Improved design and test of flexible cotton stalks puller

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Abstract: In Xinjiang, in the process of whole stalk harvesting of cotton stalks, there is a problem that the cotton stalks are easily pulled off, and there is an urgent need to develop flexible stalk-pulling machines. Through literature, patent summary, and field research, it is found that domestic researchers have designed many kinds of machines for the problem of easy breaking of cotton stalks, but there is no flexible cotton stalk-pulling machine for the time being. In this study, two flexible cotton stalk-pulling machines were intended to address the problem of easy breakage of cotton stalks. On the basis of the first-generation machine, the design of the second-generation machine was improved. In order to further improve the operational performance of the flexible cotton stalks pulling tools, the operational mechanism of the core working parts of the tools was analyzed and a comparative test was done in a large field. Analysis and the comparative tests proved that improving the clamping working stroke s of the stalk-pulling components can effectively reduce the cotton stalks leakage rate. By using a flexible clamping process, a part of the deformation of cotton stalks can be transferred to the flexible material. To a certain extent, the deformation length L of the contact surface between the cotton stalk and the stalk pulling part is reduced, and the deformation displacement Δy is correspondingly lower. The toughness of the cotton stalk is not significantly decreased and the cotton stalk does not break easily. The improved second-generation machine has a 3.67% to 3.79% lower cotton stalks leakage rate and a 5.65% to 6.30% lower cotton stalks breakage rate than the first-generation machine. As the land in Xinjiang is clay soil, soil bonding to cotton stalks pulling force F_2 is larger, resulting in cotton stalks being more difficult to be pulled out of the machine at once. The test proved that the improved second-generation implements had a significant improvement in the cotton stalk-pulling effect because of the subsequent pulling interval CD. The test results verify the analysis results and the research results can provide a theoretical basis for the subsequent structural improvement and performance enhancement of the flexible cotton stalk-pulling machine, which is of reference significance for solving the problem that the cotton stalks are easily pulled and broken in Xinjiang, China.

Keywords: agricultural machinery, flexible material, optimized design, verification test, cotton stalks puller
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1 Introduction

In order to promote the resource utilization of cotton stalks in Xinjiang and reduce the stalks pulling breakage rate, there is an urgent need to study the flexible whole stalk pulling and harvesting technology of cotton stalks. Cotton stalks can be used to produce livestock feed, fiber products, industrial packaging paper, etc., which is an important renewable resource[1,2]. In 2020, the cotton stalks production in China is 2250-3750 kg/hm^2[3]. The annual production of cotton stalks in Xinjiang can reach 7×10^9 kg[4]. Whole stalk harvesting of cotton stalks can bring huge economic benefits[5]. The complete ban on solid waste imports in China from 2021 has led to a shortage of raw material supply for the paper industry, which has intensified the demand for cotton stalks in the paper industry[6]. Whole stalk harvesting of cotton stalks can alleviate the shortage of raw materials for the paper industry and is a major mechanical solution to the bollworm problem[7, 8]. There is no cotton stalks flexible whole stalk pulling harvester in Xinjiang. The study of flexible whole stalk pulling harvesting technology for cotton stalks is of great significance for ecological protection and economic development in Xinjiang.

Due to the short development time of cotton stalks pulling harvesting machines, there is no cotton stalks pulling technology suitable for wide and narrow row planting patterns in Xinjiang[9,10]. The main problem of cotton stalks' whole stalk harvesting is the high rate of cotton stalks pulling off. Regarding the design of cotton stalks and whole stalk harvesting machines, scholars at home and abroad have achieved some results.

