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Analysis and Experiment of Dynamic Picking Process of Spindle of Cotton Picker

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Abstract: The spindle is a key core component of a cotton picker, and its operating parameters directly affect the quality of cotton harvesting. In this study, the spindle was selected as the research object. The kinematics and mechanics analysis of the cotton-picking process was conducted, the dynamic motion trajectory of the spindle was obtained, and the working parameters affecting the picking performance of the spindle were determined. A test bench for spindle picking performance was built; the spindle speed and feed speed were used as test factors; the seed cotton rejection rate, picking time, and picking force were used as evaluation indices for spindle picking performance; and a full-factor test was conducted. The range, variance, and regression analyses were conducted on the test results, and the results showed that spindle speed and feed speed had significant effects on seed cotton rejection rate, picking force, and picking time ($p < 0.01$). The primary and secondary order of factors affecting seed cotton rejection rate and picking time were spindle speed and feed speed, and the primary and secondary order of factors affecting picking force were feed and spindle speed. By comprehensively analyzing the influence of factors on the evaluation indices, the best combination was obtained as the spindle speed and feed speed of 4000 r/min and 1.8 m/s, respectively. The research results have theoretical research value and practical significance for revealing the picking law of spindles when rotating at a high speed and then realizing efficient cotton harvesting.

Keywords: cotton picker spindle; cotton picking process; spindle speed; feed speed

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1. Introduction

Cotton is mainly produced in China, the USA, India, Uzbekistan, Egypt, and other places [1]. It is an important textile and chemical raw material [2,3], and plays an important role in the development of a country's economy [4,5]. The suitable environment and climate in Xinjiang, China, provide conditions for the growth and boll formation of cotton [6]. In 2021, Xinjiang's cotton output will reach 5.129 million tons [7], accounting for 89.5% of the country's total output. Xinjiang has become the main cotton-producing area in China. Cotton harvesting is a time-constrained and heavy-duty job, and the traditional manual harvesting methods are inefficient and costly. Due to the advantages of the high efficiency and low cost of mechanized cotton harvesting [8,9], cotton pickers have been widely used in Xinjiang [10].

The spindle is a key core component of a cotton picker [11–14], and its performance will directly affect the harvesting quality and collecting rate of cotton [15–18]. In addition, the spindle is easily worn during the fieldwork process [19–21]. Yanqing, Haiyang, and Youqiang used a scanning electron microscope to characterize the wear morphology of the spindle hook teeth of cotton pickers under different working areas and found that the wear failure of spindles were abrasive and fatigue wear, as well as the combined results of oxidative wear [10,22–24]. Youqiang proposed to perform an electromagnetic treatment on the surface of the spindle to reduce its residual stress and improve its wear resistance [25]. Amanov utilized ultrasonic energy to induce severe plastic deformation to increase its mechanical properties and improve its wear resistance [26]. The spindle structure and rotation speed will affect the picking of cotton by hook teeth. Researchers have performed numerous studies to optimize the spindle structure and rotation parameters. Baker compared the effects of different diameter spindles on fiber quality, cotton loss, and impurity content of machine-picked cotton and showed that the spindle with a diameter of 1.59 cm had the best performance [15]. In addition, the fiber quality, harvest loss, and impurity content of machine-picked cotton at different spindle speeds were tested. The higher the spindle speed, the greater the damage to cotton fibers, and the optimal speed range was further determined [16]. Moreover, Baker tested the picking performance of round- and square-section spindles at different speeds and showed that the probability of seed cotton being picked from the boll shell increased exponentially with the increase of spindle speed. The picking capacity of round-section spindles is approximately twice that of square cross-section spindles [17]. Lei tested the influence of different hook angle parameters on the picking performance of the spindle and determined that the optimal values of the spindle hook tooth angle parameters are determined to be 70°, 89°, and 65° for the cogging, tooth front, and tooth inclination angles, respectively [27]. The existing study lacks a unified standard for the evaluation indices of the spindle performance. In addition, the study on the spindle-picking performance mainly starts with the spindle speed, ignoring the influence of the feeding motion. The cotton-picking process of the spindle is a spiral winding process, and the comprehensive influence of spindle rotation and feeding motion needs to be considered.

A test bench for spindle performance was then built taking the spindle as the research object. Taking the spindle picking and feed speed as the test factors, and the seed cotton rejection rate, picking time, and picking force as the evaluation indices, the full-factor test method was used to analyze the picking performance of the spindle under different operating parameters. This study aims to provide a theoretical basis for efficient harvesting and is of great significance for optimizing the transmission structure of the picking head, thereby improving the operating efficiency of the cotton picker.

