DESIGN AND TESTING OF A COTTON STALK CLAMP-PULLING TEST BENCH
/
棉秆对夹拉拔试验台设计与试验

Jiaxi ZHANG *[1,2], Zhenkun LI [1], Gang GUO [1], Yasenjiang BAIKELI [1], Yichao WANG [1], Jialin CAI [1], Zhenwei WANG [1,3]

[1]Xinjiang Agricultural University, School of Mechanical and Electrical Engineering, Urumqi / China;
[2]Xinjiang Key Laboratory of Intelligent Agricultural Equipment, Urumqi / China
[3] Nanjing Institute of Agricultural Mechanization, Ministry of Agriculture and Rural Affairs / China
Tel: 8613899961137; E-mail: 563810112@qq.com
Corresponding author: Zhang Jiaxi
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ABSTRACT

In order to explore the relationship between displacement-pulling force and the change of clamping force during the clamping and pulling process of cotton stalks in the field by different types of clamps, a test bench for cotton stalks clamping and pulling was designed. Based on the combination of virtual instrument technology and external hardware, the device is programmed by Gx Works2 and LabVIEW programming software to complete the operation of the test bench clamping and pulling device and the measurement and acquisition of information. From the mapping of the collected information, the average value of the maximum uplift force on the cotton stalks was 500 N, corresponding to an upward movement of 12 mm at the root of the cotton stalks. Through the collected information the effect of two types of clamps on cotton stalks clamping and pulling was analyzed, rigid splints with the clamping force of 750 N and a linear speed of 0.18m/s having the best effect on the cotton stalks clamping and pulling. Rubber splints have the best effect on cotton stalks clamping and pulling when the clamping force is 500 N and the linear speed is 0.36 m/s. Among them, the striped rubber splint has the best effect. The collected information was subjected to analysis of variance (ANOVA), and the results showed that the coefficient of friction of the clamping plate showed a high influence on both the pull-up force and the reduction of clamping force. Based on the obtained results, it can provide a reference for the design of clamping type cotton stalk harvesting machinery.

摘要

为探讨不同类型夹板对田间棉秆夹持起拔过程中位移-起拔力之间的关系及夹持力变化情况，设计了一种棉秆对夹拉拔试验台。该装置基于虚拟仪器技术与外部硬件相结合，通过 Gx Works2 及 LabVIEW 编程软件进行编程，完成试验台夹持、起拔装置的运行及信息的测量采集。由所采集信息绘图，棉秆所受最大起拔力均值为 500N，对应棉秆根部上移 12mm。通过所采集信息分析两种夹板对棉秆夹持起拔效果，刚性夹板在夹持力 750N 线速度 0.18m/s 时对棉秆夹持起拔效果最优。橡胶夹板在夹持力 500N 线速度 0.36m/s 时对棉秆夹持起拔效果最好，其中条型纹路橡胶夹板效果最优。将所采集信息进行方差分析，结果表明，夹板摩擦系数对起拔力及夹持力减少量均呈现出高度影响。根据所得结果，可为夹持类棉秆收获机械设计提供参考。

INTRODUCTION

As one of the important cash crops in China, cotton is widely planted. In the national cotton planting area, Xinjiang is the main planting area, occupying 82.7% of the share, reaching 2.506×10^6 hm^2. Meanwhile, the cotton production in Xinjiang also occupies 89.5% of the national production, reaching 5.129×10^6 t (*Announcement of National Bureau of Statistics on cotton production in 2022, 2022*). In addition to cotton itself, cotton stalks are one of the main by-products of cotton cultivation. Cotton stalks have a wide range of applications and can be used as renewable biomass resources, poultry feed, paper making, edible mushroom culture, environmental protection materials, and other fields (*Wang Y.J. et al, 2022; Guo T.J. et al, 2018; Song X.Z. et al, 2013*). Therefore, if the recycling of cotton stalks resources can be realized, it will bring great economic benefits *(Gao R.F. et al, 2016; Fire H.X, 2021; Zhang W.Z, 2015*).

*[*1,2]Jiaxi Zhang, Prof.Ph.D.Eng.; [1]Zhenkun Li, M.S.Stud.Eng.; [1]Gang Guo, M.S.Stud.Eng.; [1]Yasenjiang Bakeli, M.S.Stud.Eng.; [1]Yichao Wang, Ph.D. Stud Eng.; [1]Jialin Cai, Ph.D. Stud Eng.; [1,3]Zhenwei Wang, Ph.D. Stud Eng.*

However, manual harvesting of cotton stalks is time-consuming and labor-intensive due to their different shapes and sizes. Therefore, the study of mechanical harvesting technology of cotton stalks has become one of the focuses of mechanization technology research in cotton production in recent years (*Xie J.H. et al, 2023*).