Kemp et al.[11,12] designed a tire-to-roller device for uprooting cotton stalks to facilitate disease control. Ramadan[13] chose two cleat cylinders as the method of stalk pulling, which were placed on a main chassis. Gadir et al.[14] designed the cotton stalks puller, which consists of a series of disc blades mounted on a frame. Tang et al.[15] designed cotton stalks plucking harvester using the principle of the pushing and pulling action of the tooth knife. Chen et al.[16] using the principle of the tine disc clamping method has studied the process of cotton stalks lifting and designed the tine disc puller device. At present, there is a lack of theoretical analysis of the movement process and mechanism of the flexible whole-stalk harvesting mechanism of cotton stalks. Flexible cotton stalks plucking technology needs to be studied in depth urgently[17-20].

In view of the soil conditions of cotton fields in Xinjiang,

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combined with the wide and narrow row planting pattern of machine-picked cotton, this study proposes the idea of flexible cotton stalks pulling machine. Due to the shortcomings of high cotton stalks pulling breakage rate and large leakage rate during the use of the first generation prototype machine, the key components were optimized and improved. Through the analysis of the process of pulling cotton stalks from key components, the purpose is to improve the performance of machine harvesting cotton stalks and provide a theoretical basis for future research.

2 Materials and methods

2.1 Experimental site

A pilot study of a cotton stalks puller was conducted in Yuli County, Xinjiang, China (86°16′41.6″E, 41°21′8.9″N). Soil texture was homogeneous and clay loam. In order to facilitate cotton harvesting by cotton pickers, most areas in Xinjiang use a pattern of wide and narrow rows to grow cotton, with a spacing of 660 mm for wide rows and 100 mm for narrow rows, as shown in Figure 1. The cotton roots were about 165 mm deep in the ground and covered with a layer of mulch of 0.1 mm thickness.

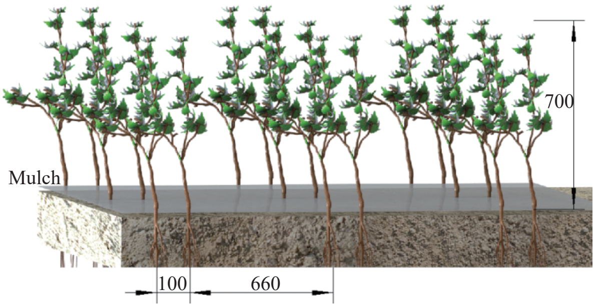


Figure 1 Diagram of cotton planting pattern (mm)

2.2 Machine specifications

A tractor-operated model of cotton stalks flexible puller was designed by Xinjiang Agricultural University. A total of two generations of machines were developed. Table 1 lists the operating parameters of the two machines.

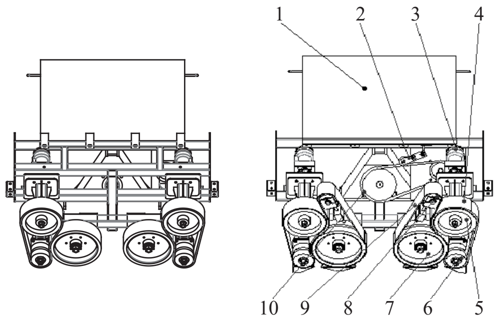
Table 1 Working parameters of cotton stalks pulling machine

Items	Operating parameters of the first-generation prototype	Operating parameters of the second-generation prototype
Machine size/mm	1232×992×1350	1232×992×1350
Operating width/mm	1021	1021
Driving form	Hydraulic drive	Hydraulic drive
Hanging and connection form	Three-point hitch	Three-point hitch
Number of the working row	4	4
Cotton stalks breaking rate	≤15%	≤10%
Cotton stalks leakage rate	≤15%	≤10%

2.3 Description of machine components

There were two generations of machines in total. Both the first and second-generation machines were connected to the tractor through a three-point hitch. Both machines consisted of three components, namely the hydraulic system, the drive system, and the flexible stalks puller, as shown in Figure 2. This study focuses on improving the components for pulling cotton stalks.

