Research and Application of Motor-Driven Gear-Rack Pre-compression Packaging Machine Set

Shuiming Wang[1, 2, *], Pengfei Li[1, 2], Jiazhi Ni[1, 2], Dong Li[1, 2], Qianjin Chen[1, 2], Hao Wang[1, 2], Xiangang Zhou[1, 2], Jianhua Liu[1, 2], Rui Peng[1, 2], Li Wang[1, 2], Tao Qiu[1, 2], Lianfeng Huang[1, 2]

[1]China Tobacco Hubei Industrial Co, Ltd, Wuhan 430000, China

[2]Hubei Xinye Reconstituted Tobacco Development Co, Ltd, Wuhan 430000, China

*Corresponding author e-mail: 1430173134@qq.com

Abstract. The tobacco sheet pre-compression and packaging machine is primarily used for the pre-compression and packaging process in the reconstituted tobacco production line. It compresses the loose reconstituted tobacco sheets (after being weighed) that have been sliced by a shredding machine and boxed into a tobacco sheet pile of a specific size and specification, meeting the packaging and transportation requirements of subsequent processes. Currently, pre-compression and packaging machines in the reconstituted tobacco industry utilize hydraulic systems for packaging due to their unique characteristics and installation positions (with piston rods and pressing heads located within the packaging material box). The transmission medium primarily relies on hydraulic oil. During the process of the piston rod descending to compress the package, the piston rod emerges from the main cylinder, bringing out a certain amount of oil film, which poses a risk of contamination in the tobacco leaves. Starting from the source of risk control, namely the hydraulic oil, this paper conducts research and design on the power source of pre-compression and packaging. The power system is converted from hydraulic drive to electric motor drive, transforming the hydraulic pre-compression and packaging machine into an electric motor-driven rack and pinion pre-compression and packaging machine. This change eliminates the risk of oil contamination from the source and simultaneously achieves effective energy savings and reduces spare part and maintenance costs.

Keywords: Reconstituted Tobacco Leaf; Pre-compression and Packaging Machine; Rack and Pinion Drive System.

1. Introduction

The pre-compression and packaging machine used before the modification was a dual-hydraulic pre-compression and packaging machine driven by a variable-frequency motor-powered hydraulic pump. Research has shown that this hydraulic system mainly has the following issues: Firstly, the power source employs hydraulic drive, and there is a potential risk of hydraulic oil leakage in the hydraulic system, posing a significant threat to the purity of the finished tobacco leaves. Secondly, during equipment operation, there is significant noise and vibration, and it is difficult to directly diagnose faults in the hydraulic system. Only those familiar with the hydraulic system can identify and address issues, requiring a large number of maintenance personnel, a long period, and significant difficulty. Thirdly, when the over-frequency motor operates at low frequencies, the self-priming capacity of the vane pump decreases, generating pulsating torque, which causes fluctuations in motor speed and insufficient low-frequency torque, resulting in poor low-speed stability of the system. Since the system uses a high-power 25 KW motor, it has a large rotational inertia, leading to slow system response and low control accuracy (Figure 1). [1]-[3]

Figure 1. Double-Hydraulic Pre-Pressing and Packaging Machine of Hubei Xinye Tobacco Sheet Development Co., Ltd.

2. Technical Research

The new pre-compression and packaging system is designed to address the issues existing in current production. Therefore, it is necessary not only to ensure the stability and reliability of the system but also to completely eliminate the risk of hydraulic oil contamination from the source. Additionally, the economic costs of equipment construction and maintenance should be considered, facilitating ease of maintenance for repair personnel. Taking all these factors into account, our company, in collaboration with Kunming Shipbuilding Equipment Group Co., Ltd., after continuous research and verification, ultimately proposed the adoption of a motor-driven rack and pinion pre-compression and packaging system to replace the original hydraulic system of the hydraulic packaging machine[4]-[6].An electric servo torque and speed synchronization system technology was also adopted to ensure the synchronous drive of the pressing heads and meet the requirements for speed, pressure, and pressure holding time. The following table 1 compares the parameters of the motor-driven rack and pinion pre-compression and packaging system with the hydraulic pre-compression and packaging system:

Table 1. Comparison of Parameters Before and After Renovation

Model	Electric Motor-Driven Gear-Rack Pre-compression Packing System	Hydraulic Pre-compression Packing System
Packaging Specifications and Format	Compliant with YC/T 137.1-1998 standards or C48 cartons	Compliant with YC/T 137.1-1998 standards or C48 cartons
Rated Production Capacity (boxes/hour)	52	48
Maximum Dimensions (L×W×H) (mm)	8180×6430×9315	8180×6430×9315 (excluding hydraulic pump station)
Hydraulic Pump Station (mm)	None	3000×3000×1500
Feed Height (mm)	8745	8745
Discharge Height (mm)	610	610
Material Box and Pressing Head Drive Motor Power (kW)	59	67
Hydraulic Oil Consumption (L)	None	3500
Hydraulic Oil Cooling System	None	Cooling tower, 3KW fan motor, 3KW water pump motor, 2.2KW hydraulic oil circulation motor
Hydraulic Seal Wear	None	Yes (replaced every 2 years)
Estimated Gear Lifespan (years)	3	None
Estimated Rack Lifespan (years)	5	None
Hydraulic System Maintenance	None	Required
Risk of Hydraulic Oil Leakage	None	Present
Risk of Hydraulic Oil Contamination to Tobacco Leaves	None	Present
Maintenance Workload	Low	High
Maintenance Difficulty	Easy	Difficult
Maintenance Time	Short	Long

3. Hydraulic Technology with Motor Drive Technology

3.1. Complete Replacement of Hydraulic Technology with Motor Drive Technology

3.1.1 The complete replacement of the hydraulic system with a motor-driven rack and pinion eliminates the constraints imposed by the hydraulic system on the entire equipment, thereby eradicating the risk of hydraulic oil leakage contaminating tobacco leaves.

3.1.2 The removal of hydraulic piping, hydraulic pump stations, hydraulic oil, hydraulic cylinders, etc., significantly reduces the equipment's footprint and maintenance workload, eliminating the need for periodic replacement of sealing rings, hydraulic oil, etc.

3.1.3 The system is energy-efficient, structurally simple, reliable, convenient for use and maintenance, operates smoothly without noise, and significantly improves electrical control accuracy. (Figure 2)

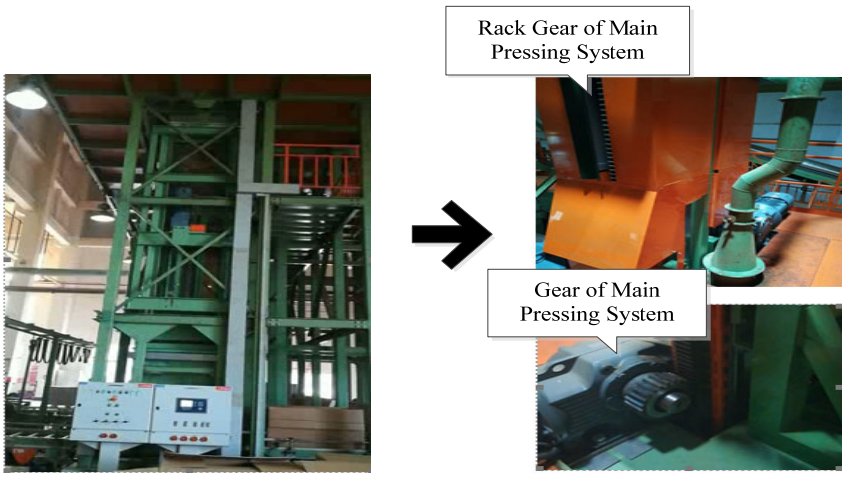

Figure 2. Conversion from Hydraulic Packaging System to Electric Packaging System

3.2. Driving the Pressing Heads with an Electric Servo Torque and Speed Synchronization System

3.2.1 The original piston rods driving the pressing heads are removed, and rack gears on the left and right sides of the pressing heads are used to drive their upward and downward movements. Since it is necessary to ensure that the speeds of the rack gears on both sides match, an electric servo torque and speed synchronization system technology is adopted to drive the pressing heads, achieving synchronous operation of the rack gears. At the same time, while satisfying the pressing force requirements, it fulfills the speed and pressure holding requirements of the pressing heads under various operating conditions. (Figure 3,4)