2. The Process of Spindle Picking Cotton

2.1. Kinematics Analysis of the Spindle-Picking Process

This study abstracts and simplifies the picking mechanism (as shown in Figure 1c) into a hinged four-bar mechanism to analyze the movement process of the spindle. Since the rack rod is the shortest and the picking mechanism contains a cam mechanism, the picking mechanism is further abstracted as a variable rod length double-crank guide rod mechanism [28] (Figure 1a). In addition, Figure 1b is the closed vector polygon of the mechanism.

In Figure 1a, points O, C, A, B, and D are the center of the picking drum, the center of the cam groove, the intersection of the crank and the drum, the intersection of the crank and the cam groove, and the end vertex of the spindle at this position, respectively. The OA rod represents the picking drum, the rod length is the drum radius l_1, and the included angle with the horizontal direction is θ_1; the AB rod represents the crank, the rod length is the crank length l_2, and the included angle with the horizontal direction is θ_2; the CB rod represents the pole diameter from the center of the cam groove to a point on the contour of the cam groove, the rod length is the pole diameter length l_3 at this position, and the included angle with the horizontal direction is θ_3; the OC rod represents the frame, and the rod length is l_4; the AD rod is the guide rod, which represents the spindle fixed with the crank, the rod length is l_5, and the included angle with the crank AB rod is φ. Taking point O as the origin, a plane rectangular coordinate system is established.

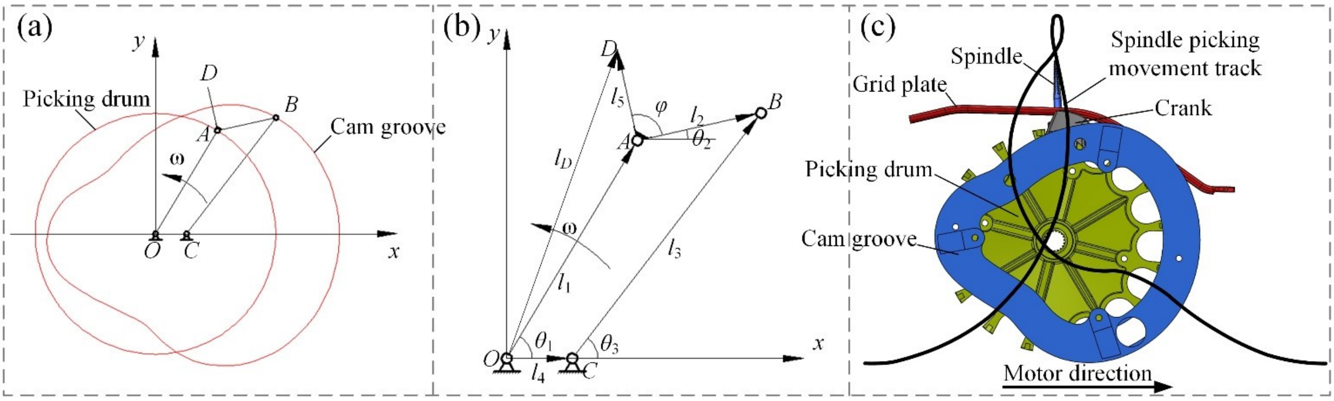

Figure 1. Kinematics analysis of the spindle picking process: (**a**) variable rod length double crank guide rod mechanism, (**b**) closed vector polygon, and (**c**) spindle-picking movement track.

In the figure, the OA rod is the active part, and its angular velocity is ω, so

$$\theta_1 = \omega t \tag{1}$$

In the formula, ω and t are the angular velocities of the picking drum (radians per second) and the working time of the picking drum (in seconds).

In Figure 1b, the CB rod is an indefinite long rod, and its length l_3 changes with the change of the angle θ_3 in the horizontal direction. In addition, the θ_3 is used as a discrete variable, and l_3 is a discrete function with θ_3 as the variable, as shown in Formula (2). The cam groove curve is imported into the AutoCAD2020(Autodesk, United States) software, and the length l_3 of the rod is obtained when the CB rod rotates 1° in the counterclockwise direction.

$$l_3 = f(\theta_3)\ \theta_3 \in \left[0, 360^{\circ}\right] \tag{2}$$

The OA rod rotates counterclockwise at the angular velocity ω, which drives the AB and AD rods to move along the contour of the cam groove. After checking the length of the rod, the trajectory formed by any point on the rod is definite and unique, and the vector equation can be obtained:

$$\vec{l}_1 + \vec{l}_2 = \vec{l}_3 + \vec{l}_4 \tag{3}$$

When writing the above vector equation in scalar form, Formulas (4) and (5) are obtained:

$$l_1 \cos\theta_1 + l_2 \cos\theta_2 = l_3 \cos\theta_3 + l_4 \tag{4}$$

$$l_1 \sin\theta_1 + l_2 \sin\theta_2 = l_3 \sin\theta_3 \tag{5}$$

From the OA rod and the AD rod, the vector equation of the vertex D of the spindle is obtained:

$$\vec{l}_D = \vec{l}_1 + \vec{l}_5 \tag{6}$$

When writing the above vector equation in scalar form, Formulas (7) and (8) are obtained:

$$x_D = l_1 \cos\theta_1 - l_5 \cos(\theta_2 + \varphi) \tag{7}$$

$$y_D = l_1 \sin\theta_1 + l_5 \sin(\theta_2 + \varphi) \tag{8}$$

Taking the Pro16 (the type of picking head) picking head as an example, according to the actual size of the picking head of the cotton picker, the characteristic values of the double crank guide rod mechanism with variable rod length are determined as follows: $\theta_1 = \omega t$, l_1 = 160 mm, l_2 = 53 mm, $l_3 = f(\theta_3)$, l_4 = 14 mm, l_5 = 130 mm, and $\varphi = \pi/2$. Simultaneous Formulas (4), (5), (7) and (8) can be used to obtain the coordinate equation of point D, i.e., the motion trajectory of the end of the spindle. Based on the above theoretical analysis, the MATLAB2019a(Mathworks, United States) software can be used to solve the dynamic trajectory of the cotton picker spindle (Figure 1c).

2.2. Mechanical Analysis of Spindle-Picking Process

Figure 2 shows that the mechanical model of the spindle-picking process. During the picking-cotton process, the spindle rotates at the speed n and simultaneously moves towards the cotton at the feed speed v. When the hook teeth touch the cotton, the cotton fibers are hooked, and the cotton is spirally wound on the surface of the spindle under feed speed v and the rotation speed n. When spindle picking cotton, a picking force T_p is formed on the cotton surface due to the friction influence. Taking point O on the cotton surface as the analysis object, the picking force T_p is decomposed to obtain the axial picking force T_a and the radial picking force T_r [27]. The relationship between them is shown in Formula (9).

$$\vec{T_p} = \vec{T_a} + \vec{T_{\mathrm{r}}} \tag{9}$$

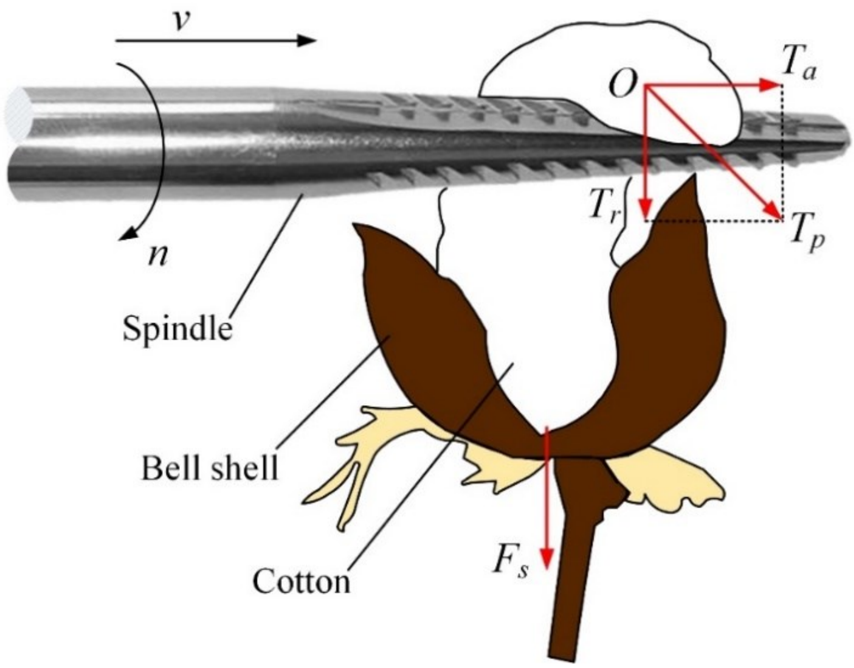

Figure 2. Mechanical model of the spindle-picking process: v, feed speed; n, spindle speed; T_p, picking force; T_a, axial picking force; T_r, radial picking force and F_s, picking resistance.

Simultaneously, cotton will be subjected to picking resistance F_s generated by the boll shell when picking cotton from the spindle due to the biological connection force between cotton and boll shell. To ensure the effective separation of cotton and boll shell, the following conditions must be met [29].

$$T_{\mathrm{p}} > F_s \tag{10}$$

3. Materials and Methods

3.1. Test Materials and Equipment

The experimental material in this study was machine-picked cotton Huiyuan 720, which was taken from the experimental field of Shihezi University (Xinjiang, China). The experimental field was sprayed with defoliant on 12 September 2021, and the sample collection time was 27 September 2021. During this time, the cotton defoliation and the boll opening rates reached >85% and >90%, respectively. To avoid the interference of unknown factors and ensure the validity of the test results, cotton plants with good growth and without pests and diseases were selected on the day of defoliant spraying. The cotton with four cotton petals at the sixth fruit branch of the cotton plant from the bottom to the top was marked as a test sample in advance, and samples were taken at 12:00 noon, 15 days after defoliant spraying. The samples were then stored in sample bags.

