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RESEARCH NOTE

Simulation and Experiment on Conveying Device of Cutting System of Small Sugarcane Harvester

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ABSTRACT

The main problem is less efficiency and blocking during sugarcane harvesting in hilly areas. This paper researched the cutting and transporting system of a small sugarcane harvester using virtual prototype technology. The dynamics simulation analyses were carried out to study the transporting status with different friction coefficients between the sugarcane and the spiral and different numbers of the rubber around the drum. The virtual test results show that increasing the friction coefficient can enhance the transporting speed of the sugarcane, and adding more rubbers on the drum can also increase the speed further. Then, the paper analyzed the logistic process of the cut sugarcane with different friction coefficients between the sugarcane and the spiral and four rubbers mounted on the drum based on the high-speed photography in the field simulation test. The results also show that the transporting speed of the cut sugarcane can increase 40% when the friction coefficient and the rubbers are added. The simulation and field test results verify that the virtual prototype technology can provide reference for the development of the physical prototype.

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NOMENCLATURE

ω	Angular velocity of spiral	R_1	Radius of low feed roller (mm)
V_n	Combination velocity of V_z and V_0	f_0	Static friction coefficient between sugarcane and spiral
V_z	Axial velocity of spiral (mm.s^{-1})	f_1	Dynamic friction coefficient between sugarcane and spiral
V_0	Circumferential velocity (mm.s^{-1})	F_0	Static friction between sugarcane and spiral (N)
V_x	Backward velocity of sugarcane (mm.s^{-1})	F_1	Slidind friction between sugarcane and spiral (N)
V_y	Lateral velocity of sugarcane (mm.s^{-1})	k	Stiffness (N.mm$^{-n}{}_{4}$)
V_m	Forward velocity of harvester (mm.s^{-1})	r_2	Penetration depth (mm)
n	Cutter rotate speed (rpm)	f_3	Static friction coefficient between sugarcane and base cutter, knock-down roller, crop lifter
f	Friction coefficient between sugarcane and spiral	f_4	Dynamic friction coefficient between sugarcane and base cutter, knock-down roller, crop lifter
ρ	Angle of friction between sugarcane and spiral (^{0})	f_5	Static friction coefficient between sugarcane and feed roller
S	Helical pitch (mm)	f_6	Dynamic friction coefficient between sugarcane and feed roller
α	Helical angle (^{0})	n_2	Force exponent
δ	Angle between point A and spiral center and harvester's move direction (^{0})	n_1	Rotational speed of crop lifter and knock-down roller (rpm)
h	Height between low feed roller center and spiral (mm)	n_3	Rotational speed of feed roller (rpm)
h_1	Height of spiral (mm)	V_1, V_2, V_3, V_4	Are coordination the average backward speed of 1st sugarcane to 4th sugarcane (mm.s^{-1})
S_1	Horizontal distance between spiral center and low feed roller center (mm)	V	Average backward speed of 1st sugarcane to 4th sugarcane (mm.s^{-1})
r_1	Radius of sugarcane (mm)		

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1. INTRODUCTION

Sugarcane is a major economic crop in the south of China. For a long time, the sugarcane harvesting mainly depends on manual work. With China's rapid economic development, the costs of sugarcane harvesting, which have reached 20$ per ton at present, are constantly rising. The south of China is mainly in the hilly areas. The tests on the smaller plots of land growing sugarcane indicate that foreign large-scale sugarcane harvesters are not suitable. This development has caused China to devote major efforts to developing a small-scale sugarcane harvester which will be a mainstream direction in quite a long period time [1].

The cutting system of the small-scale sugarcane harvester is located in the front of the entire system. Conveying the sugarcane to the next process is directly related to the working performance of the system and the leaves stripping and tails cutting process. Currently the main problems are less efficiency and blocking during harvesting sugarcane to the extent that it seriously hinders application of the harvester. In order to solve the problems above, the cut sugarcanes should instantly fall on the disk cutter, and quickly be conveyed backwards to ensure the continuous harvest.

Traditional mode of product design usually adopts a serial design process where design, manufacturing, testing and improvement are performed in sequence with a long cycle time and high cost. However, adopting a virtual design procedure and experimentation by virtual prototyping on computer is better for research and analysis of key technologies, which can save large amounts of time and costs [2, 3]. Virtual prototyping technology has been widely used in the mechanical design and test. M. H. Korayem et al. designed a six degree freedom robot, and simulated it with MATLAB and ADAMS, then verified the simulation by test [4].

At present, there are many applications of virtual prototyping technology in sugarcane harvester, for example, Xie Fuxiang and Fu Longzheng used ADAMS to design and simulate the logistics systems of whole stalk sugarcane harvester, which consists of propped device, cutting device, gripping conveyor, placement conveyor and leaf stripping device. They studied the logistics process when every part was harvesting sugarcane [5, 6]. Liu Qingting used AutoCAD software to simulate and study the working process of single-disc cutting device [7]. Huang Handong and Lin mao simulated and analyzed the cutting force of different blades of sugarcane cutter with ANSYS software [8, 9]. Li Lixin et al. used PROE and ADAMS to design and simulate anti-block mechanism of small sugarcane harvester [10]. Pu Minghui simulated feeding mechanism in mini sugarcane harvester with ADAMS [11]. However, there are few study of virtual test on cutting system of sugarcane harvester and the process of logistics transportation. For this reason, virtual prototyping of sugarcane harvester's conveying mechanism was simulated in UG software and ADAMS software aiming at developing sugarcane harvesters.