At present, during cotton stalk harvesting, mostly clamping type cotton stalk harvesting machinery is dominated (*Chen J.L. et al, 2018; Jian S.C. et al, 2011*). Clamping type cotton stalk harvesting machinery operation is mainly a process of clamping and pulling (*Liu X. et al, 2017; Tang Z.F. et al, 2018; Zhou S.P, 2019*). So, different types of clamping components on the cotton stalk clamping and pulling effect is different, so the clamping force, pulling force is an important theoretical basis for the design of the key components of the cotton stalk pulling. Existing cotton stalk pulling measurement devices mainly use rigid sleeves or clasps to clamp the cotton stalks, and manually or electrically drive the pulling of the cotton stalks at low speeds. The main drawbacks are that the pulling speed is too slow (*Li Y. et al, 2013*), during the pulling process, the cotton stalks are often ruptured, slipped off and so on.

Aiming at the above existing problems, this paper designs a kind of cotton straw pair clamping and pulling test bed. In the field test, different types of splints were used to clamp and pull the cotton stalks to observe the operation effect. The computer was used to collect the changes in the clamping force of the measured splints and the upward displacement of the roots of the cotton stalks corresponding to the pulling force. Through the test, the relationship between the collected information can be derived, in order to provide the basis of mechanical and structural parameters for the design of the clamping type of cotton stalk harvesting machinery.

MATERIALS AND METHODS

Overall structure

The counter clamp pulling test bench consists of a clamping device, power unit, and transmission mechanism, of which the clamping device and power unit are the main components and the structure of the whole machine is shown in Figure 1.

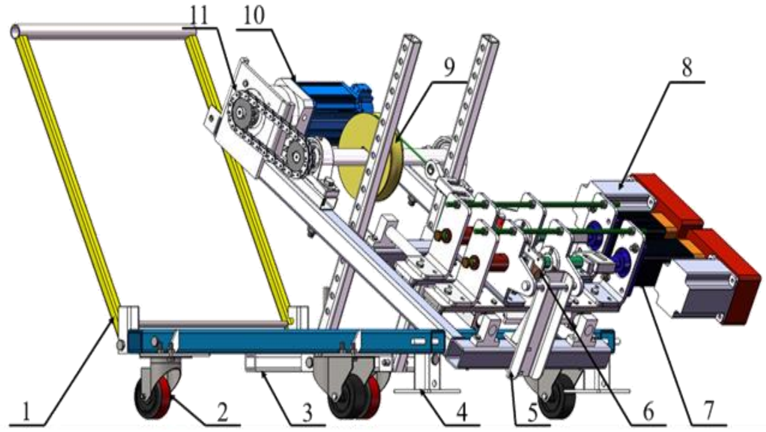


Fig. 1 - Schematic diagram of the structure of the clamping and pulling test bench

1 – Drawbar; 2 – Walking wheel; 3 – Support device; 4 – Rear support device; 5 – Fixed traction frame riser device; 6 – Cotton stalks; 7 – Clamping device Ⅰ; 8 – Clamping device Ⅱ; 9 – Pulley; 10 – Power unit; 11 – Transmission mechanism

Working principle

The working principle is to send digital signals to the programmable logic controller PLC through the computer to drive the power unit and the clamping device, to realize the clamping and pulling action on the cotton stalks. The analog signals from the pulling sensors at the clamping and pulling points are transmitted to the data acquisition card through the analog transmitter, and the data is collected by the card, and the collected data is transmitted to the LabVIEW acquisition program for data acquisition, and through analysis and calculation, the real-time data of the clamping force on the cotton stalks, the pulling force, and the upward displacement of the cotton stalks can be seen on the computer. The distance measuring sensor is directly connected to the data acquisition card for digital signal acquisition, and the edge counting acquisition module in the LabVIEW acquisition program displays and saves the acquired data in real-time. According to the measured data, the clamping force and the relationship between the pulling force and the displacement of the cotton stalks during the pulling process can be obtained. Figure 2 shows the schematic diagram of the pulling force on the cotton stalks in the field test.

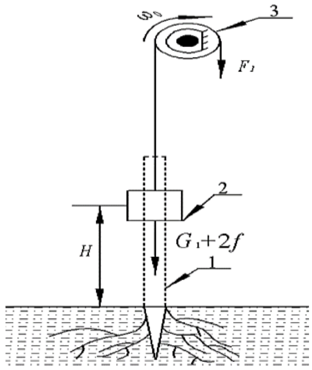


Fig. 2 - Sketch of tensile forces on cotton stalks in the field

1 – Cotton stalk main stem; 2 – Cleat; 3 – Pulley

Note: 90 degrees to pull up the cotton stalks, G_1 is the gravity of the clamping device itself, f is the force of friction, H is the clamping height, F_1 is the pulling force on the cotton stalks.