The test equipment used in this study mainly included a spindle dynamic picking performance test bench, spindles (Reliable, China; diameter, 12.4 mm), a JM-B5003 electronic balance (Jiming, China; range, 0–500 g; precision, 0.001 g), a Fastec TS3 high-speed camera (voltage and current acquisition frequency is 50 Hz synchronously), and an Edberg push–pull gauge (range, 0–10 N; accuracy, 0.001 N).

The dynamic picking performance test bench for spindle picking is shown in Figure 3a. It is mainly composed of a frame, a guide rail motion platform, a spindle drive device, a cotton holding device, a high-speed camera, and an electrical control system. The guide rail motion platform consists of one X-direction guide rail, two Y-direction guide rails, and two servo motors. The guide rail adopts a synchronous belt module structure, and the servo motor drives the guide rail slider to perform the reciprocating linear motion. The spindle-picking drive device is installed on the X-direction guide rail, which is composed of a BLDC motor (Rated power, 275 W; rated current, 4.9 A; rated speed, 6000 r/min; rated torque, 0.45 N·m), a fixture, and a spindle, and is used to drive the spindle to rotate at a high speed. The push–pull gauge is fixed at one end of the rack, the cotton-holding device is fixed on the upper end of the push–pull gauge.

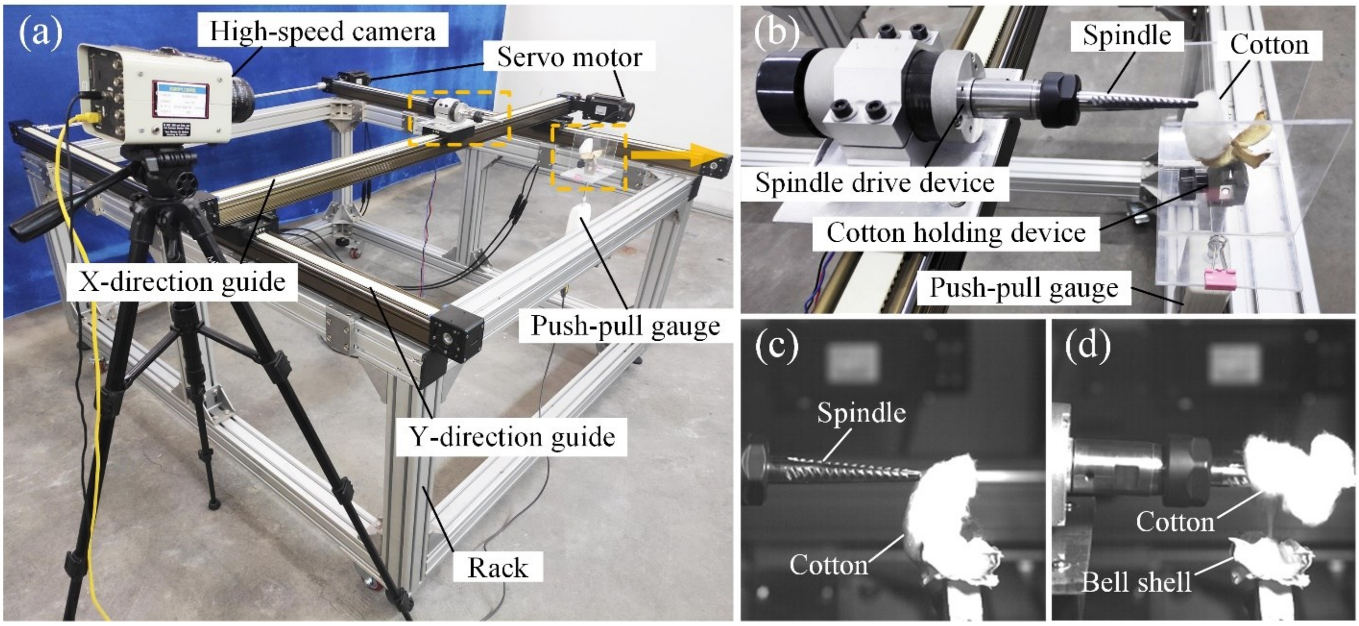

Figure 3. Spindle picking performance test bench: (**a**) the overall structure of the test bench, (**b**) the partial structure of test bench, (**c**) spindles come into contact with cotton, and (**d**) cotton and boll shell are completely separated.

