:

(1) Segmented pressure control: Each roller blade can independently adjust pressure to adapt to the local characteristics of the material.

(2) Modular design: Designed in segments, only a single roller segment needs to be replaced when damaged, reducing maintenance costs.

(3) High adaptability: compatible with materials of different widths (by increasing or decreasing the number of roller blades).

4 Implementation verification and result analysis

4.1 Implementation verification and results

4.1.1 Before implementation

Taking the press roller assembly for the composite of the inner liner and tire sidewall in the building machine as an example: The composite of the inner liner and tire sidewall in the all-steel building machine is pressed and bonded using two sets of integrated aluminum press rollers before and after use, with two sets on each side, and driven by two sets of pneumatic mechanisms respectively. See Figure 7 for the old press roller structure. Due to the different thicknesses of the tire sidewall and inner liner, when the integrated aluminum press rollers roll, the thin parts outside the bonding trajectory do not receive pressure rolling, resulting in problems such as joint bubbles and loose bonding at the joint area. This can easily lead to tire defects such as joint cracking and tire thinning, seriously affecting tire quality.

Figure 7 Old pressure roller structure

4.1.2 Implementation content and purpose

(1) Replace the rigid pressure roller with multi-piece pressure rollers, one set on each side, driven by pneumatic cylinders.

(2) Each set of multi-piece calender rollers adopts two pressure zones to precisely control the position of the inner liner and sidewall compound.

(3) The stroke of the multi-piece press roller is greater than the thickness difference of the cross-section of the inner liner and the sidewall compound, and each piece can effectively press and bond various parts of the composite under the push of a separate small cylinder.

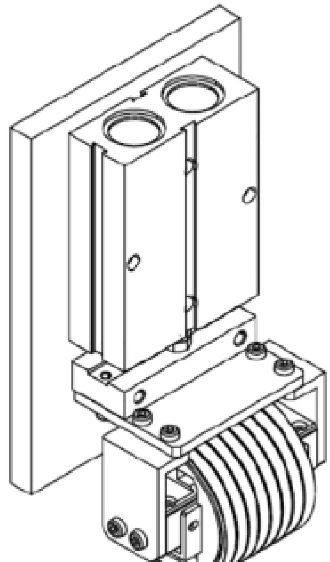

Figure 8 Multi-piece pressure roller structure

(4) The pressing width of the left and right multi-piece pressing rollers can cover the adjustment range of specifications. See Figure 8 for the structure of the multi-piece pressing rollers.

4.1.3 Result analysis

The improvement results are shown in the comparison between Table 2 and Table 3. For the same machine and tire specification, the use of multiple calender rolls for the compounding of the inner liner and tire sidewall has significantly reduced the defect rate.

Table 2 Defect rate before implementation

Machine	Specification	Composite scheme	Output	Defect ID (C# + sorting)						Total incidence of defects
A4	235/75R17.5-16PR	Use hard rollers		5	72	125	401 Organize	72 Organize	125Organize	16.08%
			939	5	3	0	138	4	1	
			incidence	0.53%	0.32%	0	14.70%	0.34%	0.11%	

Table 3 Defect rate after implementation

Machine	Specification	Composite scheme	Output	Defect ID (C-down + sort)						Total incidence of defects
A4	235/75R17.5-16PR	Multi-piece pressure roller		5	72	125	401 Organize	72 Organize	125 Organize	5.69%
			1353	10	0	0	66	1	0	
			incidence	0.74%	0	0	4.88%	0.07%	0	

Note: Defect ID represents: 5—Bead delamination; 125—Bubbles between wear-resistant rubber and inner liner; 72—Sidewall blisters; 401—Bubbles between bead toe and heel

Therefore, the molding process adopts multi-piece roller pressing, which can significantly improve the accuracy, efficiency, and material adaptability of the molding process, especially for molding scenarios with complex cross-sections, multi-layer composites, or high-precision requirements.

4.2 Actual production testing

The technical transformation project completed by a tire factory in Shandong, aimed at improving molding quality and efficiency, revolves around three directions: equipment upgrading, process optimization, and intelligent integration. By introducing advanced equipment and technologies, the project addresses pain points in traditional production.

Technical transformation content (part):

(1) Equipment upgrade, replacing and updating the worn-out parts of the original molding machine due to usage.

(2) The pressure roller is required to adopt a multi-piece roller structure, encompassing the roller pressing of the tire side and inner liner, the roller pressing of the cord fabric and bead, the roller pressing of the pad rubber, and the roller pressing of the tread.

(3) Deploy a visual inspection system, utilizing cameras and deep learning algorithms, to monitor the size and surface defects of tire embryos in real-time.

After the technical transformation, the comparison of effects is shown in Table 4.

Table 4 Comparison of effects before and after technical renovation

Indicator	Before technical transformation	After technical transformation	Increase margin	Remarks
Tire blank qualification rate	95%	99.2%	The defect rate has been reduced by 84%	
Single tire molding time	220s	190s	Efficiency increased by 13.6%	
Energy Consumption/kW.h. unit	1.85	1.27	Energy consumption is Reduced by 30%	

The domestic and international high-end tire markets (such as new energy vehicle tires and high-performance radial tires) are becoming increasingly stringent in their requirements for product consistency, durability, and uniformity. The core needs of tire factories for technological transformation lie in the coordinated upgrading of quality, efficiency, and cost. It is necessary to develop a technological transformation plan that takes into account industry trends and the actual pain points of the enterprise. By introducing intelligent equipment, improving quality, and reducing energy consumption, enterprises can achieve a transformation from "scale expansion" to "value creation" in the fierce competition. As a key execution component for proper jointing and compaction, the multi-piece press roller directly affects the quality of tires and is a highlight of future technological transformation for tire factories.

5 Conclusion and outlook

The multi-piece press roller, through modular design and intelligent control technology, possesses advantages such as pressure segmented control, high adaptability, and high efficiency. It significantly enhances the rolling and bonding quality during the tire molding process, improves the uniformity of tire movement, and boosts tire molding efficiency. This verifies the practicality of the theoretical model and provides key technical support for the intelligent upgrade of the tire manufacturing industry.

Future research directions include:

(1) Develop a real-time monitoring and pressing system based on machine AI vision.

(2) Explore the possibility of manufacturing segmented modules using 3D printing technology.

(3) In the future, it is expected to further expand applications in emerging fields such as flexible electronics and ultra-thin materials.