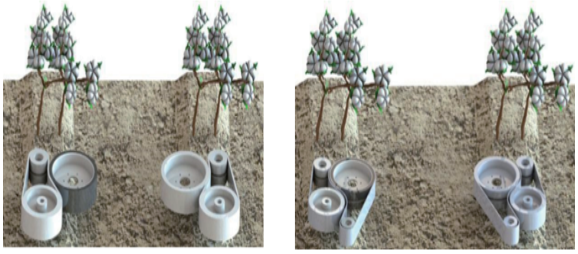
The main difference between the two generations of machines was the stalks puller, as shown in Figure 3. The stalks puller of the first-generation machine consisted of one belt and one wheel. The cotton stalks were pulled out by clamping them with a belt and a wheel. To extend the machine stalk pulling time and improve harvesting results, the second generation machine has a stalks puller consisting of two belts. The cotton stalks were pulled out with a belt and belt clamping. The width and thickness of the belt were 96 mm and 11 mm respectively. The stalks puller could pull 4 rows of stalks at a time. The stalks puller forms an angle with the ground and clamps and pulls the stalks from 50 mm above the ground. The height of the stalks puller could be adjusted according to the terrain.



a.First generation prototype b. Second generation prototype

1. Hydraulic oil tank 2. Tensioner 3. Gear pump 4,9. Flexible belts 5-8. Wheels 10. Chain

Figure 2 Cotton stalks flexible pulling machine



a. First generation prototype b. Second generation prototype

Figure 3 Flexible cotton stalks puller

2.4 Soil and crop measurements

Field soil compaction test: Ten sites were randomly searched from the field to determine soil compaction. The instruments used were TJSD-750-Ⅱ digital display soil compaction tester and QS-WT type soil moisture tester. The average compactness of the soil was 3 MPa at a soil depth of 100 mm, 3.8 MPa at a soil depth of 150 mm, and 4.5 MPa at a soil depth of 200 mm. The field soil moisture content was 15%-20% at a soil depth of 50 mm.

The mean values of cotton stalk height and root length were 700 mm and 200 mm, respectively. The mean value of the cross-sectional diameter of the part where the cotton stalks were clamped was 15 mm. The average spacing between the front and back of the stalks was 100 mm, the average spacing between the left and right side rows was 660 mm, and the average spacing between the left and right narrow rows was 100 mm. The mean cotton planting density was 30 plants/m^2.

2.5 Experimental setup

To verify that the harvesting performance of the second-generation machine was improved over the first-generation machine, the two machines were subjected to comparative experiments in the field. Refer to GB/T 8097-2008 “Harvesting Machinery-Combine Harvester Test Methods” for testing. Preparation for the field trial: Adjust the working width of the machine according to the spacing of the cotton stalks. The forward speed of the tractor was set to 2.5 km/h, the angle formed between the culm pulling part and the ground was set to 40°, and the speed of the main wheel was set to 300 r/min. In order to reduce the error, a distance of 15 m in length needs to be reserved to stabilize the tractor and the culm pulling components before the machine officially enters the test area. The overall length of the test was set to 75 m and the width was set to 1 m, with 1 testing area every 15 m length, for a total of 5 testing areas, as shown in Figure 4. The model of the tractor used is Changfa CFG1204-B with 120 horsepower.

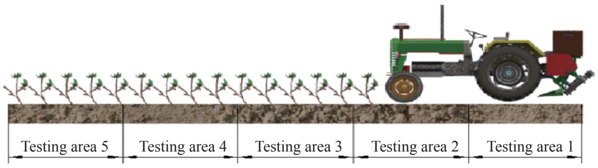


Figure 4 Testing area diagram

2.6 Harvesting performance

The cotton stalks leakage rate S_1 and breakage rate S_2 are used as the main indicators to evaluate the harvesting performance of the machine, as shown in equation 1.

$$\begin{cases} S_1 = \dfrac{Z_1}{Z} \times 100\% \\ S_2 = \dfrac{Z_2}{Z} \times 100\% \end{cases} \tag{1}$$

where, Z_1 is the number of cotton stalks leakage in the unit area; Z_2 is the number of cotton stalks breakage in unit area; Z is the total number of cotton stalks in the unit area.