This paper discusses the kinematic analysis, modeling, simulation and experimental analysis of conveying device for cutting system of small sugarcane harvester. First, structure and working principle of small sugarcane harvester were presented. Kinematic modeling and simulation were investigated. The modeling were built in UG software and simulated in ADAMS software. Finally, experimental analyses of the cutting and conveyance system were carried out and the results of the test performance are presented below.

2. STRUCTURE AND WORKING PRINCIPLE

2. 1. Structure Small sugarcane harvester is shown in Figure 1 and consists of crop lifer 1, knock-down roller 2, spiral lifter 3, dual base cutter 4, feed roller 5, cleaning device 6, hydraulic tank 7, diesel engine 8, oil tank 9, gear box 10, drum 11 and so on. Spirals are mounted on disc cutter and cutter shafts. The spiral direction on the double cutter is wound in the opposite direction to convey material to the feed rollers. The surface of spiral is covered with high friction coefficient and high fatigue strength rubber to reduce damage to the sugarcane by the high-speed rotating spiral and to raise the conveying ability.

2. 2. Working Principle As the knock–down roller pushes the sugarcane down to a certain angle, the dual base cutter cuts the root of the sugarcane. The base of the sugarcane then lies on the sugarcane cutter disk. When the sugarcane harvester goes forward and the spirals rotate, the sugarcane is moved along the spiral axis direction and transported backward along the horizontal direction. Due to these two movements, the sugarcane is transported to the entrance and the gripping conveyors.

3. KINEMATIC ANALYSIS OF SUGARCANE FLOWING THROUGH SPIRAL

Kinematic diagram of the system is shown in Figure 2 (right cutter only). The sugarcane's absolute velocity is produced by the harvester's convected velocity and spiral surface's relative velocity. When the spiral rotates at an angular velocity ω, the velocity of point A which sugarcane contacts with spiral surface can be calculated by a velocity triangle. Without considering friction, V_n is a combination of the spiral's axial velocity V_z and circumferential velocity V_0. Due to the friction between the sugarcane and spiral surface, the sugarcane's velocity V of point A is the normal deflection angle of friction ρ. After the decomposition of V, the axial velocity V_z and the circumferential velocity V_2 of point A can be acquired.

According to velocity vector chart in Figure 3, the axial velocity of sugarcane is as follows:

$$V_z=V\cos(\alpha+\rho) \tag{1}$$

As $V=V_n/\cos\rho$ (2)

$$V_n=V_0\sin\alpha \tag{3}$$

$$\therefore\quad V_z= V_0\sin\alpha\cos(\alpha+\rho)/\cos\rho \tag{4}$$

Meanwhile,

$$V_0=\omega\cdot r=\frac{2\pi n}{60}\cdot\frac{S}{2\pi tg\alpha}=\frac{n\cdot S}{60\cdot tg\alpha} \tag{5}$$

$$\tan\alpha=S/2\pi r \tag{6}$$

So Equation (1) turns to :

$$V_z=\frac{S\cdot n}{60}\cdot\frac{1-fs/2\pi r}{1+(s/2\pi r)^2} \tag{7}$$

Similarly the circumferential speed:

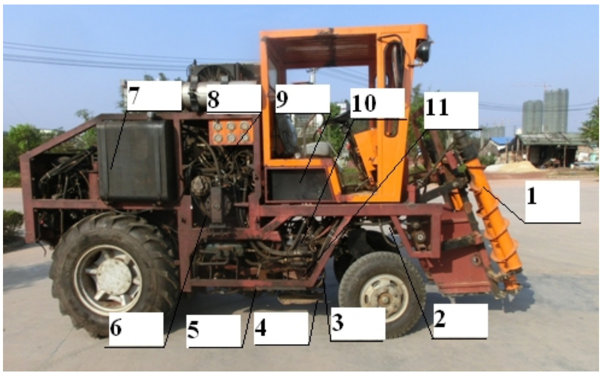


Figure 1. Small sugarcane harvester
1. Crop lifter 2. Knock-down roller 3. Spiral lifter 4. Dural base cutter 5. Feed roller 6. Cleaning device 7. Hydraulic tank 8. Diesel engine 9. Oil tank 10. Gear box 11. Drum