Design of key components

Design of the clamping device

The WDW-20 microcomputer-controlled electronic universal testing machine was utilized to carry out the pressure test on the measured cotton stalks. It was measured that under the same pressure, the cotton stalks did not rupture between the two materials of the clamping plate. According to the test results, it was determined that the pressure range of the cotton stalks to withstand is 0~1000 N. In view of the previous problems of the cotton stalks clamping device, the clamping device was analyzed, and the cotton stalks were prone to slip and rupture in the clamping part. In order to prevent this from happening to ensure the accuracy of the test data, a controllable electric cylinder is used as the power source of the clamping device based on the measured data when selecting the clamping device. At the same time, the head of the clamping device is installed with a tensile pressure sensor for real-time transmission of clamping force data. The schematic structure of the clamping device is shown in Figure 3.

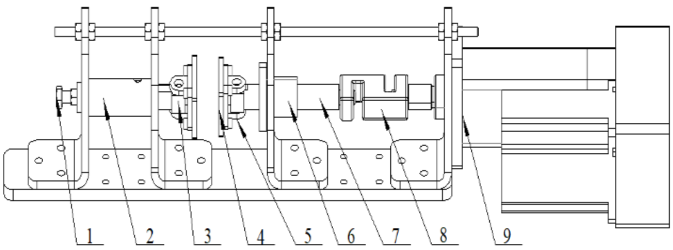


Fig. 3 - Schematic diagram of the structure of the clamping device

1 – Adjusting bolt; 2 – Adjusting sleeve; 3 – Adjustable push rod; 4 – Clamping plate; 5 – Clamping plate fixing plate; 6 – Round flange linear bearing; 7 – Pressure applying push rod; 8 – Pulling pressure sensor; 9 – Electric cylinder

Selection of electric cylinder

The working principle of the electric cylinder is: the motor drives the screw rod to rotate, realizing the axial displacement of the extended end of the electric cylinder. (*Ren M.H, 2018*). Therefore, in the process of applying pressure to the cotton stalks, the motorized cylinder is subjected to axial force-F_a, as shown in the sketch of cotton stalks subjected to clamping force in Figure 4.

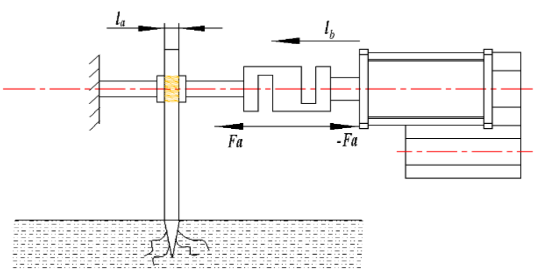


Fig. 4 - Sketch of cotton stalks subjected to clamping forces

Note: l_b is the electric cylinder stroke, l_a is the plywood spacing, F_a is the maximum clamping force

Cotton stalks are subjected to a clamping force F_a.

Therefore:

$$\left|-F_a\right| = F_a = 1000N \tag{1}$$

When selecting an electric cylinder, the most important things are load and speed. Based on the load of 1000 N and speed of 10 mm/s determined before selecting the electric cylinder, a screw with a diameter of 20 mm and a lead of 5 mm was selected. Since the average diameter of the cotton stalk is 12 mm, and the thickness of the clamp plate is 5 mm, in order to leave sufficient space between the clamp plates for clamping the cotton stalks, the clamp plate spacing (la) is designed to be 50 mm. Based on the spacing between the two clamp plates, the stroke of the electric cylinder is selected. The final choice is KDJ60 return electric cylinder with a stroke (l_b) of 50 mm. In order to select a motor that matches the electric cylinder, and the motor torque and power must meet the test requirements, the final choice is an 86-step two-phase motor with a power of 0.05kW and a reduction ratio of 1:1, providing a torque of 1.27 N·m.

Design of power unit and transmission mechanism

In order to accurately measure the pulling force on cotton stalks, and to ensure that the pulling of stalks can be rapid, the average value of the distance from the main rootstock to the ground surface of 10 sampled cotton stalks was measured. The results show that the distance from the bottom of the main rhizome to the ground surface is 180mm, therefore the velocity is set between 0.18 m/s~0.36 m/s to achieve the actual pulling speed. Therefore, the rotation speed and torque of the motor selected for the uprooting force test should meet the requirements. Furthermore, in order to avoid problems such as slipping of cotton stalks or device collision that may be caused by too high a speed, factors such as control precision, overload resistance and stable operation need to be considered in the selection of the power unit. According to the test requirements and actual operation, the final choice is a servo motor as the power source for plucking cotton stalks. In order to ensure that the pulling speed and pulling torque meet the demand or even more, a precision planetary gear reducer and servo motor with a reduction ratio of 1:10 were chosen. Regarding the transmission, the power transmission mechanism of the whole machine adopts the chain transmission and the transmission ratio of 1:1. This transmission mode helps to work in the heavy-duty low-speed and can maintain a stable average ratio. Figure 5 shows the overall schematic diagram of the power unit and transmission mechanism.

