Computational Research Progress in Applied Science & Engineering

ISSN 2423-4591

CRPASE Vol. 05(03), 85-91, September 2019

# Research on the Cut-throwing Performance of Chopper of Sugarcane Harvester

Hai Xu, Tao Wu, Qingting Liu*, Jinxin Li

*College of Engineering, South China Agriculture University, Guangzhou, China*

**Keywords**

Chopper,
Billets,
High speed photography,
Throw velocity,
Spatial posture.

**Abstract**

To solve the problem of the lack of theory about interaction between cutting blade and billets, and analyze the situation that the stratification of trajectory of thrown billets after whole cane was cut by chopper. The spatial posture of billets at the blade at the moment of cutting was analyzed. Through high-speed photography test, three kinds of spatial postures of billets at the blade were obtained, which were upward warping, kept feeding inclined posture and drooping, and the number of sugarcane feeding layers had no significant influence. The throwing velocity of billets was obtained by high-speed photography test tracking analysis at thrown moment, and the two-factor test analysis showed that the cutting speed of cutting blade had a significant influence on the throwing velocity, which increased with the increase of the speed of blade, and showed a strong linear correlation,but the throwing angle had no significant effect on the throwing velocity. Moreover, the linear regression analysis showed that the correlation coefficient between the blade edge linear velocity and the throwing velocity was 0.999, and the throwing velocity equivalent was 1.058. Therefore, cutting blade had a small thrust effect on billets and provided a basis for further research on the trajectory of billets.

## 1. Introduction

Chopper is a key component of the sugarcane harvester, the interaction between the cutting blade of chopper and the billet at the moment of cutting determines the instantaneous throwing angle and the initial throwing velocity of the billet by the cutting blade, Those will affect the movement trajectory of billets after throwing and the impurity content of the harvest.

At present, many scholars at home and abroad have mainly studied the interaction mechanism between cutting blade and the materials,and the throwing performance of chopped blade rolls on pasture, sorghum and corn [1-8]. But the research on the chopper of sugarcane harvester mainly focuses on the cutting method, cutting quality, cutting power consumption and cutting mechanism. Hockings P R et al. [9] give three kinds of tool setting methods of chopper for the sugarcane chopper harvester : the blade edge is opposite, the edge bevel is coincident and the edge bevel gap is opposite. Liu Fangjian et al [10,11] studied the working process of chopper of sugarcane harvester, and the movement and force of sugarcane stem during that process, which obtained the movement pattern of the billet and the separation form of the sugarcane leaf and the sugarcane stem during the cutting process, but the interaction between the cutting blade and the billet was not involved in the instant separation of the billet and blade. Zhou Jinwei et al. [12] studied the influence of the relative position of the cutting blades of the sugarcane harvester on the cutting quality, and obtained the optimum tool setting parameters. Kroes S[13] studied the damage form of sugarcane in the cutting process of chopper by pendulum device, and obtained three kinds of failure modes: in-plane tension, in-plane shear and anti-plane shear. Norris C P et al [14] researched the relationship between the axial load of the sugarcane chopper and the installation position of the cutting blade, the influence of the cutting blade wear on the performance of the sugarcane chopper, and the relationship between the chopper rotation speed and the feeding delivery speed. Luxin Xie et al. [15] developed a system of chopper and studied the effects of the rotational speed of the chopper, the overlap length of the upper and lower cutting blade, and the chamfer angle on the quality and power requirements of the segment. At present, there are few literature on the interaction between the cutting blade and the billet when the sugarcane is cut. Therefore, the mechanism of action between the cutting blade and the billet is of great significance when the sugar cane is cut off.

In this paper, high-speed photography technology is applied to study the spatial posture of the billet, and the interaction between the cutting blade and the billet, and analyze the throwing mechanism and performance of the

* Corresponding Author:
E-mail address: qingting@scau.edu.cn– Tel, (+86) 13543488545

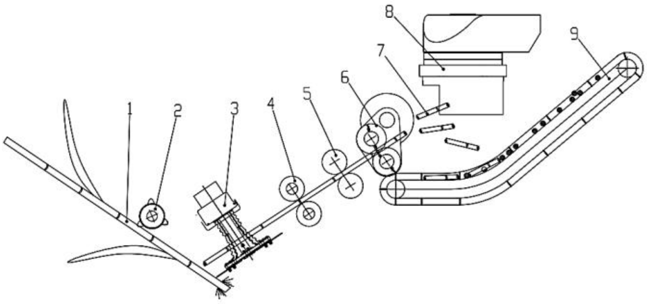
Received: 2 September 2019; Accepted: 25 September 2019

chopper. The results can provide a theoretical basis for the analysis of the throwing trajectory of the billet .

