Design and Optimization of the Collector of Electric Sugarcane Leaves Returning Field Machine

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Abstract. In this paper, the collector is designed for electric sugarcane leaves returning field machine. According to the working principles of the collector and the moving trace rules of collecting components, we confirm the important structural parameters of the collector by using the ADAMS software for motion simulation optimization, including the rotor radius, crank length, the locus curve in the center of cam disc slide and et al. The ADAMS software is used for simulating the movement of the collector with different combinations of two factors (the forward speed of machine and rotate speed of roller plate), and we can obtain the results about the angular acceleration at the end of collecting components and the leakage area per meter. The data obtained from the simulation test is analyzed by Central Composite Design (CCD) with the aim of assessing the best working parameter combination on low leakage rate. The best parameter combination of two variables are determine, i.e., the forward speed is v=0.4 m/s, and the rotate speed is ω=49.41 rpm. The sum area of leakage area is 26.95cm2/m, and the largest angular acceleration at the end of collecting components is 200 rad/s2. The collector based on the theoretical design results is produced, and it would be tested in the forward speed of v=0.4 m/s, and rotate speed of ω=50 rpm for analyzing its performance. The test results show that the collecting effect of the collector is well, and the leakage rate is 2.93 %, which can be up to the requirement of agricultural technical index. The collector can complete the collecting work of the sugarcane leaves returning field machine.

1. Introduction

Sugarcane is the main raw material of sugar in China, its planting yield is just less than Brazil and India, and it is mainly distributed in Guangdong, Guangxi, Yunnan, Hainan and other South places of China. The main by - product of it is its leaves, which have a large quantities of inorganic substances, so that they can be used to increase soil nutrients when returning them to the field. At present, there are many foreign developed countries adopt sugarcane combine harvesters, which harvest sugarcane while cut off the sugarcane leaves and returning them to field. The development of sugarcane harvesting machinery is still lagging in China. When the machine harvests sugarcane, at the same time, it can't cut sugarcane leaves, so that most of leaves are left in the field [1-6]. The treatment of sugarcane leaves is still dominated by incineration, which brings environmental pollution and fire safety. Our research on the sugarcane leaves returning field machines are still in the developing stage. Yueqian Jin designed the 3S-Y140 type sugarcane leaves returning field machine, which collected and cut the sugarcane leaves by means of high speed rotating knives, but the knives were easy to damage themselves and the perennial root; Ming Liang added spring - finger cylinder pickup for the sugarcane leaves returning field machine, which could collected the sugarcane leaves to a height and then the leaves would be brought to the cutting area by the flail knives; Ming Li designed a sugarcane leaves

returning field machine with profiling pick-up device, which could lift the leaves out the earth, so that the leaves could be brought into the cutting area by the flail knives; Yuxing Wang designed the flexible knives with nylon, which could cut the leaves in the field by the high - speed revolution of double knives roll, and the cutting effect was good but the flexible knives were easy to abrasion. The foreign collecting machines have been mature basically, and they mainly engage in the development of the machine performance and increasing the technological content [7-10]. While in China, most of our returning field machines are large - scale machines, mainly based on the tractors, which consume more energies. The machines have higher requirements on the height and width of field ridge, and will compact the soil and damage the perennial root. Besides, the high - speed rotating knives will cut the stones in the soil and the perennial root easily. In addition, there are mainly hilly lands in the south China, where the adapTableility of machine is poor. Thus, it is not suitable to push the development of large - scale returning machines. This returning field mode is not conducive to the sustainable development of sugarcane cultivation [11].

Therefore, it is necessary to design such a small - scale electric sugarcane leaves returning field machine. Its advantage lies in light volume and weight, low power consumption, and it can be controlled remotely and has low damage to perennial root. The workflow of the whole machine is to pick up the leaves by means of collector, and then the leaves will be delivered to the working area by brush roller for cutting and returning field. Sugarcane leaves are picked up by pickers, and then is cut by knives, so that knives will not cut the stones in the soil and the perennial root. The collector is a critical part of the sugarcane leaves returning field machine, which has connection with the effect of collecting and the framework of the whole machine. In order to study the principles of structure and motion, in this research, we use the ADAMS software to make motion simulation on the collector, so that it can confirm the key structural parameters of the collector. The Central Composite Design (CCD) is used to analyze the influence of motion parameters with the aim of assessing the best motion parameters combination on low leakage rate.