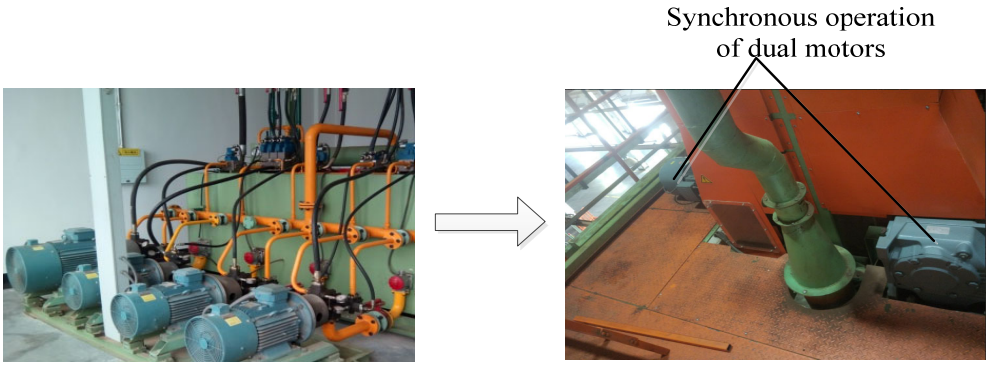

Figure 3. Hydraulic Drive Converted to Electric Motor Drive

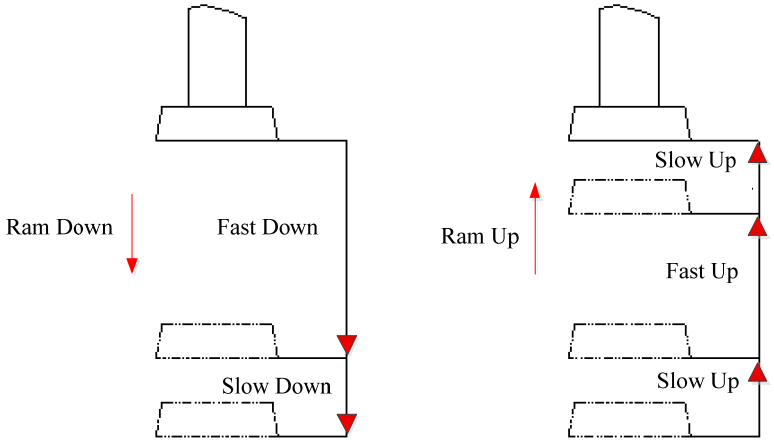

Figure 4. Schematic Diagram of Ram Motion Process

3.2.2 The original hydraulic system operated continuously, but now with the adoption of the servo electric drive system, it operates intermittently. Compared to the previous hydraulic pump, the new system consumes no electricity during the rapid descent process, resulting in a significant reduction in operating power. This significantly conserves energy consumption and aligns with the national tobacco industry's requirements for improving quality and reducing consumption. (Figure 5)