## 2. Chopper Structure and Working Principle

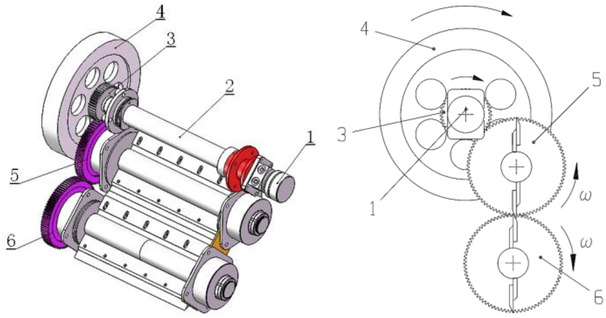
### *2.1. Chopper Structure*

During the operation of the sugarcane chopper harvester, the root cutter cuts off the sugar cane which is pushed down at a certain angle by the push-down roller, and then the feeding roller will feed the whole stalk sugarcane into the conveying channel which had cut by root cutter, and then the conveying roller conveys it to the chopper.What is more,the chopper cut off the sugar cane which conveyed by the conveying roller, and the billet is then thrown by the cutting blade to the extractor fan to perform the impurity removing operation. Finally, the billet falls into the secondary conveying device, and the secondary conveying device completes the lifting and transporting of the billet. The working process is shown in Figure 1 .




1 sugarcane 2 push-down roller 3 root cutter
4 feeding roller 5 conveying roller 6 chopper
7 billet 8 extractor fan 9 secondary conveying device
**Figure 1.** Working process of sugarcane chopper harvester

The chopper cuts the transported sugarcane into a certain length of billet and throws it into the extractor fan. The chopper of the 4GDLS-132A chopper sugarcane combine harvester independently developed by South China Agricultural University ,which adopts the roller plate straight edge blade cutting method. The chopper mainly consists of upper and lower cutting roller, cutting blades and meshing gear pairs, flywheel and hydraulic motor.Two groups of cutting blades are symmetrically mounted on the upper and lower cutting rollers and fixed by bolts. The upper and lower cutting blades adopt the opposite cutting edge bevel gap method, and the optimal tool setting parameters are as follows [16]. Therefore, the upper and lower cutting blades will have a common passing area during the operation,which is called the interlaced area. The upper cutting blade will contact the sugar cane and cut in before the lower cutting blade, that is, there is a phase difference between them ,which results in the cut-in time difference. The hydraulic motor supplies power to the chopper, it drives the pinion and the flywheel, the pinion drives the upper blade gear, and the upper blade gear drives the lower blade gear. When the chopper is working, the upper and lower cutting blade rotate in the opposite direction at the same speed. The structure and power transmission movement relationship are shown in Figure 2. The inertia of the flywheel can improve the stability of the chopper.




1 hydraulic motor 2 input shaft 3 pinion
4 flywheel 5 upper blade gear 6 lower blade gear
**Figure 2.** Structure and power transmission diagram of the chopper

### *2.2. Chopper Working Principle*

According to the structural analysis of the above-mentioned chopper, it can be seen that when the opposite cutting edge bevel gap method is used for the chopper, the sugarcane is cut in the intersecting area of the cutting blade, and the principle is as follows: when the whloe stalk sugarcane conveyed by the conveying device enters cutting area of the chopper, the corresponding cutting blade on the blade roller first bites the sugarcane, and then completes the clamping, the extrusion cutting and conveying of the sugarcane with its own rotation. when the upper and lower paired cutting blades reach a certain staggered depth, the sugarcane is cut off, and the billets which are cut off preferentially are thrown under the rotation of the cutting blade; the sugarcane which is to be cut later continues to be fed into the chopper, and is completed holding, squeezing and cut-in by the next pair of paired cutting blades. the cycle is repeated until the end of the sugarcane is thrown directly through the chopper at the initial velocity imparted by the conveying roller.