2. Structure and Working Principles of the Collector

The collector is composed by cam disc, roller, crank, roller plate, power shaft, collecting components, clamping rings, carbon fiber bar, and fender apron, which can be seen in the Figure1. The motor drives the power shaft to rotate through the chain drive and the roller plates connected with the power shaft will also rotate together. The two ends of the four carbon fiber rods are connected to the two roller plates by means of bearings. The clamping rings are isometric distributed in the carbon fiber rods, and the collecting components are fixed at the clamping rings. Besides, the one side of the carbon fiber rods are fixed with cranks and the other end of the cranks are fitted with rollers which can move along the cam disc slot. The fender aprons cover the whole machine; so that the collecting components push sugarcane leaves along the surface of them with the leaves can't be involved inside.

The collecting components can pick up the sugarcane leaves leaved spreading on the field and achieve the complex motion, which requires three movements to be compounded including the forward moving of the machine, rotation of the roller plates and the swing of the collecting components. (1) The forward moving: the forward power of the whole machine is provided by the two back driving wheels; (2) Rotation of the roller plates: the power shaft drives the roller plates to rotate, thereby the four carbon fiber rods mounted on the roller plate can rotate around the power shaft. The collecting components distributed on the carbon fiber rods evenly also can rotate around the power shaft; (3) Swing of the collecting components: the carbon fiber rods and cranks are connected fixedly, and the cranks drive the rollers to move along the slot of the cam disc. The irregular motion of the rollers is fed back to the carbon fiber rods through the cranks. Because the carbon fiber rods are in articulated connection with the roller plates, they can be repeatedly rotated by the influence of the rollers. Thus, the collecting components can swing repeatedly. By means of the complicated move, the cycle of the move of collecting components can have four different stations, which are picking up, lifting, pushing and returning. In order to keep ordered operation of the cycle of the four stations, it should be controlled by the critical component cam disc, so that it is necessary to have parameter design and simulation assistance analysis on the slide curve of cam disc [12-15]. Cam disc can be regarded as a "reverse swinging follower disc cam mechanism" [16]. The designed cam disc slide

central trajectory is composed by three sections of arcs and one straight line, which can be seen in Figure 2.
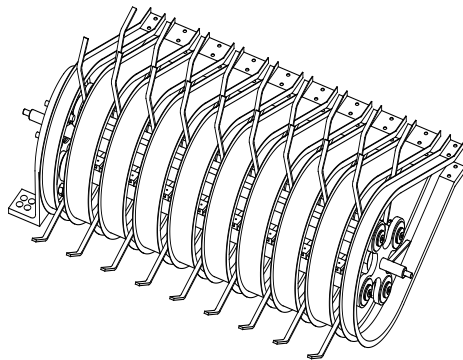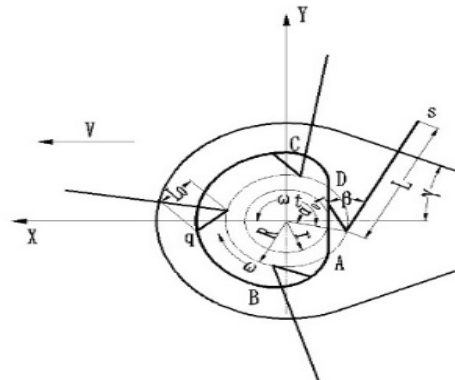

Figure1. Schematic Diagram of the Collector   **Figure 2.** Motion Analysis of the Collector