After the machine is harvested, the number of leakage plucks and the number of breakage of the cotton stalks in the testing area are registered. Five tests were conducted for each machine, and the test data of each testing area were recorded and averaged. After the field comparison test, the harvesting performance indexes of the two machines are listed in Tables 2 and 3.

Table 2 Leakage rate test results

Model	Leakage rate of each testing area S_1/%					Average value S_1/%
	1	2	3	4	5	
First generation prototype	12.73	11.54	12.0	10.43	13.99	12.14
Second generation prototype	9.70	7.39	6.64	8.29	9.83	8.37

Table 3 Breakage rate test results

Model	Breakage rate of each testing area S_2/%					Average value S_2/%
	1	2	3	4	5	
First generation prototype	17.56	12.74	11.75	14.48	16.79	14.66
Second generation prototype	11.27	9.28	7.28	6.15	10.58	8.85

3 Results and discussion

3.1 Machine performance under unleveled cotton field conditions

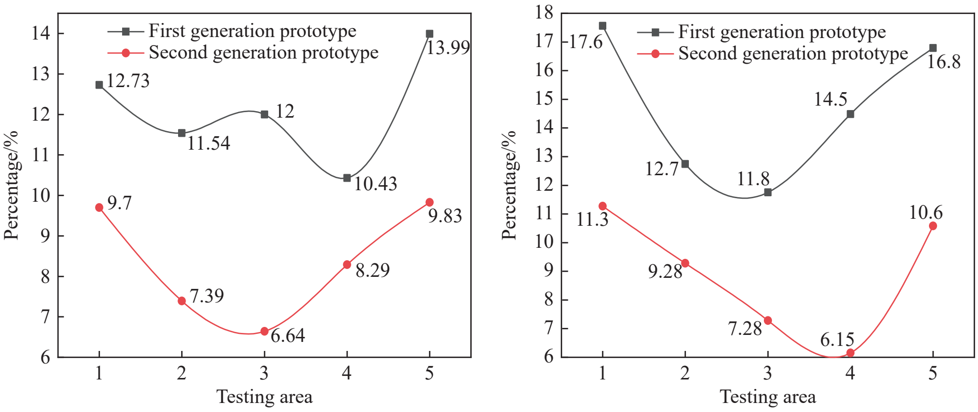
As shown in Figure 5, the stalk pulling effect of the 2nd generation prototype was better than that of the 1st generation prototype. The improved flexible cotton stalks plucker is stable and reliable in operation and can complete its work smoothly. In the second generation prototype site, the cotton stalks breaking phenomenon was less and the harvesting efficiency was higher.


a. First generation prototype b. Second generation prototype

Figure 5 The test site

As shown in Figure 5, the stalk-pulling effect of the 2nd generation prototype was better than that of the 1st generation prototype. The improved flexible stalks puller was stable and reliable in operation and could complete the cotton picking work smoothly. In the second generation prototype site, the cotton stalks breaking phenomenon was less and the harvesting efficiency was higher.

The pulling performance of the first-generation prototype was low, with the leakage rate ranging from 10.43% to 13.5% and the breakage rate ranging from 11.80% to 17.6%. The improved 2nd generation prototype has a very substantial improvement in stalks pulling performance. As shown in Figure 6, the leakage plucking rate can be reduced to between 6.64% and 9.83%, and the plucking breakage rate can be reduced to between 6.15% and 11.30%. The improved second-generation prototype did not have stalk clogging phenomenon, and the stalk clamping belt could effectively grab the stalks and throw them so that the whole stalk root stubble was separated from the soil and laid on the ground.



a. Percentage of leakage rate b. Percentage of breakage rate

Figure 6 Machine performance in uneven cotton field conditions

3.2 Working process of stalk pulling parts

The cotton stalks harvesting components of both the 1st generation prototype and the 2nd generation prototype were clamping and pulling components. The 1st generation prototype clamps and throws the cotton stalks by means of belts and wheels. As shown in Figure 7a, when the stalks enter the stalk pulling part, the wheels and belts clamp, pull and throw them.