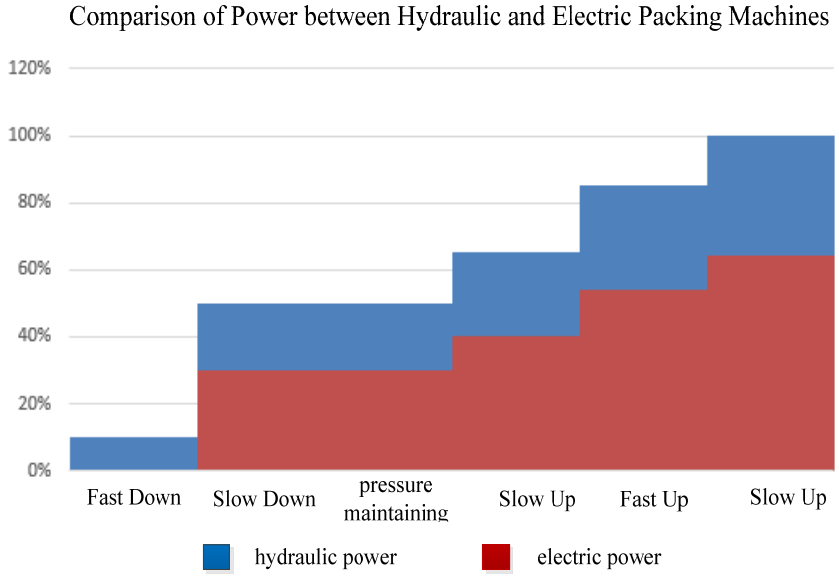

Figure 5. Comparison Chart of Power Consumption

3.3. Rational Material Selection and Precision Machining to Ensure System Efficiency and Stability

3.3.1 Military-grade processing techniques and quality standards are adopted to enhance the meshing accuracy and transmission precision of the gears and rack gears, ensuring stable and reliable transmission of the long rack gears. The maximum pressure of the original hydraulic packaging machine was 12 tons, while the current electric-driven packaging machine can achieve a pressure of up to 16 tons. (Figure 6)

Figure 6. Military-Grade Machining Site

3.2.2 Military-grade ion plating technology is adopted to meet wear resistance and lifespan requirements. (Figure 7)

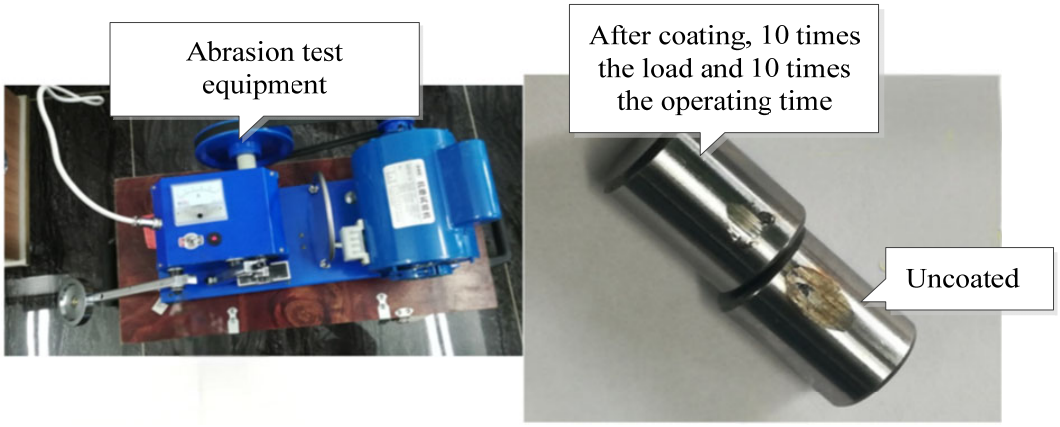

Figure 7. Comparative Test of Military-Grade Ion Coating

3.4. Optimizing the Structure of the Pressing Head to Solve Practical Problems in Production and Maintenance

The original pressing head, during the ascent after pressure holding, would lift some tobacco leaves due to the adhesive properties between the leaves and the pressing head. This issue was particularly evident when processing tobacco leaves with high oil content and a fluffy texture. During this renovation, the structure of the pressing head was optimized in two ways: first, a material guiding hood was added to the pressing head to prevent material accumulation above it, thereby solving the problem of material being carried by the pressing head; second, a new non-stick coating technology (PTFE coating) was applied to the pressing head to reduce the phenomenon of material sticking to its underside. The left image below shows the pressing head before the renovation, and the right image shows it after the renovation. (Figure 8)

Figure 8. Optimized Structure Diagram of Press Ram

4. Application Effects

For the electrically-driven pre-compression and packaging unit of the tobacco threshing and air classification equipment under research and application, we have evaluated its technical indicators, conducted comparisons with traditional hydraulic packaging units in terms of economic benefits and maintenance costs, performed energy-saving test verifications, and analyzed the benefits.

4.1. Technical Indicators Meet Standards

4.1.1 Through visual observation, the leaf rebound rate is relatively low, the molding is good, there is less tobacco left on the ground at the site, and the hygiene is better. Through instrumental testing, the packing density remains within 10.

4.1.2 The overall structure is simple and intuitive, with few faults, easy maintenance and repair, easy location of fault points, good stability, and few spare parts required with low costs.