3.2. Test Method

The key evaluation indices of the picking performance of the cotton picker are the operation efficiency and the collection rate [30]. As the key picking component of the cotton picker, the picking performance of spindles should reflect the picking efficiency and the collection rate. To facilitate measurement and detection, the picking time (the time required to pick single-petal cotton by spindle) was used in this study instead of picking efficiency as the evaluation index of spindle picking performance. Through pre-experiment and related literature search [31], high-speed rotating spindles were found to effectively separate cotton from boll shells for fully mature cotton. However, the seed cotton will be partially thrown off under the action of centrifugal force when the seed cotton is separated from the boll hull. Therefore, the seed cotton rejection rate was used in this study as the evaluation index of the picking performance of the spindle, i.e., the ratio of the cotton quality is thrown off by the spindle in the process of winding cotton to the total mass of the tested cotton. In the actual picking process in the field, incompletely mature cotton was observed, which is difficult to pick [32,33] and requires high picking force. Thus, this study uses picking force as an evaluation index.

In this study, the spindle rotation and feed speed were used as test factors, and the picking force T_p, picking time t_p, and seed cotton rejection rate Z were selected as the evaluation indices of the picking performance of the spindle. During the test, only one petal of the cotton sample was retained on the cotton clamping force measuring device, and the height of the cotton clamping force measuring device was adjusted so that the highest point of the cotton petal and the end of the spindle were on the same horizontal line. The spindle rotation and the spindle feeding speed were controlled by the host computer program, the test program was written by Oto Studio(Googol, China). The picking force T_p was measured by the tension sensor on the cotton clamping force measuring device when picking the cotton. The actual picking time t_p of the spindle-wound cotton was collected by a high-speed camera. Finally, the quality of the effectively picked and the detached seed cotton were measured by an electronic balance, and the seed cotton detachment rate Z was calculated.

The calculation formula of the above evaluation index is:

$$T_{\mathrm{p}} = T_{p2} - T_{p1} \tag{11}$$

In the formula, T_{p1} is the initial picking force of cotton when the spindle is not in contact with cotton, N, and T_{p2} is the maximum picking force of cotton when the spindle is picked, N.

$$t_p = t_{p2} - t_{p1} \tag{12}$$

In the formula, t_{p1} is the time when the spindle starts to contact the cotton (Figure 3c), s; t_{p2} is the time when the cotton is completely separated from the boll shell (Figure 3d), s.

$$Z = \frac{M_2}{M_2 + M_1} \tag{13}$$

In the formula, M_1 is the mass of cotton effectively picked by the spindle, kg; M_2 is the mass of cotton thrown away by the spindle in the process of picking cotton, kg.

In this study, a full factorial experimental design scheme was adopted, and the variation range of the experimental factors was determined through preliminary tests as follows: the spindle speed and feed speed are 3000–5000 r/min and 0–1.80 m/s, respectively [28]. The experiment was conducted following two factors and five levels. The factor coding table is shown in Table 1. Each group of experiments was repeated 10 times, and the average value was taken.

Table 1. Encoded experimental factors and levels.

Level	Spindle Speed/(r·min^{-1})	Feed Speed/(m·s^{-1})
1	3000	0.36
2	3500	0.72
3	4000	1.08
4	4500	1.44
5	5000	1.80

4. Results and Discussion

The full factorial experimental protocol and results are shown in Table 2.

Table 2. Full factor test program and results.