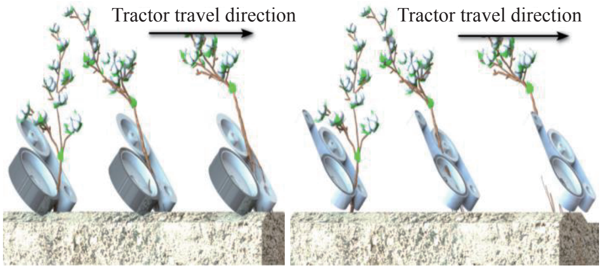


Figure 7 Working process of stalk pulling parts

The 2nd generation prototype could realize the secondary pulling of cotton stalks by cross placement between belts and belts to achieve flexible belt clamping of cotton stalks and complete curved continuous harvesting. As shown in Figure 7b, the four pulleys were staggered and the flexible belt was in an “S” shape to pull the cotton stalks. The belts were rolled relative to each other. The cotton stalks are pulled out under the friction of the belt and thrown to the side and rear of the ground in the forward direction of the machine to complete the harvesting operation.

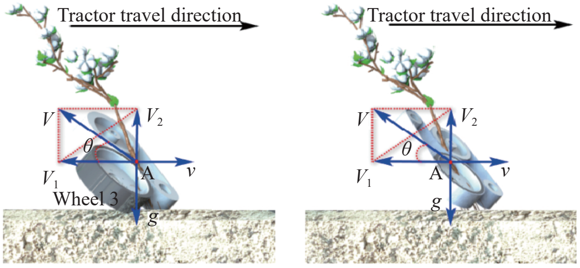
3.3 Leakage analysis

From the comparison experiment, it can be found that the reasons for the stalks leakage are the following 3 points: on the one hand, due to the stalks being scattered by the sheep gnawing and trampling after the cotton picking, the stalks are more difficult for the divider to collect the stalks, resulting in leakage. On the one hand, the stalks were pulled by the stalk-pulling mechanism with insufficient force and slippage, which led to leakage. On the other hand, the stalks pulling mechanism did not have enough pulling time and the cotton stalks were not pulled out, which led to missed pulling. In order to study the reasons for the missed stalks by the stalk-pulling parts, two generations of stalk-pulling prototypes were designed and analyzed in comparative experiments.

3.3.1 Pulling direction analysis

The direction in which the cotton stalks are pulled and thrown has a great influence on the analysis of missed pulling and pulling off, so this study analyzes the force state at the moment the cotton stalks are pulled out. The aim is to analyze the pulling and throwing direction of the cotton stalks. Since the gravity of the cotton stalk themselves has little effect on the pulling motion of the machine, the effect of gravitational acceleration g is not considered in the analysis of the cotton stalk pulling and throwing direction.

The tractor drives the flexible stalk pulling component to work forward, and the cotton stalks are held, pulled, and thrown by the flexible belt under the action of the grain splitter. As shown in Figure 8, the pulling motion is a combination of the forward motion of the part and the clamping motion of the flexible part. There will be two situations: one is that the forward speed is greater than the horizontal part speed of the clamping part, and the stalks will have the tendency to be pulled and thrown forward because of being clamped; one is that the forward speed is less than the horizontal part speed of the clamping part, and the stalks will have the tendency to be pulled and thrown backward because of being clamped. The moment when the cotton rod is pulled out is selected and the force analysis is performed on point A.



a. First generation prototype b. Second generation prototype

Figure 8 Diagram of cotton stalks throwing process

It is known that the speed n of the active wheel 3 is 300 r/min, the radius of motion of the active wheel 3 at point A is 160 mm, and the angle between the cotton stalks pulling part and the ground is 40°, by Equation (2).

$$\begin{cases} V = \dfrac{2\times 60\pi rn}{10^6} \\ V_1 = V\cos\theta \end{cases} \tag{2}$$

where, V is the clamping instantaneous motion speed, km/h; V_1 is the clamping belt horizontal subspeed, km/h; r is the radius of motion of active wheel 3 at point A, mm.