In order to analyze the relative positional relationship between the blade and the billet at the moment when the whole stalk sugarcane was cut off by the cutting blade. The Cartesian coordinate system is established as shown in Figure 3. The center point of the center line of the rotation of the cutting blade is taken as the coordinate origin, the horizontal right is the positive direction of the X axis, and the vertical direction is the positive direction of the Y axis.The offset of the central axis of the sugarcane is not considered in the cutting process of the upper and lower cutting blades, that is, the central axis of the sugarcane always coincides with the X axis.

It can be seen according to the geometric relationship of Figure 3 that the phase difference is as Eq. (1)

$$\theta=\arccos\frac{2R^2-b^2}{2R} \tag{1}$$

It is assumed that when the upper cutting blade starts to cut into the sugarcane at $t_p$=0s, the depth of the upper and lower blades cut into the sugarcane is a function of time $t_p$, that is, for the upper cutting blade, the depth of cutting into the sugarcane is as Eq. (2)

$$\begin{cases} \Delta y_u = R\cos(\beta-\omega t_p) - R\cos\beta \\ \Delta x_u = -R\sin(\beta-\omega t_p) + R\sin\beta \end{cases} \tag{2}$$

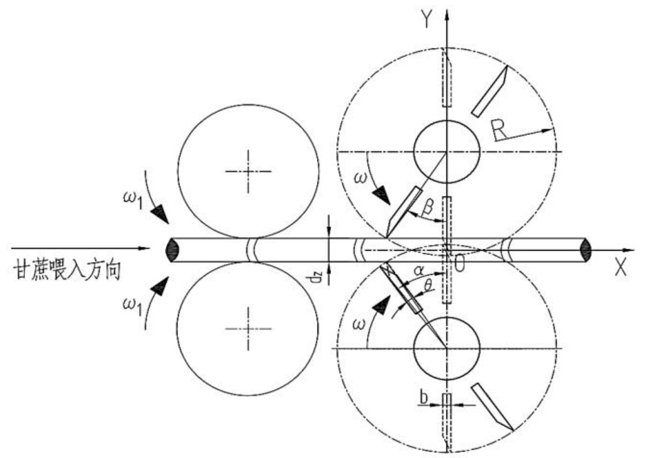



**Figure 3.** Analysis of the cutting mechanism of the cutting blade

For the lower cutting blade, the depth of cutting into sugarcane is as Eq. (3)

$$\begin{cases} \Delta y_d = R\cos(\partial - \omega t_p) - R\cos\beta \\ \Delta x_d = -R\sin(\partial - \omega t_p) + R\sin\beta \end{cases} \quad (3)$$

where $\Delta y_u$ is the longitudinal depth of the upper cutting blade cutting into sugarcane, m; $\Delta x_u$ is the axial depth of the upper cutting blade cutting into sugarcane, m; $\Delta y_d$ is the longitudinal depth of the lower cutting blade cutting into sugarcane, m; $\Delta x_d$ is the axial depth of the lower cutting blade cutting into sugarcane, m; β is the cutting stroke angle of the upper cutting blade, rad, and $\beta = \arccos\frac{L_g - d_z}{2R}$; $\partial$ is the cutting stroke angle of the lower cutting blade, rad, and $\partial = \beta + \theta$; $t_p$ is the time of cutting blade cuts into sugarcane, s; R is the the radius of gyration of the cutting edge, m; ω is the angular speed of the cutting blade, rad/s; $L_g$ is the center distance of the upper and lower blade rollers, m; $d_z$ is the sugarcane diameter, m.

It can be seen from the cutting operation principle of the chopper that the sugarcane will be cut off when the staggered depth of the interlaced zone of the upper and lower corresponding paired cutting blades is greater than the diameter of sugarcane. Therefore, the relationship of sugarcane cut into sections is as Eq. (4)

$$\sqrt{2(1+\cos\theta)}\sin(\omega t + \varphi') \geq d_z \quad (4)$$

where the $\varphi' = \arctan\frac{\cos\beta + \cos\partial}{\sin\beta + \sin\partial}$.