In one work cycle, when the rollers comes to the AB segmental arc of cam disc slide central trajectory, the collecting components stretch out from the fender apron quickly, and pick up the leaves on the ground. Because of the flexible features of the sugarcane leaves, they are easy to be attached on the collecting components. The radius of AB segmental arc should not be too small, in case that there a big impact force to the rollers, which will reduce the service life of the rollers. BC segmental arc is the lifting stage of the sugarcane leaves. In order to keep the smooth movement of the sugarcane leaves, the collecting components should not swing, so the BC segmental arc should share the same center with the roller plate. When the rollers move to the point C, the collecting components should keep a vertical mode with the fender apron. The movement of rollers from point C to point D is the pushing stage of the sugarcane leaves; the collecting components push the leaves to the brush roller area along the surface of the fender apron. The reason for this design is the leaves can avoid to be brought into the fender aprons by the collecting components. DA line segment is the returning stage, and the collecting components can hide in the fender apron for the next work of collecting [19-20].

3. Mathematical Modelling

The motion of collecting components is composed with three single movements, and the mathematical modelling will be composed by these three movements. The moving direction of the collector is X axial, the vertical direction is Y axial, and the coordinate system is as the Figure 2. Thus, we can get the displacement equation of Q in the roller center, and get the velocity equation and acceleration equation by derivation (Eq. 1).

$$\begin{cases} x_q = Vt + R\cos\omega t - L_0 \cos(\omega t + \alpha_0 + \alpha) \\ y_q = R\sin\omega t - L_0 \sin(\omega t + \alpha_0 + \alpha) \end{cases}$$

$$\begin{cases} V_{x_q} = V - R\omega\sin\omega t + L_0\omega \sin(\omega t + \alpha_0 + \alpha) \\ V_{y_q} = R\omega\cos\omega t - L_0\omega \cos(\omega t + \alpha_0 + \alpha) \end{cases} \quad (1)$$

$$\begin{cases} a_{x_q} = -R\omega^2\cos\omega t + L_0\omega^2 \cos(\omega t + \alpha_0 + \alpha) \\ a_{y_q} = -R\omega^2\sin\omega t + L_0\omega^2 \sin(\omega t + \alpha_0 + \alpha) \end{cases}$$

The rationality of the designed collector can be analyzed and modified by the trace of the end of the collecting components. In the coordinate system of Figure2, the displacement equation, velocity equation and acceleration equation are at the end of the collecting components S (Eq. 2).

$$\begin{cases} x_s = Vt + R\cos\omega t - L\cos(\omega t + \alpha_0 + \alpha + \beta) \\ y_s = R\sin\omega t - L\sin(\omega t + \alpha_0 + \alpha + \beta) \end{cases} \quad (2)$$

$$\begin{cases} V_{x_s} = V - R\omega\sin\omega t + L\omega \sin(\omega t + \alpha_0 + \alpha + \beta) \\ V_{y_s} = R\omega\cos\omega t - L\omega \cos(\omega t + \alpha_0 + \alpha + \beta) \end{cases}$$

$$\begin{cases} a_{x_s} = -R\omega^2\cos\omega t + L\omega^2 \cos(\omega t + \alpha_0 + \alpha + \beta) \\ a_{y_s} = -R\omega^2\sin\omega t + L\omega^2 \sin(\omega t + \alpha_0 + \alpha + \beta) \end{cases}$$

Where the V is forward velocity of the machine, (m/s); t is operating time, (s); R is roller radius, (m); ω is rotating speed of the roller, (rpm); L_0 is length of the crank, (m); L is length of the collecting components, (m); α_0 is the initial angular of the collecting components, (°); α is tilt angle of the collecting components, (°); β is the intersection angle of the collecting components and the crank, (°).

4. Preliminary Determination of Critical Parameters in the Collector

At present, the drum - type collectors are mostly used for the collecting of straw, herbage, and oilseed rape, which have the features of large capacity in collecting and large size. The size of the collector studied in this paper is small, and collectors sold on the market do not meet the design requirements of this article, so we need to redesign it. Analyzing the working principles of current collector, and considering the total size of the machine, we determine the radius of roller plates is R=60 mm, the length of cranks is L0=40 mm, and the length of collecting components is L=150 mm. The following design is the central orbit curve in the slide of cam disc; it is also the most critical part, which decides that if the collector can meet the requirements of the design. It can be optimized and modified by the ADAMS software motion simulation, without complicated mathematical calculation to get the reasonable trajectory curve.