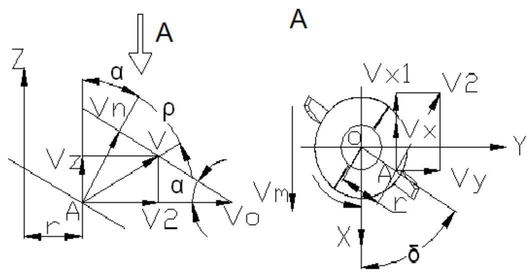


Figure 2. Instantaneous movement of the sugarcane head on the spiral

$$V_2=\frac{S\cdot n}{60}\cdot\frac{f+S/2\pi r}{1+(S/2\pi r)^2} \tag{8}$$

Backward velocity of sugarcane:

$$V_x=V_{x1}-V_m=V_2\sin\delta-V_m$$
$$=\frac{S\cdot n}{60}\cdot\frac{f+S/2\pi r}{1+(S/2\pi r)^2}\cdot\sin\delta-V \tag{9}$$

Sugarcane lateral velocity:

$$V_y=V_2\cos\delta=\frac{S\cdot n}{60}\cdot\frac{f+S/2\pi r}{1+(S/2\pi r)^2}\cdot\cos\delta \tag{10}$$

where, V_z is the axial velocity of sugarcane on the spiral($mm.s^{-1}$), V_x is the backward velocity of sugarcane ($mm.s^{-1}$),V_m is the forward velocity of harvester ($mm.s^{-1}$), V_y is the lateral velocity of sugarcane ($mm.s^{-1}$), n is the cutter rotate speed(rpm),f is the friction coefficient between sugarcane and spiral, f=tanρ. ρ is the angle of friction between sugarcane and spiral (^{0}) ,S is helical pitch(mm),α is helical angle (^{0}) ,and δ is the angle between point A and spiral center and harvester's move direction (^{0}) .

Equation (7) shows that because of the spiral, the head of sugarcane is lifted quickly to the rollers. In order to limit the height of sugarcane a limit rod should be added at a certain height above the spiral.

Equation (9) depicts V_x which must be greater than 0 so that the sugarcane can be moved backwards. By adding friction coefficient, increasing the helix angle, or increasing spiral diameter can also improve the conveyance velocity of the sugarcane.

Equation (10) shows that the lateral velocity of the sugarcane would lead to the sugarcane moving to the side and off the spiral, but the double-disc cutter on the other side prevents this movement.

When the spiral replaces the spiral surface, r=R(R—half of pitch diameter), then

$$V_x=V_{x1}-V_m=V_2\sin\delta-V_m$$
$$=\frac{S\cdot n}{60}\cdot\frac{f+tg\alpha}{1+tg^2\alpha}\cdot\sin\delta-V_m \tag{11}$$

$$V_z=\frac{S\cdot n}{60}\cdot\frac{1-f\cdot tg\alpha}{1+tg^2\alpha} \tag{12}$$

Equations (10) shows, when δ= 90^0, the sugarcane moves towards the rollers at the fastest velocity. When the transmission distance is the same, the height of sugarcane being lifted will be the lowest.

When $\frac{V_z}{V_x}\geq\frac{h-h_1+r_1}{S_1-R_1}$ (Seen Figure 3) (13)

the sugarcane can be conveyed to the entrance smoothly.

where, h is the height between low feed roller center and spiral (mm), h_1 is the height of spiral (mm), S_1 is the horizontal distance between spiral center and low feed roller center (mm), r_1 is the radius of sugarcane (mm), R_1 is the low feed roller radius (mm). Calculation:

1. When S=300mm, n=800rpm, r=250mm, V_m=400mm.s^{-1}, f=0.09, δ=60^0, according to Equation (9), the backward transportation speed of sugarcane is 539.12mm.s^{-1}
2. When S=300mm, n=800rpm, r=250mm, V_m=400mm.s^{-1}, f=0.35, δ=60^0, according to Equation (9), the backward transportation speed of sugarcane is 1408mm.s^{-1}

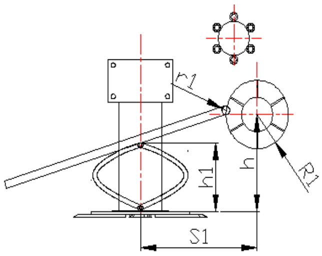


Figure 3. Sugarcane trajectory

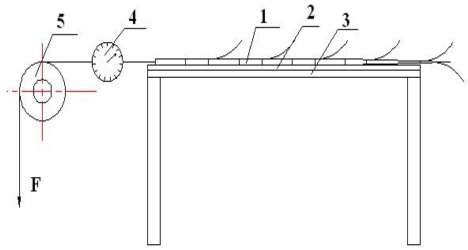


Figure 4. Measuring coefficient of friction between sugarcane and rubber Sugarcane 2. Rubber 3. Desk 4. Spring balance 5. Pulley

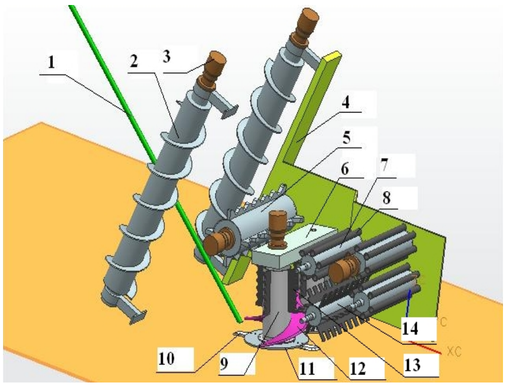


Figure 5. Virtual modeling of the cutting and conveyance system of small sugarcane harvester