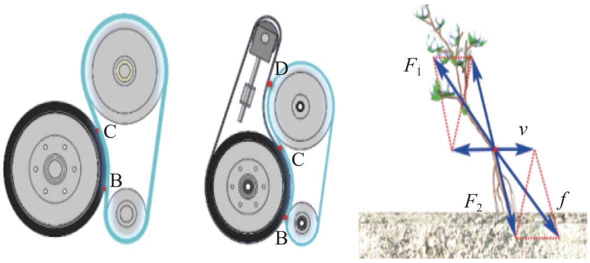
The horizontal component speed V_1 of the clamping part is 13.86 km/h. Since the forward speed is 2.5 km/h, it is known that the horizontal component speed of the clamping part is greater than the forward speed. The second scenario discussed holds, the stalks will be clamped and have a tendency to be pulled and thrown backward.

3.3.2 Analysis of the reasons for the decrease in the leakage rate of extraction

The improved second-generation prototype showed a reduction of 3.67% to 3.79% in the leakage rate compared with the first-generation prototype. In order to find out the main reason for the reduction of the leakage rate, the process of stalk pulling by the stalk pulling part was analyzed. As shown in Figure 9, when the stalks enter the interval BC, the stalks are subjected to a centripetal combined force F that causes them to move in a curve around the center of the circle of the main wheel 3, and treating the stalks as masses, there is

$$F = \frac{mV^2}{r} \tag{3}$$

where, F is the combined centripetal force of the cotton stalks by wheel 2 and wheel 3, N; m is the mass of cotton stalks, kg.



a. 1st generation prototype b. 2nd generation prototype c. Cotton stalk force diagram

Figure 9 Diagram of clamping interval of the stalk pulling parts

The stalk pulling component relies on the frictional force of the stalk pulling component on the stalk for pulling operation, which is discussed in two cases.

One is that the contact surface between the clamping belt and the stalk slips during the pulling process, at which time the stalk is subject to dynamic friction.

The other is that the clamping belt can pull out the stalks smoothly, that is, no slippage when the stalks are subject to static friction.

Since the magnitude of the static friction force F_1 is variable, determined by the fraction f of the soil bond to the stalk pulling force F_2, this study explores the maximum static friction force $f_{\max}$ on the stalk. If the pulling fraction f is greater than the maximum static friction force, the first situation will occur, slipping; in order to make the stalk can be pulled out smoothly, it is necessary to ensure that the maximum static friction force is greater than the pulling f. From the formula of the maximum static friction force, the following equation can be found:

$$f_{\max} = \mu F \tag{4}$$

where, μ is the coefficient of friction.

Substituting Equation (3) and into Equation (4) gives

$$f_{\max} = \mu\sqrt{\left(\frac{mV^2}{r}\right)^2 + 4F} \tag{5}$$

Speed equation:

$$V = \frac{s}{t} \tag{6}$$

where, s is the length of interval BC, mm; t is the time required for the cotton stalk to travel through the interval BC, min.

Substituting Equation (6) into Equation (5), then,

$$f_{\max} = \mu\sqrt{\left(\frac{ms^2}{rt^2}\right)^2 + 4F} \tag{7}$$

As can be seen from Equation (7), the time t required for the cotton stalk to travel through the interval BC affects both the maximum static friction and the pulling effect. A shorter time t can increase the maximum static friction, but it may appear that the cotton stalk has left point C, but the roots have not been completely pulled out, resulting in missed pulling; too large a time t makes the maximum static friction correspondingly lower, and it is easy to slip and thus missed pulling.