No.	Spindle Speed/(r·min^{-1})	Feed Speed/(m·s^{-1})	Seed Cotton Rejection Rate/%	Picking Time/s	Picking Force/N
1	3000	0.36	5.53 ± 1.03	0.127 ± 0.031	0.629 ± 0.123
2	3000	0.72	5.08 ± 1.31	0.119 ± 0.042	0.641 ± 0.142
3	3000	1.08	4.71 ± 0.98	0.110 ± 0.023	0.639 ± 0.171
4	3000	1.44	4.21 ± 1.09	0.095 ± 0.019	0.669 ± 0.146
5	3000	1.80	3.94 ± 0.88	0.096 ± 0.015	0.691 ± 0.103
6	3500	0.36	6.77 ± 1.50	0.103 ± 0.024	0.603 ± 0.201
7	3500	0.72	6.04 ± 1.33	0.095 ± 0.030	0.631 ± 0.187
8	3500	1.08	5.08 ± 1.23	0.087 ± 0.020	0.633 ± 0.172
9	3500	1.44	4.29 ± 0.97	0.067 ± 0.016	0.661 ± 0.181
10	3500	1.80	4.61 ± 0.77	0.079 ± 0.013	0.668 ± 0.134
11	4000	0.36	7.33 ± 0.93	0.086 ± 0.024	0.601 ± 0.109
12	4000	0.72	7.97 ± 0.81	0.078 ± 0.030	0.609 ± 0.099
13	4000	1.08	7.04 ± 1.53	0.082 ± 0.028	0.613 ± 0.190
14	4000	1.44	6.23 ± 0.66	0.064 ± 0.025	0.624 ± 0.151
15	4000	1.80	5.45 ± 0.91	0.067 ± 0.023	0.646 ± 0.207
16	4500	0.36	12.51 ± 2.33	0.072 ± 0.019	0.599 ± 0.141
17	4500	0.72	11.34 ± 1.91	0.079 ± 0.027	0.603 ± 0.153
18	4500	1.08	11.77 ± 1.63	0.074 ± 0.017	0.612 ± 0.123
19	4500	1.44	9.76 ± 1.32	0.065 ± 0.021	0.621 ± 0.161
20	4500	1.80	9.17 ± 0.99	0.061 ± 0.016	0.636 ± 0.104
21	5000	0.36	15.63 ± 1.87	0.068 ± 0.014	0.579 ± 0.113
22	5000	0.72	14.79 ± 2.53	0.063 ± 0.012	0.583 ± 0.119
23	5000	1.08	14.27 ± 2.01	0.069 ± 0.009	0.613 ± 0.130
24	5000	1.44	11.15 ± 1.55	0.080 ± 0.017	0.623 ± 0.214
25	5000	1.80	11.94 ± 1.13	0.058 ± 0.016	0.627 ± 0.190

4.1. Range Analysis of the Influence of Each Test Factor on the Evaluation Indices

The range analysis was performed on the above test results, and the results are shown in Table 3. From the range analysis results, for the seed cotton rejection rate and picking time, the primary and secondary orders of each influencing factor are the spindle picking speed being greater than the feeding speed, as well as the influence of the feed speed on the seed cotton rejection rate and picking time, followed by the spindle speed. For the picking force, the primary and secondary order of each influencing factor is the feed speed being greater than the spindle speed.

Table 3. Range analysis of test results.

Test Indices	Project	Spindle Speed/(r·min^{-1})	Feed Speed/(m·s^{-1})
Seed cotton rejection rate/%	AVG_K1	4.694	9.554
	AVG_K2	5.358	9.044
	AVG_K3	6.804	8.574
	AVG_K4	10.910	7.128
	AVG_K5	13.556	7.022
	R	8.862	2.532
Picking time/s	AVG_K1	0.109	0.091
	AVG_K2	0.086	0.087
	AVG_K3	0.075	0.084
	AVG_K4	0.070	0.074
	AVG_K5	0.068	0.072
	R	0.042	0.019
Picking force/N	AVG_K1	0.654	0.602
	AVG_K2	0.639	0.613
	AVG_K3	0.619	0.622
	AVG_K4	0.614	0.640
	AVG_K5	0.605	0.654
	R	0.049	0.051

Note: AVG_K and R indicate the average value of the test results at each level and the range value, respectively.

4.2. Variance Analysis of the Influence of Each Experimental Factor on the Evaluation Indices

Range analysis cannot distinguish between data fluctuations caused by changes in test conditions and data fluctuations caused by experimental errors during the test process, nor can it provide an accurate assessment of the significance of factors [1]. To make up for the insufficiency of range analysis, this study performed variance analysis on the above test results, and the results are shown in Table 4. From the variance analysis, the spindle speed and feed speed have significant effects on seed cotton rejection rate, picking time, and picking force ($p < 0.01$).

Table 4. Analysis of variance of test results.

Factors	Spindle Speed/(r·min^{-1})	Feed Speed/(m·s^{-1})
Seed cotton rejection rate/%	0.000 **	0.000 **
Picking time/s	0.000 **	0.008 **
Picking force/N	0.000 **	0.000 **

Note: ** Indicate significant difference at 0.01 levels.

4.3. Regression Analysis of the Influence of Each Experimental Factor on the Evaluation Indices

In order to visually show the influence of each test factor on each of the evaluation indices, taking the spindle speed and feed speed as the abscissa, and the AVG-K value of each of the evaluation indices in Table 3 as the ordinate, a scatter diagram was drawn of the relationship between each influencing factor and the evaluation indices. A regression analysis was performed on it, and the results are shown in Figure 4.