1. Sugarcane 2. Crop lifter 3. Hydraulic motor 4. Side panel (right only) 5. Knock-down roller 6. Gear box 7. Upper feed roller 8. Rubber pipe 9. Drum 10. Cutter 11. Cutter disk 12. Spiral 13. Rubber 14. Lower feed roller

4. THE MEASURING OF THE COEFFICIENT OF FRICTION BETWEEN SUGARCANE AND RUBBER

The contact force between sugarcane and rubber is necessary in the simulation experiment, and it's related to the coefficient of friction, so it's necessary to measure the coefficient of friction of sugarcane and rubber before the simulation. The smooth-surfaced rubber and rough-surfaced rubber were fixed respectively on the table at a certain height, and sugarcane was placed on the surface of rubber. One end of the string was tied to the root of sugarcane, and the other end was tied to the hook of the spring balance, shown in Figure 4. Then, the spring balance was dragged slowly and uniformly as far as possible in the horizontal direction. The value of the spring balance had increased to a value until sugarcane began to move, and this value was the static friction F_0; when sugarcane moved uniformly, the spring balance displayed F_1, and F_1 was the sliding friction. The weight of sugarcane was G. Then, the coefficient of static friction f_0 and dynamic friction f_1 are calculated as follows.

$$f_0 = F_0 / G \tag{14}$$

$$f_1 = F_1 / G \tag{15}$$

Finally, it is measured that the coefficients of static friction and dynamic friction between sugarcane and smooth-surfaced rubber are 0.13 and 0.09, and the coefficients of static friction and dynamic friction between sugarcane and rough-surfaced rubber are 0.5 and 0.35.

5. SIMULATION ANALYSIS OF THE CUTTING SYSTEM'S CONVEYING MECHANISM

5. 1. Simulation Purpose The purpose of the simulation is to study the transportation logistics process of the sugarcane after it is cut down and provide a scientific basis for the development of the physical prototypes in order to improve the success rate of prototype development.

5. 2. Experiment Materials Based on the sugarcane growth data measured in different lands in Guangxi China, the parameters of sugarcane model are as following: the length of the sugarcane is 2000 mm, diameter is 30mm, density is 1100kg.m^{-3}, the modulus of elasticity is 1.531E+9N.m^{-2} and the Poisson ratio is 0.33 [12]. The parameters of the rubber are as follows: density is 900kg.m^{-3}, modulus of elasticity is 7.84e8N.m^{-2} and the Poisson ratio is 0.47 [13].

ANSYS (10.0) was used in this paper to simulate the flexing action of the sugarcane and rubber. After that, it was used to build a MNF file which was imported into ADAMS software.

5. 3. Modeling of Cutting and Conveyance System

The modeling of cutting and conveyance system were built, which were simplified appropriately with UG software. Virtual modeling of prototype is shown in Figure 5 and consists of sugarcane 1, crop lifer 2, hydraulic motor 3, side panel (right panel only) 4, knock-down roller 5, gear box 6, upper feed roller 7, rubber pipe 8, drum 9, cutter 10, cutter disk 11, spiral 12, rubber 13, lower feed roller 14.

5. 4. Virtual Experimental Design

Optimum parameters were selected according to the efficiency of small-scale sugarcane harvester and literature [13], and the contacting parameters were based on the literature [14]. The constraint was bushing between sugarcane and soil. Simulation time was 1s. The sugarcane had broken away from the soil after 0.4s. Since the rotating velocity of the cutter and the forward velocity of the harvester are related to the harvester's efficiency, miss-cutting and the rate of perennial root rupture, the rotational speed of the cutter should be in the range of 600~1000 rpm [15, 16], and the forward speed of the sugarcane harvester should be in the range of 0.2~0.6m.s^{-1} [17]. Thus, this paper selected the rotational speed of the cutter of 800rpm and harvester's forward speed of 0.4m.s^{-1} for simulation. The following four conditions were selected for simulation:

1) The static friction coefficient between sugarcane and spiral is 0.13, and the dynamic friction coefficient is 0.09 for the drum without rubber.
2) The static friction coefficient between sugarcane and spiral is 0.5. dynamic friction coefficient is 0.35 for the drum without rubber.
3) The static friction coefficient between sugarcane and spiral is 0.5, and the dynamic friction coefficient is 0.35. The rubbers were uniformly distributed in the drum of the cutter disk, each drum was mounted two pieces of rubbers. The shape of rubber is shown in Figure 6.
4) The static friction coefficient between sugarcane and spiral is 0.5, and the dynamic friction coefficient is 0.35. The rubbers were uniformly distributed in the drum of the cutter disk, each drum was mounted four pieces of rubbers. The shape of rubber is shown in Figure 6.