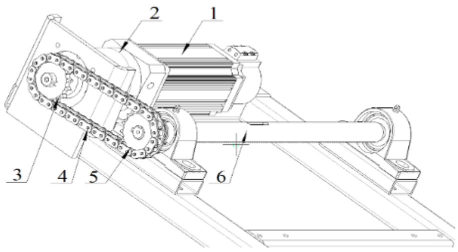


Fig. 5 - Schematic diagram of the power unit and transmission mechanism as a whole

1 – Servo motor; 2 – Precision reducer; 3 – Active sprocket; 4 – Chain; 5 – Driven sprocket; 6 – transmission output shaft

Power unit servo motor selection

Calculation of the power unit motor parameters based on the relevant parameters of the unit.

Servo motor torque calculation:

$$T_1 = F \times r \tag{2}$$

$$T_2 = \frac{T_1}{\eta \bullet \eta_1 \bullet \eta_2} \tag{3}$$

where:

r - pulley radius, 0.0145 m;

F - maximum pulling resistance F_0=2f (850 N) and clamping device's own gravity G_1 (150 N), N;

T_1 - Ideal motor torque, N;

T_2 - motor torque in actual condition, N;

η - servo motor efficiency, 0.87;

η_1 - reducer efficiency, 0.96;

η_2 - transmission efficiency between wire rope and pulley, 0.96;

Servo motor power calculation:

$$P_1 = F \times v \tag{4}$$

$$P_2 = \frac{P_1}{\eta \bullet \eta_1 \bullet \eta_2} \tag{5}$$

where:

P_1 - Ideal motor power, kW;

v - Lifting speed, m/s;

P_2 - motor power in actual condition, kW;

Calculation of servo motor speed:

$$n = \frac{v}{\pi D} \tag{6}$$

Where:

n - motor speed, r/min.

D - pulley diameter, 0.029 m;

After the above calculation, the servo motor parameters are obtained.

According to the parameters obtained, and considering the operating conditions, to prevent the motor from being damaged in the field test due to overloading and overheating, the final choice is the MIG 90ST-M02430 220 V AC servo motor, with a power of 0.75 kW, a speed of 2,500 r/min, and a torque of 2.4 N.m, which can satisfy the requirements of the test.

Design of control and measurement systems and determination of friction coefficients

Design of the control system

This control system is composed of GX Works2 programming software and a domestic Lingyi FX-32 series PLC programmable control module. Programming is done using GX Works2 programming software and communicating with the PLC module at the RS232 serial port. This PLC supports 4-channel high-speed pulse output, and the maximum pulse speed of each channel is up to 100 KHz. In this module, the Y0 and Y2 terminals output pulses, and the Y4 and Y6 terminals control the direction to realize the control of servo motors and electric cylinders. Figure 6 shows the operation control wiring diagram of the whole machine.

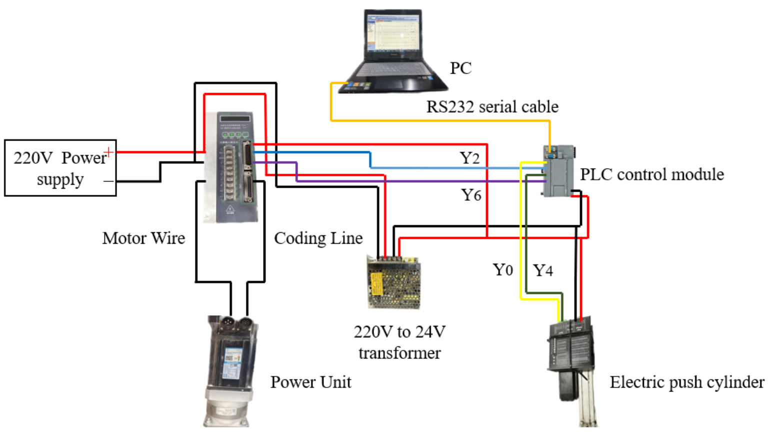


Fig. 6 - Wiring diagram of machine operation control

Design of the measurement system

This test rig requires the following measurements: the pulling force on the cotton stalks, the clamping force on the cotton stalks, and the distance traveled corresponding to the pulling force. In these three sets of measurements, the pulling force on the cotton stalks will change as the pulling distance increases. When the pulling distance reaches the pulling threshold, the cotton stalks will be subjected to the maximum pulling force.

Because this maximum pulling force exists for a very short time and is not easy to collect instantly, according to this feature, this test bench selected an Altech USB3200N type data acquisition card and LabVIEW platform measurement software combination, to collect the data of clamping force, pulling force and displacement distance. It is connected to the computer through the USB serial port and can display the collected data in real-time on the data acquisition page on the computer so that the value of each point can be recorded in time. The virtual control panel of this measurement program is divided into 5 parts: acquisition channel display area, parameter setting input area, the graphic display area of the acquired signal, numerical value display area, save path display area and the data acquisition page of the cotton stalks are shown in Figure 7.