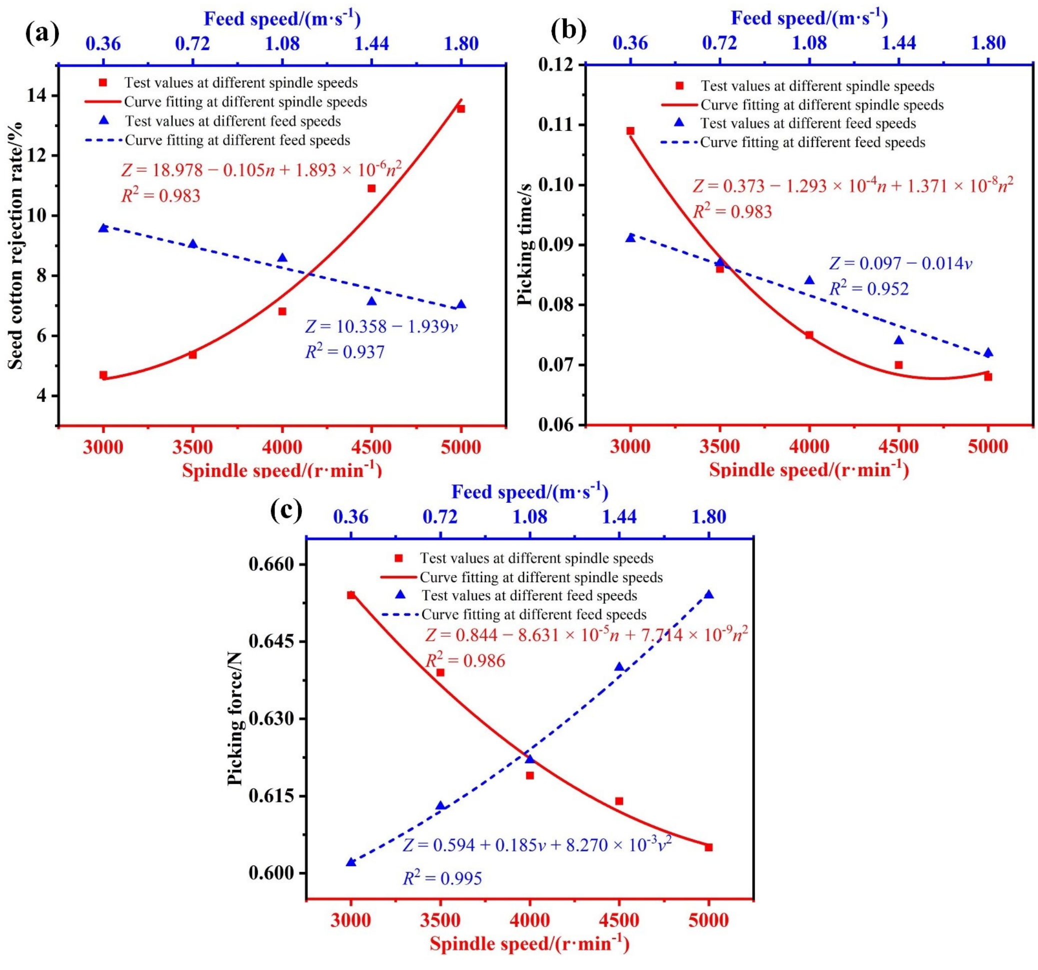

Figure 4. The influence of various experimental factors on the evaluation indices: (**a**) the influence of experimental factors on seed cotton rejection rate, (**b**) the influence of experimental factors on picking time, and (**c**) the influence of experimental factors on picking force.

Figure 4a shows that the seed cotton rejection rate gradually increased with the increase of spindle speed because the centrifugal force of the cotton wrapped around the surface of the spindle increases and is easily thrown away with the increase of the spindle speed [31]. With the increase in the feed speed, the rejection rate of the seed cotton gradually decreased. This is because winding the cotton by the spindle changes from overlapping winding (shown in Figure 5a) to helical winding (shown in Figure 5b) with the increase of the feed speed. Helical winding can make the hook teeth on the spindle surface be more closely in contact with the cotton and is not easily thrown away [34].