Virtual experimental design and parameters are shown in Table 1.

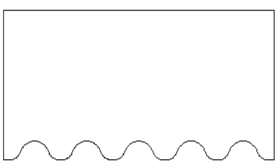


Figure 6. Shape of rubber

TABLE 1. Virtual experimental design and parameters

Item	f_0	f_1	Drum with rubber	Contact parameters with sugarcane
1	0.13	0.09	none	k=2855, n_2=1.1, r_2=0.1mm
2	0.5	0.35	none	
3	0.5	0.35	two pieces of	
4	0.5	0.35	four pieces of	

Note: Contact parameters between sugarcane and base cutter, knock-down roller and crop lifter are $k=3800$, $n_2=2$, $f_3=0.13$, $f_4=0.09$, $r_2=0.1$mm; contact parameters between feed roller and sugarcane are $k=2855$, $n_2=1.1$, $f_5=0.5$, $f_6=0.35$, $r_2=0.1$mm; $v_m=400$mm.s,$^{-1}$ $n_1=160$rpm, $n=800$rpm, $n_3=250$rpm

where, k is stiffness (N.mm^{-n}$_4$), r_2 is penetration depth(mm), f_0 is static friction coefficient between sugarcane and spiral, f_1 is dynamic friction coefficient between sugarcane and spiral. f_3 is static friction coefficient between sugarcane and base cutter, knock-down roller, crop lifter, f_4 is dynamic friction coefficient between sugarcane and base cutter, knock-down roller, crop lifter, f_5 is static friction coefficient between sugarcane and feed roller, f_6 is dynamic friction coefficient between sugarcane and feed roller. n_2 is force exponent, v_m is the forward speed of harvester (mm.s^{-1}), n_1 is rotational speed of crop lifter and knock-down roller (rpm), n is rotational speed of base cutter (rpm), n_3 is rotational speed of feed roller (rpm)

5. 5. Results and Analysis Figure 7 shows the velocity curve which reflects the backward movement of the sugarcane head under the four cases. In the 1st case (curve number 1), the static friction coefficient between sugarcane and spiral is 0.13, and the dynamic friction coefficient is 0.09 for the drum without rubber. In the 2nd case（curve number 2）,the static friction coefficient between sugarcane and spiral is 0.5, and the dynamic friction coefficient is 0.35 for the drum without rubber. In the 3rd case（curve number 3）,the static friction coefficient between sugarcane and spiral is 0.5, and the dynamic friction coefficient is 0.35, when each drum with two rubbers. In the 4th case（curve number 4, the static friction coefficient between sugarcane and spiral is 0.5, and the dynamic friction coefficient is 0.35, when each drum with four rubbers.

Tests show that adding friction between the sugarcane and spiral can improve the conveyance speed of the sugarcane. At the same coefficient of friction between sugarcane and the spiral, the conveyance speed of the sugarcane could be also improved by adding rubber on the drum. It also shows that the backward speed of sugarcane fluctuates and the sugarcane was repeatedly stroke by the spiral or rubber in the backward conveying process.

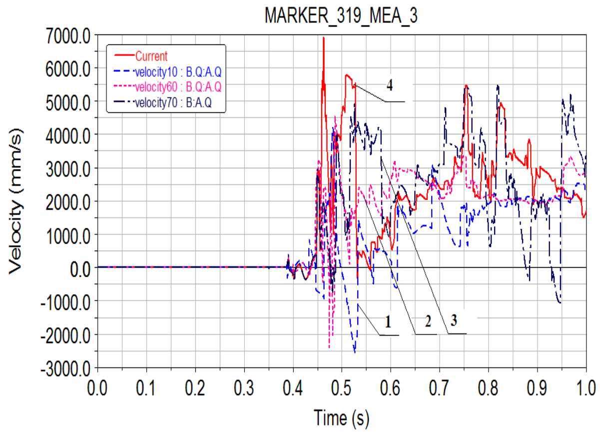


Figure 7. Velocity curve of conveying sugarcane backward in the following cases

1. f_0=0.13, f_1=0.09,drum without rubber
2. f_0=0.5, f_1=0.35,drum without rubber
3. f_0=0.5, f_1=0.35,drum with two rubbers
4. f_0=0.5, f_1=0.35,drum with four rubbers

f_0 is static friction coefficient between sugarcane and spiral, f_1 is dynamic friction coefficient between sugarcane and spiral

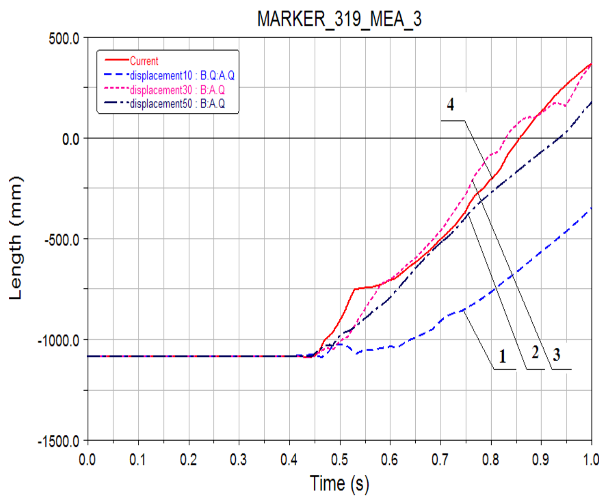


Figure 8. Distance curve of conveying sugarcane in backward in the following cases Parameters of curve 1 to 4 are the same as those shown in Figure 7