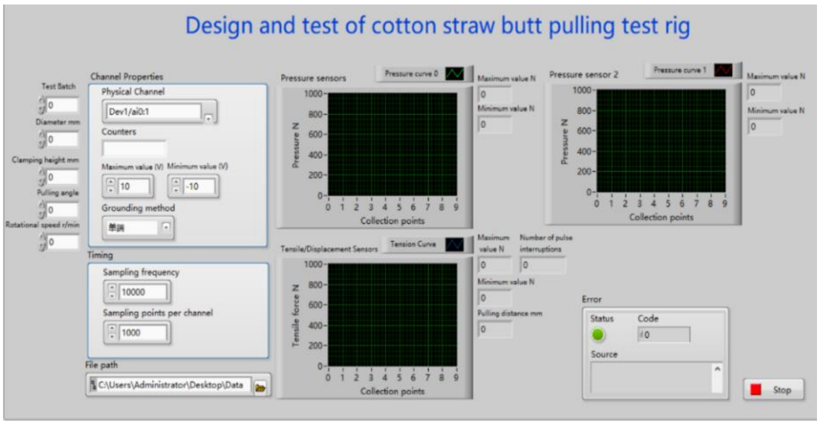


Fig. 7 - Cotton stalk data collection page

Calibration of measurement systems

Before the test, the acquisition and measurement program and the tension and pressure transducer were calibrated by running the WDW-20 microcomputer-controlled electronic universal testing machine produced by Jinan Chuanbai Instrument and Equipment Co Ltd (*Zhao B. et al, 2010*). The calibration results are shown in Table 1. The load value collected by the measurement system is compared with the load output of the universal testing machine, and the maximum relative error is only 0.2%. The calibration results show that there is a linear relationship between the load value and the output voltage signal value of the tensile transducer.

Table 1

Calibration results

Universal tester load	System measured voltage	The system measures the load	Error
[N]	[V]	[N]	[%]
100	0.361	100.13	0.13
300	1.040	300.62	0.2
600	2.019	600.37	0.061
900	3.038	900.14	0.015
1200	4.088	1200.26	0.021
1500	5.106	1498.78	-0.081
1800	6.230	1801.9	0.1
2100	7.184	2097.45	-0.12
2400	8.234	2398.64	-0.056
2800	9.598	2800.79	0.028

Determination of coefficient of friction

Measurement program

In order to determine the friction coefficient between different splints and the skin of cotton stalks, the BM-V computerized pendulum friction coefficient tester was selected to carry out the determination of the friction coefficient between different types of splints and cotton stalks, in order to obtain the accurate friction coefficients between the two, and to provide an accurate and relevant theoretical basis for the later tests.

Measurement results

The measured contact points between the cleat and the cotton stalks were measured five times (*Zhu Y.Y. et al, 2018*) and the measured pendulum values were recorded and the results are shown in Table 2.

Table 2

Measurement results

Number of tests	The determined friction coefficient value between rigid clamp and cotton stalk	The determined friction coefficient value between rubber splint and cotton stalk
1	29.9	107.2
2	30.7	107.8
3	32.1	101.7
4	28.5	106.5
5	27.3	107.5

The formula for the coefficient of friction from the pendulum tester:

$$\mu = \frac{1}{5}\sum_{i=1}^{5} X_i \frac{1}{100} \tag{7}$$

Where:

μ - measurement of coefficient of friction;

X_i - determination of pendulum value.

Substituting the five pendulum values of different types of splint tests into Equation (7), the friction coefficients between rigid splints, rubber splints, and cotton stalks were obtained as μ_1=0.297, μ_2=1.06, and for the convenience of post-test data processing, the rounded counting retention method was used so that the measured friction coefficients were retained to the second two decimal places so that μ_1=0.3, μ_2=1.06.

Experimental conditions and program design

Test condition

On March 13, 2023, tests on mechanical and displacement data collection of cotton stalks were conducted in the Polar Fly Super Cotton Field in Yuli County, Korla City, Xinjiang. The cotton field was in a post-winter irrigation condition with loose geology and a soil moisture content of 6.5%. The soil firmness was 42 kg/cm2 as measured by a soil tester, the cotton variety was Xinluzhong 46, the average plant height of the cotton stalks was 750 mm, and the spacing between the stalks was 50 mm, and the pinch point was 100 mm above the ground surface. The diameter of the cotton stalks at the clamping point was 8~12 mm. To facilitate the clamping of the cotton stalks by the fixture, the main stem and lateral branches above 300 mm from the ground surface were removed to ensure that the fixture was not affected by the influence of the lateral branches, which would lead to wide-ranging errors when clamping the cotton stalks. The test site is shown in Figure 8.

a. Test sample

b. Operational state

Fig. 8 - Field test

Test design

In order to test the clamping and pulling effect of different material pattern splints on cotton stalks, clamping force, linear velocity and friction coefficient were selected to carry out a three-factor general factorial test program, and the pull-up force and clamping force reduction were taken as the test indexes. Through the measurement data, the change curves of the pulling force and clamping force are made, and the test data are analyzed by variance. The test factors and levels are shown in Table 3. The magnitude of the clamping force was based on the data after clamping and pulling of cotton stalks in the test chamber as a reference. Under the three linear velocities measured, there was no slippage of cotton stalks at clamping forces of 500 N and above for rigid splints and 300 N and above for rubber splints. The two types of cleats did not break the cotton stalks when they were clamped at a clamping force of 1000 N or less. In order to compare the effect of both types of clamping and pulling on cotton stalks, 500 N, 750 N and 1000 N were chosen as the influencing factors.