As to the modelling of the collector, in order to reduce the simulation time, model conveniently, and be added constraints easily el at., it can shorten the length of carbon fiber bar and save some features of the power crank and fasteners. We use the three - dimensional software SolidWorks for modelling and saved it into the form of Parasolid, and then led it to the ADAMS software; the total modelling can be seen in the Figure 3. In the ADAMS software, the parts of the modelling are endowed with material performance, and also the relationships for restraining them. When adding the drive, the moving vice between the cam disc and the earth simulates the forward movement of the machine, and the rotary vice between the roller plate relative and cam disc simulates the rotating of roller plate [21]. Such an example of the collector, it is required in the program that the initial selection of the forward speed is v=0.5 m/s, and the rotating speed of the roller plates is ω=40 rpm. The simulated results could be checked and analyzed in Post Processor of the ADAMS software.
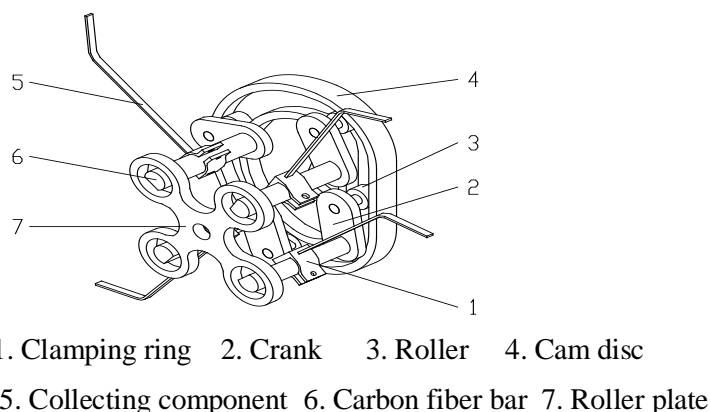

1. Clamping ring   2. Crank   3. Roller   4. Cam disc

5. Collecting component 6. Carbon fiber bar 7. Roller plate

Figure 3. Three-dimensional Simplified Model of the Collector

The Figure 4 is the trajectory picture of the end of the collecting components, and the simulation time is two cycles. We can see the buckles in the trajectory line on the figure, which means that when the machine is working, the collecting components have opposite level speed with the forward

direction of the machine, so that the collecting components can push the materials backward. That is the essential condition of collector to realize the collecting and pushing of materials [22].

The Figure 5 is the curve graph of line speed, line acceleration speed, and angular acceleration speed of the end of the collecting components with the changes of the time, and the simulation time is a cycle. It can be seen in the figure that at the time of t=1.13 ~1.2 s and 0~0.53 s, the line acceleration speed is decreasing, while the two kinds of acceleration speed nearly have no change. During these times, the collecting components are in the lifting, which lift the sugarcane leaves up smoothly. During the time of t=0.53~0.71 s, the line acceleration speed is beating down, and the collecting components push the sugarcane leaves to the cutting area along the fender apron. During the time of t=0.71~1 s, the line speed is rising, and two acceleration speeds slightly floating, that is the returning stage of the collecting components. During the time of t=1~1.13 s, there is big change on the three kinds of speeds, which will reach to the summit at the time of t=1.05 s. The collecting components stretch out from the fender apron quickly, which have big impact force on the sugarcane leaves, do bad to the collecting of the sugarcane leaves. In addition, the roller has a large impact force on the cam disc, which reduces the service life of roller. It is possible to increase the radius of the trajectory of the cam plate at this period, as to increase the route of the cam disc at this period, so that rollers can have a better transition, reduce the acceleration speed, and reduce the impact force to cam disc.
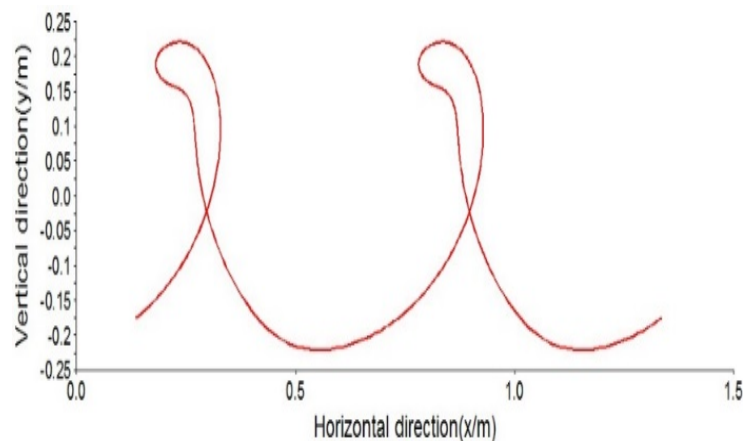