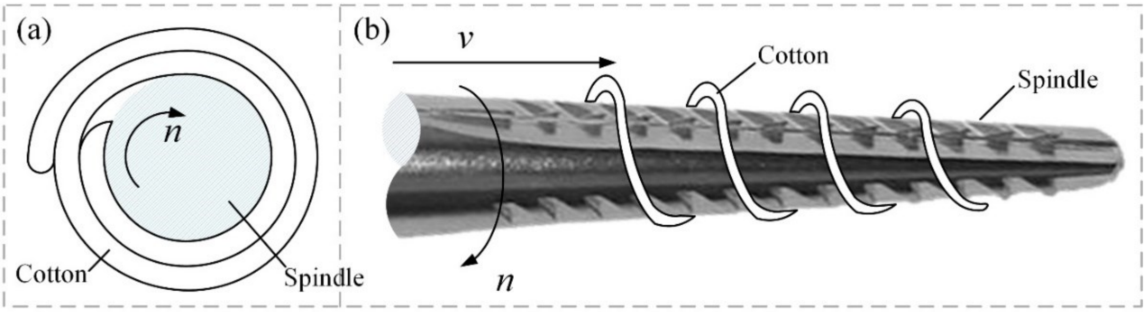

Figure 5. Spindle winding cotton method: (**a**) overlapping winding and (**b**) spiral winding.Figure 4b shows that the picking time gradually decreases with the increase of spindle speed. This is because the length of the cotton after elongation is limited under a certain elongation rate of the cotton flap, and the higher the spindle speed, the shorter the winding time. With the increase of the feed speed, the picking time gradually decreased. This is because the variation range is small due to the winding of the cotton being spiral overlapping when the feeding speed of the spindle is low. Additionally, the cotton wound on the surface of the spindle is mainly concentrated at the front end of the spindle because the diameter of the front end of the spindle is small, and the winding time is longer for a certain length of cotton. When the feed speed is high, the winding method of the spindle is spiral winding, the surface of the spindle is evenly wound with cotton, and the winding time is short for a certain cotton length [35].

Figure 4c shows that the picking force gradually decreases with the increase of spindle speed. This is because the centrifugal force on the cotton increases when the spindle speed increases, and the corresponding positive pressure between the cotton and the surface of the spindle decreases, resulting in a decrease in the friction between the cotton and the surface of the spindle, and then the picking force on the cotton wrapped around the surface of the spindle is reduced [27]. The picking force gradually increases with the increase of the feed speed. This is because, with the increase of the feed speed, the acceleration obtained when the cotton is in contact with the spindle increases, the radial picking force T_r increases, which in turn leads to an increase in the picking force.

4.4. Best Combination of Spindle Speed and Feed Speed

The best combination of spindle speed and feed speed was carried out considering the influence on seed cotton rejection rate, picking time, and picking force. First of all, to meet the requirement that the cotton picker's collect rate is >90%, it should be ensured that the seed cotton rejection rate is not >10%. Secondly, the main problem with the existing cotton-picking machine is that the operation efficiency cannot meet the needs of users. Thus, improving the picking efficiency, i.e., reducing the picking time, is necessary. Finally, the picking force is maximized under the premise of ensuring the picking time and the seed cotton rejection rate. For the seed cotton rejection rate, the lower the seed cotton rejection rate, the better the picking effect was observed. To ensure that the cotton can be effectively picked, the picking force should be the largest. From Table 2, the best combination is a spindle speed and a feed speed of 3000 r/min and 1.8 m/s, respectively. For the picking time, the picking time needs to be minimized to improve the picking efficiency. Thus, the best combination is that the spindle speed and feed speed are 5000 r/min and 1.8 m/s, respectively. For the picking force, to ensure that the cotton can be effectively picked, the picking force should be the largest. Thus, the best combination is that the spindle speed and feed speeds are 3000 r/min and 1.8 m/s, respectively.

The feed speed is determined to be 1.8 m/s by comprehensively comparing the three optimal schemes. From Figure 4b, when the spindle speed reaches 4000 r/min, the rate of reduction of the picking time becomes slower, therefore, increasing the spindle speed has little benefit in reducing the picking time. When the spindle speed reaches 4000 r/min, the seed cotton rejection rate is about 7%, which meets the requirement of a seed cotton rejection rate of <10%. For the picking force, the change of the spindle speed has little effect on it. Therefore, the spindle speed is determined to be 4000 r/min. At this time, the seed cotton rejection rate, the picking time, and the picking force were 5.45%, 0.067 s, and 0.646 N, respectively.

5. Conclusions

(1) The kinematic model of the cotton-picking process is established by analyzing the working principle of the picking head of the cotton picker, and the dynamic motion trajectory of the spindle is solved by using MATLAB software. The mechanical analysis of the cotton-picking process was conducted, and the main working parameters affecting the picking performance of the spindle were determined as the spindle speed and feed speed.

(2) A two-factor and five-level full-factor test were conducted to build a spindle-picking performance detection test bench, taking the spindle speed and feed speed as the test factors, and using the picking force, picking time, and seed cotton rejection rate as the evaluation indices of the spindle picking performance. Range, variance analysis, and regression analysis were performed on the test results. It was concluded that the spindle speed and feed speed had significant effects on picking force, picking time, and seed cotton rejection rate ($p < 0.01$). The primary and secondary order of factors affecting seed cotton rejection rate and picking time was spindle speed and feed speed, and the primary and secondary order of factors affecting picking force were feed and spindle speed. By comprehensively analyzing the influence of factors on each of the evaluation indices, the optimal parameter combination is obtained when the spindle speed is 4000 r/min and the feed speed is 1.8 m/s; at this time, the seed cotton rejection rate was 5.45%, the picking time was 0.067 s, and the picking force was 0.659 N.

This study has theoretical research value and practical significance for optimizing the operating parameters of the picking structure and improving the operating efficiency of the cotton picker.

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