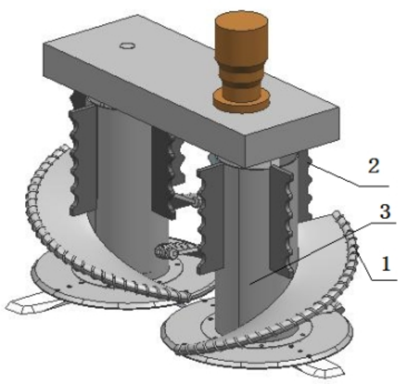


Figure 9. Cutting system 1. Rough rubber 2. Rubber 3. Drum

Figure 8 shows the backward distance in different cases after sugarcane was cut off at the same time of the simulation. In the 1st case (curve number 1), the backward distance of sugarcane is 653mm in 0.6s, the average backward speed is 1.09 $m.s^{-1}$. In the 2nd case（curve number 2）, the backward distance of sugarcane is 1180 mm in 0.6s, then the average backward speed is 1.97 $m.s^{-1}$. In the 3rd case（curve number 3）, the backward distance of sugarcane is 1453mm in 0.6s, as a result, the average backward speed is 2.42 $m.s^{-1}$. And in the 4h case（curve number 4）, the backward distance of sugarcane is 1457mm in 0.6s, as a result, the average backward speed is 2.43 $m.s^{-1}$. These also verify the backward speed of sugarcane is the fastest in the 4th case.

6. IMPROVIED CUTTING SYSTEM

Based on the dynamic analysis and simulation, the cutting system is finally designed as shown in Figure 9. The lifter spiral is coated with rough rubber and the drum is uniformly distributed with four pieces of rubbers, while crop lifter roller and feed device remains unchanged.

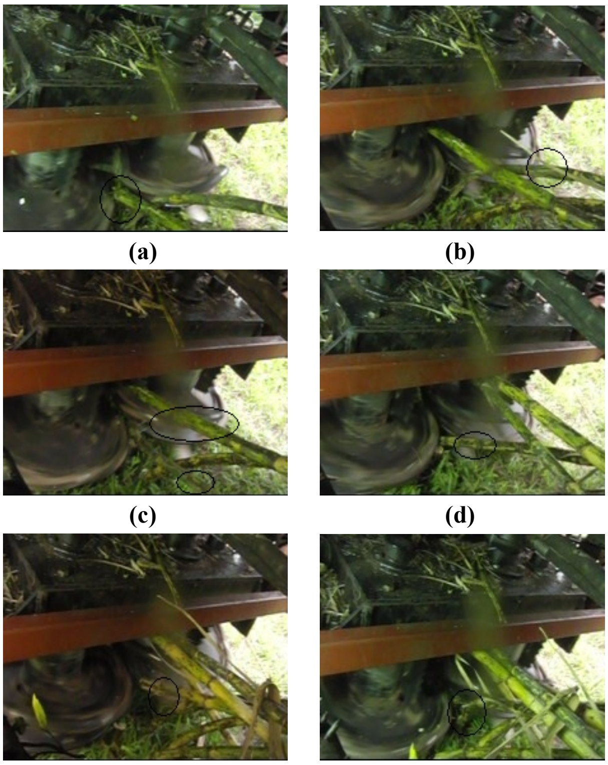
7. TEST OF HIGH-SPEED PHOTOGRAPHY

Technology of the high-speed photography was used to record the moving process, which is very useful to observe the moving state of sugarcane cut off. Taking the parameters in Table 1 as the test parameters, test of high-speed photography was carried out and the movement of sugarcane was observed and analyzed after it was cut off.

High-speed photography equipment is Casio FH100 digital camera. The recording speed is up to 1000 frames per second. Due to higher speed of the cutter, the experimental record speed is 420 frames per second (the calibration ratio of time displayed of high-speed photography and real time is 15:1), and halogen light was used to light. To facilitate testing, the planting of sugarcane was imitated by the actual sugarcane cultivation, and the soil was compacted. Each cluster had 3 or 4 sugarcanes. The cluster spacing was 400mm, and the height of sugarcane was 2000mm. Each test lasts 10 minutes.