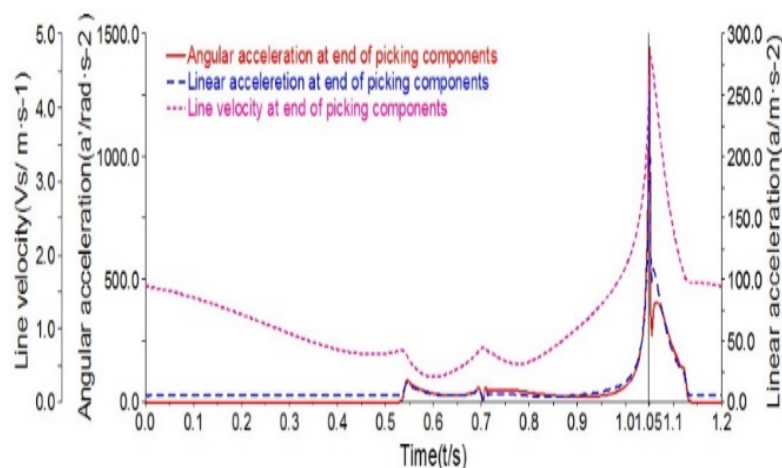**Figure 4.** The Trajectory Picture of the End of the Collecting Components

Figure 5. Curve of Line Velocity, Linear Acceleration and Angular Acceleration at End of Collecting Component

Because the cam disc slide central trajectory is a closed curve which is composed by three sections of arcs and one straight line, the reasonable parameters of the collector are finally confirmed after

several times of parameter design and simulation optimization of the ADAMS software, which can be seen in Table 1.

5. Optimization of Movement Parameter of the Collector

From the mathematical modelling, we can know that after the confirmation of critical parameters of the collector, the trajectory line at the end of the collecting components just has connection with the forward speed and the rotating speed of the roller plate. In order to get the reasonable trajectory line, it is necessary to optimize the best group of the forward speed and the rotating speed, so that the collector can pick up the sugarcane leaves and has a lower leakage rate. In this article, we use the ADAMS software for simulation experimental analysis on the model, and obtain the related data in different matching combinations of the forward speed and the rotating speed. And then, the data are processed by Central Composite Design (CCD) to optimize the best group of the forward speed and the rotating speed with minimum leakage rate [23-24].

5.1. Experimental Factor

In the simulated test, the factors are the forward speed of the whole machine and the rotating speed of the roller plate. According to the project requirements and the operating conditions of the sugarcane leaves returning field machine, the test adopts two factors and three levels, which can be seen in the following Table 2.