Table 3

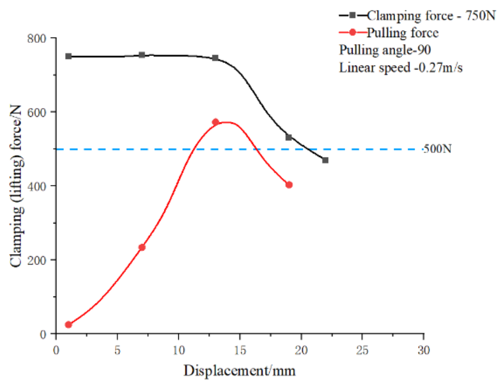
Test factors and levels

Levels	Clamping force A	Linear speed B	Friction coefficient C
	[N]	[m/s]	μ
-1	500	0.18	0.3
0	750	0.27	1.06
1	1000	0.36	

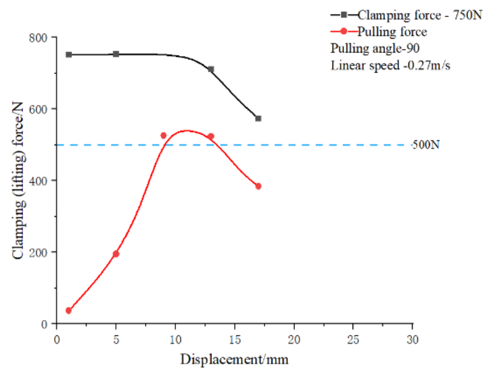
RESULTS AND ANALYSIS

Cotton stalk clamping force pull-up force variation curve

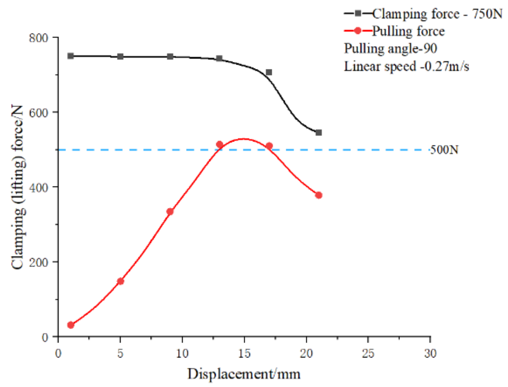
In the test, different materials and patterns of clamping plates were used to clamp the cotton stalks, and the perpendicular pulling angle, the same linear speed, and the equal clamping force were used as the variable control of the whole test. In this test, the clamping force and displacement-pulling force curves at a pulling speed of 0.27 m/s and a clamping force of 750 N were selected as the trends of the clamping force and pulling force in the whole test, as shown in Figure 9.



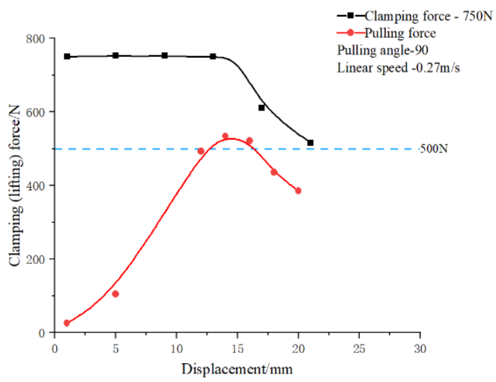
a. Rigid cleats



b. Striped rubber cleats



c. Dot rubber splints



d. Patterned rubber cleats

Fig. 9 - Clamping force, pulling force-displacement curve

The graph of clamping force, and displacement-pulling force is shown in Figure. 9, which illustrates the pulling force corresponding to the upward movement of the root of the cotton stalk by 12 mm, followed by a trend from peak to stabilization and then to zero point. At the peak of the pulling force, the clamping force tends to decrease.

Figure 9a illustrates the trends in clamping and pulling forces following the application of a rigid clamp to cotton stalks. The maximum pulling force reached approximately 500 N, at which point significant variations in the clamping force were observed, decreasing from an initial 750 N to around 400 N.

Figures 9b, 9c, and 9d depict the use of rubber clamps, differentiated by various rubber patterns as shown in Figure 10. Despite the consistent initial clamping force across these figures, variations in force are evident due to the different materials used. Specifically, Figure 9b shows the use of a striped rubber cleat; here, the trend in the graphic indicates that as the lifting force peaks, the clamping force slightly decreases from 750 N to approximately 550 N.