Let the time required for the cotton stalk to travel through the working stroke from point B to point C be t; the time required for the stalk pulling component to travel one stalk plant distance is T, and the time required for the stalks to be pulled out of the ground is T_1. At this point, two scenarios are discussed.

If time $t<T_1$: i.e. the cotton stalk is out of the grip of the stalk pulling part before it is pulled out of the ground. Since the working stroke s is certain, the time t required for the cotton stalk to travel through the interval BC should be set to a lower value to avoid missed plucking. Alternatively, increasing the working stroke s can reduce the missed plucking rate, which explains the relatively low missed plucking rate of the improved second generation prototype.

If time $t \geq T_1$, there are two cases to discuss.

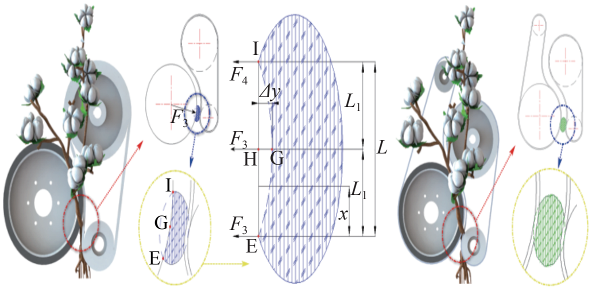
If time $T \geq T_1$, i.e., the stalk pulling component pulls out a cotton stalk and then pulls the second one, the maximum static friction force $f_{\max}$ at this time only needs to be greater than the pulling partition force f. The upper limit of the time t required for the stalk to travel through the interval BC can be determined.

If the time $T<T_1$, that is, the stalk pulling component needs to pull multiple stalks at the same time because the stalk spacing is a fixed value, the current time T is too short, there will be a pulling interval to start pulling multiple stalks, at this time the soil bonding to the cotton stalk pulling force f is much larger than the maximum static friction $f_{\max}$, leading to congestion and stalk leakage; if the time T is too long, it will lead to low efficiency of machine operation.

To summarise, increasing the maximum friction force while maximizing the working stroke s can effectively reduce the leakage plucking rate. As shown in Figure 9b, the improved second-generation prototype machine has increased the working stroke interval CD, which has been proven to be able to reduce the missed plucking rate and alleviate the problem of stalk congestion through tests. At the same time, the improved second-generation prototype has significantly improved the stalk pulling effect because of the second pulling interval CD.

3.4 Breakage analysis

The improved second-generation prototype had a 5.65%-6.30% lower pulling rate than the first-generation prototype. In order to find out the main reason for the reduction in the plucking rate, the deformation of the cotton stalk during the plucking process was analyzed. The interval of EGI for the deformation of the cotton stalk was selected for the analysis. Figure 10 shows a schematic diagram of the local forces on the cotton stalk subjected to deformation.



a. First generation prototype b. Second generation prototype

Figure 10 Diagram of local force on cotton stalk

The force of point G by the active wheel 3 is F_5; the reaction forces F_3 and F_4 of point E and point I are

$$F_3 = F_4 = \frac{F_5 L_1}{L} \tag{8}$$

where, L is the length of the line segment EHI, mm; L_1 is the length of line segment EH, mm; L_2 is the length of the line segment HI, mm.

The reaction force at point G can be found in the equilibrium equation,

$$F_h = \frac{F_5 L_2}{L} \tag{9}$$

Therefore, the cotton stalk bending moment is

$$M_x = \frac{F_5 L_2}{L}x - F_5(x - L_1)(L_1 \leq x \leq L_2) \tag{10}$$

where, x is the length of a segment of the line EHI, mm.

Both sides of the cotton stalk have the same bending moment, and the integration is performed for one section

$$EJ\frac{\mathrm{d}^2 y}{\mathrm{d}x^2} = \frac{F_5 L_2}{L}x \tag{11}$$

Since $x = L_1 = L_2$, the deflection Δy of the cotton stalk base section after being clamped is

$$\Delta y = \frac{F_5 L_2 L_1 L}{6EJ} \tag{12}$$

where, E is the modulus of elasticity, N/m^2; J is the rotational moment of inertia, kg/m^2.