Table 1. Structure Parameters of the Collector

Parameters	Numerical value
Base circle radius(r/mm)	41
Roller plate radius(R/mm)	60
Brank(L_0/mm)	40
Collecting component length(L/mm)	150
Angle between the collecting components and the fender apron (β/°)	52
Three-section arc radius(mm)	41, 53, 89
Upper guard fender apron angle(γ/°)	24
Number of carbon fiber bars (z/pcs)	4

Table 2. Test Factors and Levels

Levels	Factors	
	Forward speed (m/s)	Rotating speed of the roller plate (rpm)
-1	0.4	35
0	0.5	50
1	0.6	65

5.2. Optimizing Index and Method

The ADAMS software simulation can't directly get the leakage rate, so it is indirectly analyzed by two optimization indicators, which are leakage area per meter and the largest angular acceleration at the end of the collecting components. (1) Leakage rate is an important standard to check the performance of the collector. When the collector is working, the uncovered areas at the end of the four trajectory lines are the leakage area, which can be seen in the shadow areas of the Figure6. As to different group for two factors, the leakage area by simulated analysis is different. In order to make the analysis results comparable, it is necessary to calculate the sum area of leakage area per meter. The calculation of leakage area per meter is gotten by the MATLAB software, and makes the results as one of the indicators of the performance of the collector; (2) If the angular acceleration speed is larger at the end of the collecting components, which mean that the rollers have a large impact force on the cam disc. Thus, the rollers are easy to be damage and, and also it will influence the working of other parts, so

that the collector is unsTable to work. Therefore, the angular acceleration at the end of the collecting components should be small, and it is used as one of the indicators for simulation analysis. The angular acceleration speed at the end of the collecting components in this test is no more than 200 rad/s^2.
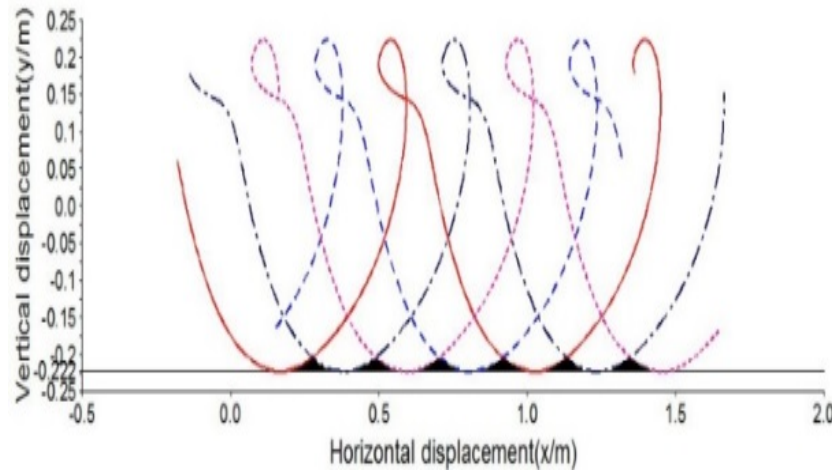

Figure 6. The Leakage Area of the Collector

5.3. Analysis on the Experimental Result

In this test, a 2-factor 3-level full factorial design method are adopted, which contained 13 sets of test data. The ADAMS software obtains date from different group of two factors, the data were as the Table.3. The data in the Table are put into the Design - Expert software for processing, so that we can obtain the response surface of the two factors, which are like the Figure7 ~ 8.

Table 3. Test Plan and Analysis Results

Forward speed(m/s)	Roller plate rotation speed(rpm)	Leakage Height(cm)	Area of leakage area (cm^2)	Number per meter	Area of leakage area per meter (cm^2)	Maximum angular acceleration in end of collecting components(rad/s^2)
0.4	35	1.26	7.22	9	64.98	105.57
0.6	35	2.40	20.54	4	82.16	105.57
0.4	65	0.47	1.34	11	14.74	308.02
0.6	65	0.87	4.09	7	28.63	308.02
0.4	50	0.72	2.77	8	22.16	203.98
0.6	50	1.34	8.21	5.5	45.16	203.98
0.5	35	1.82	12.93	5	64.65	105.57
0.5	65	0.66	2.50	8.5	21.25	308.02
0.5	50	1.03	5.06	6.5	32.89	203.98
0.5	50	1.03	5.06	6.5	32.89	203.98
0.5	50	1.03	5.06	6.5	32.89	203.98
0.5	50	1.03	5.06	6.5	32.89	203.98
0.5	50	1.03	5.06	6.5	32.89	203.98