In Figure 10(a) to (g), the spiral is coated with smooth-surfaced rubber, and the drum is without rubber. They are 10mm steps between the cutter disk and cutter. The high-speed digital camera records the sugarcane’s movement process. Sugarcane was cut off, shown in Figure 10(h). The 1st sugarcane was sent to spiral at 44s ,shown in Figure 10(a), then was rapidly lifted and backwards transported. The separation of the sugarcane and spiral was completed at 92s and the sugarcane was transported backward by inertial. The 2nd sugarcane was sent to spiral at 54s, shown in Figure 10(c) .The transportation was completed at 104s. The 3rd sugarcane was sent to spiral at 78s, shown in Figure 10(d), transportation was completed at 110s, and the former two sugarcanes were still suspended at the top of the spiral. The 4th sugarcane was cut off and then sent to the spiral at 119s, and transportation was completed at 146s. By calculating, average backward speed of the 1st sugarcane to the 4th was $0.63m.s,^{-1}$ $0.6m.s^{-1}$, $0.9375m.s^{-1}$ and $0.54m.s^{-1}$, the average backward speed of 1st sugarcane to 4th sugarcane was $0.677m.s^{-1}$, shown in Table 2. It was also found, during the experiment, since there were 10mm steps between the cutter disc and the cutter, sugarcane was unable to be successfully brought to the spiral immediately after being cut off, and some sugarcane were even cut 7or 8 times before being sent to the spiral. Figure 10(h) also shows that sugarcanes were cut repeatedly by high-speed rotating cutter since they could not enter the transmission channel, and the majority of sugarcane's head were seriously damaged.

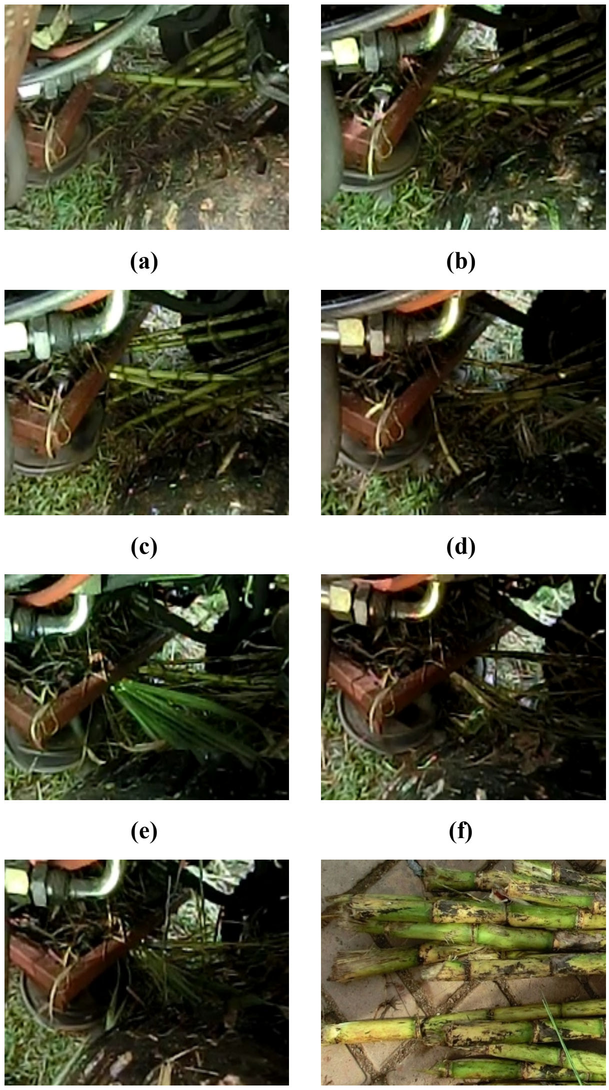
In Figure 11(a) to (g), the spiral is coated with rough-surfaced rubber (which has a larger friction coefficient between sugarcane and spiral), the drum is uniformly distributed with four pieces of rubbers, the cutter and the disc cutter is smoothly transited. Sugarcane was cut off, shown in Figure 11(h).



(a) (b) (c) (d) (e) (f)

(g) (h)

Figure 10(a)-(h). Part of video screenshots about lifter spiral coated with smooth-surfaced rubber and the drum without rubber t_a=44s t_b= 50s t_c=54 s t_d= 78s t_e= 119s t_f= 131s t_g=148s



(a) (b) (c) (d) (e) (f) (g) (h)

Figure 11(a)-(h). Part of video screenshots about lifter spiral coated with rough-surfaced rubber and the drum uniformly distributed with four pieces of rubbers t_a=06s t_b=18s t_c= 21s t_d= 28s t_e= 35s t_f= 46s t_g=57s