If the deformation deflection Δy of the cotton stalk is too large, it is easy to break the stalk fiber layer and reduce the toughness of the cotton stalk. In the process of stalk pulling, it is easy to pull the cotton stalk, which leads to high pulling rate. From Equation (12), it is known that the deflection deflection Δy of cotton stalk is determined by the modulus of elasticity. Since the modulus of elasticity of cotton stalk is certain. In order to reduce the deformation deflection Δy, flexible materials can be used as much as possible. This will wrap the cotton stalk like a human hand and reduce the pulling rate. Since the stalk pulling part of the 1st generation prototype is composed of a rigid wheel and a flexible belt. This leads to excessive deflection of the cotton stalk Δy, resulting in a high pull-off rate. The stalk pulling part of the 2nd generation prototype uses a double flexible belt clamping. Part of the deformation of the stalks is transferred to the double flexible belt. Due to the deformation buffer of the clamping belt, the deformation length L of the contact surface between the stalk and the stalk pulling part is reduced by a certain amount, and the deformation deflection Δy is also reduced. Therefore, the toughness of the stalks does not change much and the stalk breakage rate is low. The test results also prove that the double flexible belt has a good effect on the reduction of the pulling rate.

3.5 Discussion

The limitation of the machine is the slower forward speed of the machine operation. The main reasons are the following 3 points.

1) The machine needs to work strictly on the row, if the operating speed is too fast, easy to lead to an increase in the rate of missed plucking.

2) After the machine picks cotton, due to the passage of the tractor, cotton stalks are four-way scattered state, more difficult to collect, increasing the difficulty of harvesting, and the operating speed cannot be improved.

3) The oil circuit in the hydraulic transmission system is connected in parallel, as long as one group of clamping belt is blocked, the belt clamping speed of this group will be reduced and the speed of another group of belt clamping will be increased. At this time, the machine needs a certain buffer time, the two groups of parts of the belt clamping speed to return to the initial state, so the operating speed is slow.

4 Conclusions

In view of the problems of missed plucking rate, excessive plucking rate, and stalk accumulation in the field performance test of the wheeled stalks puller, the improved design of the machine was carried out. In order to further improve the operational performance of the machine, the operational mechanism of its core working parts was analyzed and field tests were conducted. Through the mechanism analysis and comparative verification tests, the following conclusions were drawn.

1) This study improves on the basis of the wheel and belt stalk plucker and proposes a new stalk plucker: the stalk plucker with clamp. It reduces the leakage rate and plucking breakage rate. Improve the stalks pulling performance. It paves the way for the resource utilization of cotton stalks. It also facilitates the mechanical recovery of residual film.

2) The analysis and the test of two generations of prototypes prove that the maximum friction force is increased while the clamping working stroke s of the stalk pulling parts is maximized, which can effectively reduce the leakage rate and alleviate the problem of stalk congestion. The improved second-generation prototype reduced the leakage rate by 3.67%-3.79% compared with the first-generation prototype.

3) Since the land in Xinjiang is clay soil, the stalks are more difficult to be pulled out by the machine at one time due to the soil bonding to the cotton stalk pulling force F_2. The test proves that the improved second-generation prototype has significantly improved the stalk pulling effect because of the second pulling interval CD.

4) The analysis and the tests on the two generations of prototypes proved that using a flexible material to hold the pulling can transfer some of the deformation of the cotton stalks to the flexible material. The deformation length L of the contact surface between the cotton stalk and the stalk pulling part is reduced by a certain amount, and the deformation deflection Δy is also reduced. In this way, the toughness of the stalks does not become significantly smaller and the stalks are less likely to be pulled off. The improved second-generation prototype has a 5.65% to 6.30% lower pulling rate than the first-generation prototype.

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