Figure 9c presents the polka dot rubber cleat, where the clamping force initially remains steady at 750 N. As the pulling force increases, leading to the maximum pulling force, a downward trend in clamping force is noted, correlating with the gradual uprooting of the cotton stalks, eventually stabilizing at around 510 N.

Lastly, Figure 9d utilizes a patterned rubber splint for clamping. Initially, when no pulling force is applied, the clamping force maintains a steady state of 750 N. With the progressive application of pulling force, a decrease in clamping force is observed, ultimately stabilizing at approximately 500 N as the stalks detach completely from the soil.

a. Stripes *b. Dots* *c. Pattern*

Fig. 10 - Rubber cleats

Significance analysis of test results

The results of the test were analyzed by a three-factor general factorial test using Design Expert 8.0.6 software, and the test protocol and results are shown in Table 4, and the ANOVA analysis was performed with the reduction of pull-up force and clamping force as the test indexes, and the results are shown in Table 5 and Table 6.

Table 4

Pilot program and results

NO	Clamping force A	Linear velocity B	Friction coefficient C	Pulling force	Clamping force reduction
	[N]	[m/s^{-1}]	μ	[N]	[N]
1	500	0.36	0.3	445.93	385.23
2	1000	0.27	0.3	513.43	494.67
3	1000	0.36	0.3	535.24	500.12
4	500	0.27	1.06	508.92	164.1
5	750	0.18	1.06	565.09	209.03
6	500	0.18	1.06	558.73	144.05
7	750	0.36	0.3	513.32	335.45
8	750	0.18	0.3	434.21	200.69
9	750	0.27	0.3	476.7	278.39
10	1000	0.18	1.06	563.63	263.61
11	750	0.36	1.06	535.29	282.72
12	750	0.27	1.06	491.34	238.33
13	1000	0.18	0.3	422.5	493.17
14	500	0.36	1.06	526.5	177.74
15	500	0.18	0.3	438.61	335
16	500	0.27	0.3	498.92	369.63
17	1000	0.27	1.06	494.27	302.74
18	1000	0.36	1.06	506	312.9

Table 5

Analysis of variance of pull-up force with three factors

Variance source	Sum of squares	Degree of freedom	Mean square	F value	P value
Model	29565.56	11	2687.78	4.65	0.0358
A	285.4	2	142.7	0.25	0.7886
B	695.34	2	347.67	0.6	1.06777
C	12319.79	1	12319.79	21.33	0.0036
AB	2056.68	4	514.17	0.89	1.06233
BC	14208.35	2	7104.18	12.3	0.0035
Residual	3465.2	6	577.53		
Cor Total	33030.76	17			

Table 6

Analysis of variance of clamping force reduction with three factors

Variance source	Sum of squares	Degree of freedom	Mean square	F value	P value
Model	2.22E+05	9	24626.2	26.32	< 0.0001
A	68392.2	2	34196.1	36.55	< 0.0001
B	5842.97	2	2921.48	3.12	0.0995
C	99931.32	1	99931.32	106.81	< 0.0001
AB	46944.17	2	23472.08	25.09	0.0004
BC	525.17	2	262.58	0.28	0.7624
Residual	7484.96	8	935.62		
Cor Total	2.29E+05	17			

The magnitude of the P-value in Tables 5 and 6 is the degree of influence of each parameter on the desired reflection of the test indicator, which is significant at $P < 0.05$, and on the contrary, the degree of influence is not significant. Tables 5 and 6 reflect the degree of influence of the three factors on the measured test metrics. From Table 5, it can be seen that each of the three factors has a different degree of influence on pull-up force, with the more significant effect on pull-up force being the interaction of BC. The degree of influence of the remaining factors was not significant at $P > 0.05$. Table 6 shows the ANOVA of the clamping force reduction, where $P < 0.05$ is the interaction effect of A, C, and AC, respectively, in which A and C showed a highly significant effect on the clamping force reduction. The results in Tables 5 and 6 show that in the test of whole plant uprooting of cotton stalks, A, B, and C played different degrees of influence on the reflected test indexes, with C showing a highly significant degree of influence on both test indexes.

CONCLUSIONS

(1) A cotton straw clamping and pulling test bench based on Gx Works2 and LabVIEW programming software was designed to realize the control of the power unit and pulling device of the test bench, and to collect real-time information about the force and upward displacement of the cotton straw in the process of clamping and pulling.

(2) Through the data measured after pulling the cotton stalks, it can be seen that the cotton root upward displacement of 12 mm corresponds to the maximum plucking force on cotton stalks in the average value of 500 N, and did not appear too much fluctuation. During the process of clamping and pulling the cotton stalks, the clamping force on the cotton stalks changes. Among the three linear speeds, the rigid clamp plate exhibits the optimal clamping and pulling effect on the cotton stalks at a clamping force of 750N and a linear speed of 0.18m/s, with the clamping force ultimately maintained at 500N or above. Rubber clamping had the best effect on cotton stalk clamping and pulling at a clamping force of 500 N at a linear velocity of 0.36 m/s. Under the same factors, the striped rubber clamp was superior to the remaining two patterned rubber clamps.