Figure 7. The Response Surface of   **Figure 8.** The Response Surface of Maximum Angular

the Leakage Area Per Meter   Acceleration in End of Collecting Components

(1) From the aspect of single factor, when the rotating speed of the roller plate is constant, the sum area of leakage area per meter is larger with the increasing of the forward speed; when the forward speed is constant, sum area of leakage is smaller with the increasing rotating speed. Thus, the response surface will lean in the direction of slower forward speed and faster rotating speed, and the sum area of leakage is smaller and smaller. (2) It can be seen in Figure8 and Table.3, the largest angular acceleration at the end of the collecting components has no connection with the forward speed, and it will be faster with the increasing rotating speed of the roller plate, but it is bad to the sTableility of the collector. With slower forward speed and faster rotating speed, the leakage area will be smaller, but it does not meet the design requirements. It is necessary to find a suitable combination of forward speed and rotating speed to meet the low leakage rate and the job requirements of the total machine. The boundary conditions are input in the software of Design - Expert, which include the angular acceleration speed at the end of the collecting components that is no more than 200 rad/s^2 and forward speed that is more than 0.4 m/s. The result shows that the most optimized parameter assembly for the two factors are that: the forward speed is v=0.4 m/s, the rotating speed of the roller plate is ω=49.41 rpm. The sum area of leakage area per meter is 26.95 cm^2, and the largest angular acceleration at the end of the collecting components is 200 rad/s^2. Based on the above motion parameters, the trajectory chart, pendulum angle, linear acceleration, and angular acceleration at the end of the collecting components are as Figure9 ~ 10.
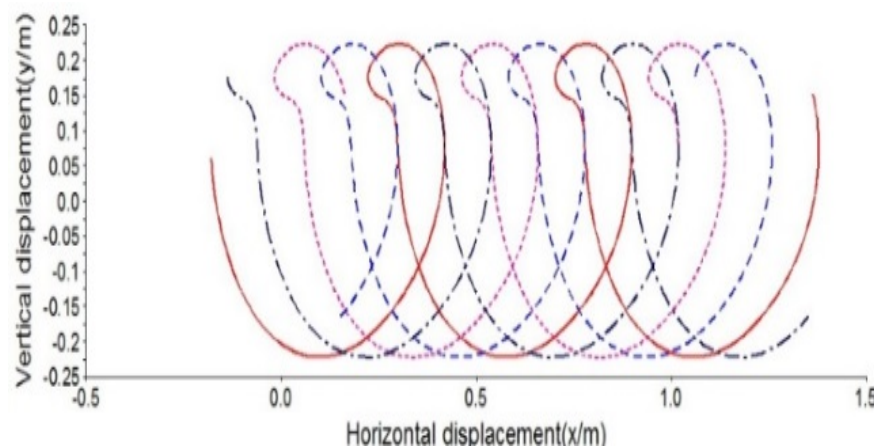

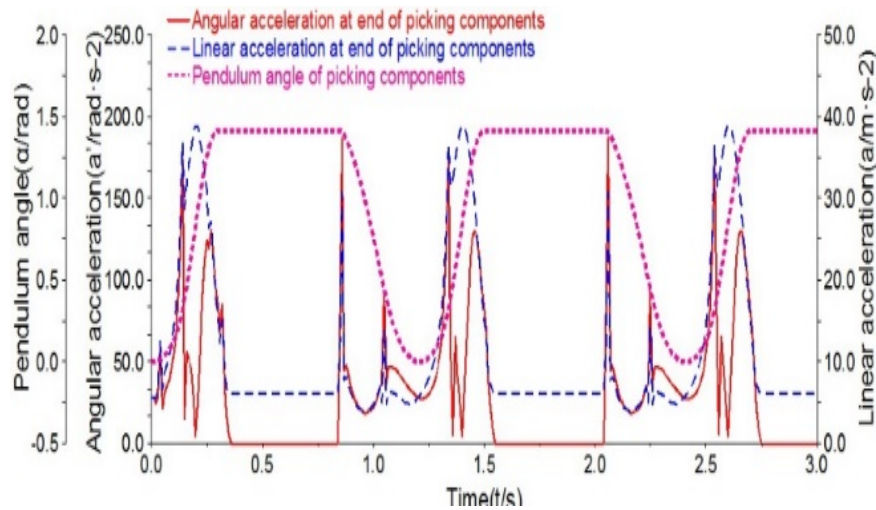**Figure 9.** The Trajectory Chart in End of Collecting Components