4.1.3 No equipment faults occurred during the operation of one tobacco drying season.

4.1.4 The gears and rack gears driving the material bin and pressing head are stable and reliable during operation, with little wear.

4.1.5 When the equipment is running, the three channels driven by hydraulics can only operate sequentially, not simultaneously, while the electrically-driven ones can operate simultaneously.

4.2. Significant Economic Benefits

4.2.1 Reduced Equipment Footprint: The electrically-driven pre-compressor eliminates the hydraulic pump room, reducing equipment footprint by approximately 15m².

4.2.2 Lower Maintenance Costs: The replacement cycle for hydraulic oil and spare parts of the hydraulic system is 2 years, with high procurement costs for spare parts, long cycles (for imported parts), and difficult installation. After switching to an electrically-driven packaging machine, the gear replacement cycle is 3 years and the rack gear replacement cycle is 5 years. The price comparison is as follows Table 2:

Table 2. Comparison of Maintenance Costs

Project	Before Renovation	After Renovation
Maintenance Material Cost	Hydraulic System Spares: 340,000/2 years Great Wall Hydraulic Oil: 90,000/2 years	Gears: 180,000/3 years Rack Gears: 180,000/5 years
Total 10-Year Maintenance Material Cost	2150000	960000

4.2.3 Lower Labor Costs: Hydraulic packaging machines require specialized maintenance, usually performed by personnel from the equipment manufacturer. The maintenance period requires 6 people for 20 days, costing 80,000 yuan. After switching to an electrically-driven packaging machine, company repair workers can complete the maintenance work without hiring additional professionals. The maintenance period requires 3 people for 7 days, costing 0 yuan. (Table 3)

Table 3. Comparison of Labor Costs

Project	Before Renovation	After Renovation
Personnel	External Hire: 6 People	Internal: 3 People
Duration	20 Days	7 Days
Labor Cost	80,000/Time	None (Completed Internally)

4.2.4 Reduced Energy Consumption: When the equipment is running, the average power of the hydraulic system is approximately 75.2KW, while the average power of the electrically-driven system is approximately 55KW, with a power difference of 20.2KW, resulting in a 26% savings in electricity costs.

4.3. Significantly Reduced Equipment Maintenance Difficulty and Workload

4.3.1 During Shutdown and Overhaul: Maintaining a triplex hydraulic packaging machine generally requires a maintenance cycle of around 20 days for 6 people, with at least 1-2 people familiar with the hydraulic system. General mechanics cannot perform the repairs. Maintaining a triplex electrically-driven packaging machine generally requires a maintenance cycle of around 7 days for 3 people, and it is more intuitive, allowing general repair personnel to perform the repairs.

4.3.2 During Normal Production: Faults in the hydraulic system are difficult to diagnose directly and require personnel familiar with the hydraulic system to identify and address them, causing long downtime and severely affecting production efficiency. There is also a risk of hydraulic oil leakage contaminating finished tobacco leaves during maintenance, and leakage from worn cylinder seals will directly contaminate the finished tobacco leaves. The electrically-driven system only has motor drives, making it more intuitive and easier to troubleshoot, without the risk of contaminating finished tobacco leaves during maintenance, resulting in faster troubleshooting and shorter downtime.

5. Summary

The overall equipment features energy conservation, consumption reduction, noise reduction, and safe operation, with a mature, reliable, and user-friendly structure. The electric servo gear and rack drive replaces the hydraulic system, thereby minimizing the potential risks of hydraulic oil leakage and associated product quality issues. It requires minimal maintenance, utilizes fewer parts, and incurs lower maintenance costs. The electric technology and mechanical structure fully replace hydraulic technology, reducing the need for hydraulic piping, hydraulic pump stations, hydraulic oil, and hydraulic cylinders, among others. The structure is simplified, and the electric control system and programming are stable, reliable, and easy to maintain. This equipment aligns with the national

tobacco industry's initiatives for energy conservation, consumption reduction, and homogenization, and meets the high standards for tobacco leaf purity. It represents a significant innovation in pre-compression and packaging technology and is worthy of promotion throughout the tobacco leaf reprocessing industry.

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