(3) The analysis of variance (ANOVA) of the measured test parameters showed the following conclusions at the test criterion of $P < 0.05$. In the ANOVA table of the pulling force, the significantly higher effect was the interaction of linear velocity with the coefficient of friction of the cleat with a P-value of 0.0035. In the ANOVA table of the reduction of the clamping force, it can be concluded from it that the interaction of the clamping force with the coefficient of friction at the value of $P < 0.0001$ is highly

significant. In the ANOVA table for both, it can be concluded that the coefficient of friction is the primary consideration for the clamping type of cotton stalk harvesting machinery in conducting the cotton stalk pair clamping and uprooting test for the clamping tools of the plywood type.

(4) The data were analyzed by clamping and pulling cotton stalk measurements. The maximum pulling force corresponding to the upward displacement of the cotton root was obtained. The optimal combination of different types of splints for cotton stalk clamping and pulling was obtained. By comparing the data of the same type of splint, the best pattern splint can be obtained. The measured data were analyzed by ANOVA to get the main influencing factors on the test indexes.

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REFERENCES

[1] Chen J.L., Cao S.L., Lu Y.T., et al., (2018), Current status and future prospects analysis of cotton stalk harvesting equipment. *Xinjiang Agricultural Mechanization*, issue 02, pp. 11-14;

[2] Fire H.X., (2021), Comprehensive Utilization of Crop Straw under the Perspective of Circular Economy. *Shanxi Agricultural Economy*, issue 14, pp. 137-138;

[3] Gao R.F., Zhang J.S., et al., (2016) Research on the development and utilization of cotton straw forage in Xinjiang. *Chinese Journal of Animal Husbandry*, vol. 52, issue 08, pp 76-80;

[4] Guo T.J., Zhang Z.J., Zhao J., et al., (2018), Analysis of the effect of steam explosion fermented cotton stalks on feeding sheep. *Transactions of the Chinese Society of Agricultural Engineering*, vol. 34, issue 07, pp. 288-293;

[5] Jian S.C., Ma J.C., Wang X.Y., et al., (2011), Research on the measurement device for cotton stalk extraction force. *Agricultural Equipment and Vehicle Engineering*, issue 06, pp. 4-6;

[6] Li Y., Zhang G.Z., Zhou Y., et al., (2013), Design and test of cotton stalk field lifting force measurement system. *Journal of Agricultural Engineering*, vol. 29, issue 18, pp. 43-50;

[7] Liu X., Sun S.L., Xiao M.T., et al., (2017), Design and experiment of a flexible clamping and pulling device for rice bowl seedlings. *Journal of Hunan Agricultural University* (Natural Science Edition), vol. 43, issue 03, pp. 324-328;

[8] Ren M.H., HOU S.X., QUAN S.P., et al., (2018), Spring fatigue testing machine loaded by servo-electric cylinder. *Engineering and Testing*, vol. 58, issue 04, pp. 87-89;

[9] Song X.S., Lei Y.F., Fu F., (2013), Preparation process and test of cotton stalk reconstituted square timber. *Journal of Agricultural Machinery*, vol. 44, issue 05, pp. 164-168;

[10] Tang Z.F., Wang H.J., Deng J.M., et al., (2018) Clamping Experiment and Simulation for High Quality String Fruit Picking. *Mechanical Design*, vol. 35, issue 11, pp. 47-52;

[11] Wang Y.J., Zhang P., Ju C.H., et al., (2022), Current situation and strategies for the recycling of cotton stalks in Xinjiang. *Cotton Science*, vol. 44, issue 06, pp. 44-49;

[12] Xie J.H., Wu S.H., Cao S.L., et al., (2023), Design and experimental study of the gripping roller-type cotton stalk pulling device. *Transactions of the Chinese Society for Agricultural Machinery*, vol. 54, issue 05, pp. 101-111;

[13] Zhang W.Z., (2015), Research on the development of China's agro-ecologization based on super-circular economy. *Hubei Social Science*, issue 11, pp. 97-101;

[14] Zhao B., Sun S.L., Wang S., et al., (2010), Research on calibration method of sensor static characteristics based on LabVIEW. *Journal of Qinghai University* (Natural Science Edition), vol. 28, issue 06, pp. 24-27;

[15] Zhou S.P, Liu Q.T, Yang D.T. et al., (2019), Design and test of vertical clamping conveyor channel leaf stripping device for sugarcane. *Journal of South China Agricultural University*, vol. 40, issue 03, pp. 117-124;

[16] Zhu Y.Y., Tang B., Chen W.H., et al., (2018) Evaluation of Uncertainty in Indication Error of Pendulum Friction Coefficient Tester. *Metrology and Testing Technology*, vol. 45, issue 06, pp. 113-114+117.

[17] ***Announcement of National Bureau of Statistics on Cotton Production in 2022, (2022). *China Information Daily.*