Figure 10. The Pendulum Angle, Linear Acceleration and Angular Acceleration in End of Collecting Components

6. Experimental Verification

6.1. Experimental Equipment and Site

Based on the above theoretical analysis and optimized result, the cam disc and other components can be assembled to the electric sugarcane leaves returning field machine. In order to verify whether the machine has a low leakage rate under theoretical motion parameters, it is necessary to carry out field test on the machine, which can be seen in Figure11. The test instruments include electronic scale, meter ruler, rotating speed measuring instrument, and computer.

Figure 11. Experimental Site Diagram

6.2. Experimental Performance Index and Method

The leakage rate of the test will be measured by weighting method. The leakage rate of the collector means that the proportion of the weight of non-pick up materials in the total weight of all materials (Eq. 3).

$$\eta = \frac{m_2}{m_1} \times 100\% \qquad (3)$$

Where η is leakage rate of the collector (%), m_1 is total weight of the materials during the collecting course (kg), m_2 is the weight of non-picking up materials during the collecting course (kg). The yield of sugarcane leaves is 7.5 t/hm^2, which mean that the yield of sugarcane leaves of per square meter is 0.75 kg [25-26], so when the test, the sugarcane leaves are laid on an area of 2 m^2, where the

length is 2 m and the width is 1 m, and the total weight of the sugarcane leaves is 1.5 kg. When testing, the forward speed and the rotating speed will be adjusted into theoretical parameter, which means that the forward speed is v=0.4 m/s, the rotating speed is ω=50 rpm, and we use the weighing method to calculate the leakage rate.

6.3. Analysis on the Experimental Result
The experimental materials are selected from the ROC 22 sugarcane leaves. The test conducting five sets of experiments, the results are showed in the Table 4. The average leakage rate is 2.93 %, which can meet the job requirements. This shows that the structural and working parameters obtained by theoretical analysis can meet the design requirements of the returning field machine.

Table 4. Experimental Data

Experimental number	Total weight of materials (kg)	Weight of non - pick up materials (kg)	Leakage rate (%)
1	3	0.0832	2.77
2	3	0.0905	3.17
3	3	0.1056	3.52
4	3	0.0745	2.48
5	3	0.0809	2.70

7. Conclusion

(1) This paper presents the design of a collector for sugarcane leaves returning field machine. The mathematical model of the collector is esTablelished by analysis its working principle. The important parameters of the collector are confirmed, including the roller plate radius, crank length, and the locus curve in the center of cam disc slide through the motion simulation of the ADAMS software.

(2) The combination of the minimum leakage rate of the collector have obtained under the two factors of the forward speed of 0.4~0.6 m/s and the roll plate speed of 35~65 m/s. Firstly, the method of the simulation analysis by the ADAMS software is used for analysis data of different combinations of factors. And then we use the Central Composite Design (CCD) to screen the best combination. The conclusions are as follows: the forward speed is V=0.4 m/s, the rotating speed is ω=49.41 rpm, the sum area of leakage per meter is 26.95 cm^2 , and the most angular acceleration at the end of collecting components is 200 rad/s^2.

(3) The test results show that the actual leakage rate of the collector meets the design requirements under the forward speed of v=0.4 m/s and the rotational speed of the roller plate of ω=50 rpm. The optimal working parameters combination obtained by the simulation meet the requirements of the agricultural technique index and the sugarcane leaves returning field machine well.

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