In Figure 11(a), the 1st sugarcane was cut off at 6s, then rapidly lifted by the spiral and transported backwards. The rubber on the drum accelerated transportation, and the transportation was completed at 38s. In Figure 11(b), the 2nd sugarcane was cut off at 18s, and the transportation was completed at 47s. In Figure 11(c), the 3rd sugarcane was cut off at 21s and the transportation was completed at 60s. In Figure 11(d), the 4th cane was cut off at 42s and the transportation was completed at 67s. By calculating, average backward speed from the 1st sugarcane to the 4th were 0.9375, 0.9677, 0.7692 and 1.2 $m.s^{-1}$, the average backward speed of 1st sugarcane to 4th sugarcane was 0.9686 $m.s^{-1}$ shown in Table 2. From the test results, by adding friction coefficient between sugarcane and spiral, add rubbers on the drum, the average backward conveying speed of sugarcane was increased from 0.677 to 0.9686 $m.s^{-1}$, that is to say, 40% faster than the original design. In Figure 11(e) to (g), the 2nd cluster of sugarcane were transported. During this test, when the sugarcane had been cut less than three times, the sugarcane was successfully sent to the spiral. With the high-speed rotation of the spiral and the added rubber, the sugarcane was constantly conveyed to the feed rollers. In addition, shown in Figure 11(h), the sugarcane was successfully transmitted to the next stage and avoided repeatedly being cutting by cutter. Most of the head surfaces of the sugarcane were in good condition. Where, V_1, V_2, V_3, V_4, are coordination the average backward speed of 1st sugarcane to 4th sugarcane, V is the average backward speed of 1st sugarcane to 4th sugarcane, *a is the spiral coated with smooth-surfaced rubber, the drum without rubber, and there are 10mm steps between the cutter disk and cutter,*b is the spiral coated with rough-surfaced rubber (which has a larger friction coefficient between sugarcane and spiral) , the drum is uniformly distributed with four pieces of rubbers, the cutter and the disc cutter is smoothly transited.

8. DISCUSSION

Virtual test results shows the average backward conveying speed of sugarcane which is increased from 1.09 to 2.43 $m.s^{-1}$ when the static friction coefficient between sugarcane and spiral is increased from 0.13 to 0.5, the dynamic friction coefficient between sugarcane and spiral is increased from 0.09 to 0.35 and the rubber is mounted around the drum. Field test results shows when the static friction and dynamic friction coefficient is increased and the rubber is mounted around the drum, the average backward conveying speed of sugarcane is increased from 0.677 to 0.9686 $m.s^{-1}$. By comparing the results of virtual test with the test of the physical prototype, it is found that there are some differences between virtual test and actual speed of sugarcane which was cut off being conveyed backwards. The main reason is that only single sugarcane's movement is taken account in the virtual test. However, multiple sugarcanes are often sent to the cutting and conveying system simultaneously in actual test. Meanwhile, the leaves entwine each other, which hinder backward transport speed of sugarcane. Besides, the friction coefficient between the spiral and sugarcane for physical prototype is a little different from virtual prototype. However, test results show that the change tendency of backward transportation speed is similar. Increasing friction coefficient of the spiral with sugarcane will raise the backward transportation speed. It is quite effective by mounting rubber on the drum.

TABLE 2. Average velocity of conveying sugarcane under different conditions ($m.s^{-1}$)

Item	*a ($m.s^{-1}$)	*b ($m.s^{-1}$)
V_1	0.63	0.9375
V_2	0.6	0.9677
V_3	0.9375	0.7692
V_4	0.54	1.2
V	0.677	0.9686

9. CONCLUSION

1) Virtual prototypes modeling of the cutting and conveyance system were built with UG software. The movement of sugarcane cut off in four cases was simulated with ADAMS software.
2) Virtual test results shows sugarcane can be accelerated by increasing the friction coefficient of the sugarcane with spiral. Adding rubber on the drum can further improve the backward transportation speed of sugarcane.
3) Field test results show that the transporting speed of the cut sugarcane can increase 40% when the friction coefficient and the rubber are added.
4) The experiment of physical prototype verifies the result of theoretical analysis and simulation.

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Simulation and Experiment on Conveying Device of Cutting System of Small Sugarcane Harvester

RESEARCH NOTE

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چکیده

مشکل اصلی، بازدهی کم و بلوکه شدن در طول دروکردن نیشکر در تپه ها است. این مقاله بریدن و انتقال سیستم یک دروگر کوچک با استفاده از فناوری نمونه واقعی را مورد تحقیق قرار می دهد. تحلیل های شبیه سازی دینامیکی برای مطالعه حالت های انتقال با ضرایب اصطکاک مختلف بین نیشکر و مارپیچ و تعداد مختلف از غلطک های لاستیکی انجام شده است. نتایج تست واقعی نشان داد که افزایش ضریب اصطکاک می تواند سرعت انتقال نیشکر را افزایش دهد و همچنین اضافه کردن لاستیک روی غلطک می تواند سرعت را بیشتر کند. سپس، مقاله فرایند لوجستیکی بریدن نیشکر را با ضرایب اصطکاک بین نیشکر و مارپیچ تحلیل کرد و چهار لاستیک روی غلطک بر پایه فوتوگرافی سرعت بالا در میدان آزمایش شبیه سازی شده نصب شد. نتایج نشان داد که هنگامی که ضرایب اصطکاک و لاستیک ها اضافه شدند، سرعت انتقال بریدن نیشکر ٪۴۰ افزایش می یابد. نتایج آزمایش شبیه سازی شده و میدانی بررسی کرد که فناوری نمونه واقعی می تواند مرجعی را برای توسعه نمونه های فیزیکی تهیه کند.

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