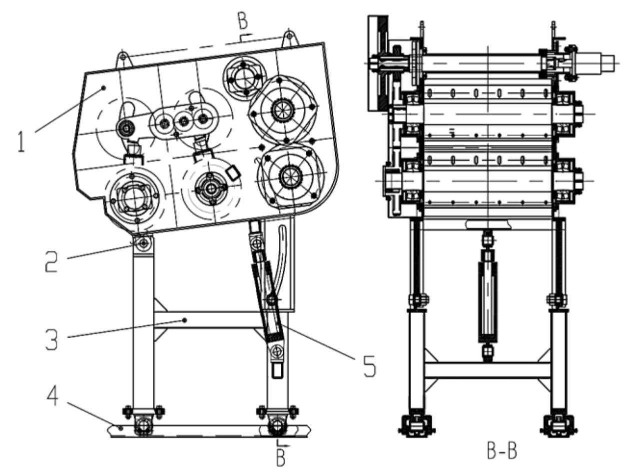
According to the above analysis, It can be seen that in the process of cutting sugarcane, the upper blade has a cutting and pressing effect on the sugarcane,so the sugarcane will be lifted up; but as the depth of the cut deepens, the effect of the sugarcane on the conveying channel which can support the billet that cutting by the cutting blade is gradually reduced. And the lift-up billet is gradually fall back under its own gravity. Therefore, when the sugarcane is cut off, the billet will be upturned, kept in a tilted state and sagging in three different spatial postures at the blade.

## 3. High Speed Photography Test

In order to study and verify the spatial attitude of the billet at the cutting blade at the moment when the whole stalk sugarcane is cut off, as well as the specific influence of the factors such as the rotation speed of the cutting blade and the throwing angle on the billet movement process in actual work. And then to obtain the throwing velocity of the billet, and to verify the throwing function relationship between the cutting blade and the billet.Those will provide a strong basis and foundation for the research on throwing trajectory billet and harvester impurity removal system in the later stage. Based on this, a high-speed photography experiment is designed.

### *3.1. Test Bench Design*

The test bench is mainly composed of feeding roller, conveying roller, chopper, a fixed support frame and the Sliding channel (Figure 4). The design dimension of the combined device of feeding, conveying and cutting refers to 4GDLS-132A harvester. During the test, it is necessary to control the throwing angle of the cutting blade, so that the combined device can be rotated around the pin shaft, and the angle can be adjusted from 7° to 36°.




1 transport cutting unit device 2 rotating pin mechanism
3 support frame 4 sliding channel 5 hydraulic cylinder

**Figure 4.** Test bench

### *3.2 Test Materials and Conditions*

The test was carried out in March 2019 at the Guangzhou Welding Bull Machinery Co., Ltd. The whole stalk sugarcane was harvested from the test field of Guangzhou Zengcheng Teaching and Research Base of South China Agricultural University on the day before the experiment. And the variety of sugarcane is Xintai Sugar No.22, its average sugarcane diameter was 25mm and the density was 1203.411 kg/m3. The test equipment and equipment include two high-speed digital cameras Phantom VEO 410L and Phantom Miro M310 produced by Vision Research of the United States; a self-made feeding, conveying,and cutting combination test bench (Figure 4); and a TRS605 torque sensor of Futek, USA (with a range of 0~200 Nm), USB520 data acquisition card; an acer laptop computer (Aspire E1, Core i5-3230M dual-core processor); 4 sets of Repman LED camera lights ( the power is 2kw); a calibration rod, two sets of camera holder and so on.

### *3.3 Spatial Posture Test of Billet*

#### *3.3.1 Test Design*

The number of sugarcane layers fed into the chopper was used as a test factor in the test, they were fed into single-layer, double-layer and three-layer respectively and the number of sugarcane fed was five, ten and fifteen [17].When feeding with double-layer, the sugarcane were divided into upper layers and lower layers,each layer has five sugarcane and fixed by adhesive tape to form double layer to feed (Figure 8a);When feeding with three-layer, the sugarcane were divided into upper, middle and lower layer, each layer has five sugarcane and fixed by adhesive tape to form three layers to feed (Figure 8b). In order to record the spatial posture of billet at the moment of cutting blade cut off the whole stalk sugarcane, the Phantom VEO 410L high-speed digital camera is used for single shooting. The main parameters of the camera are shown in Table 3.

*3.3.2 Analysis of Test Results*

After the sugarcane is fed, it enters the chopper under the conveying action of conveying roller. As the hobbing operation of cutting blade, the cutting blade will cut into and drive the sugarcane until it is cut off. After the sugar cane is cut off, the billet is immediately thrown by the cutting blade, as shown in Figure 5.

single-layer feeding　　multi-layer feeding

**Figure 5.** Instant space attitude of sugar cane being cut by sugarcane

From the Figure 5 above, it can be seen that whether the single-layer or multi-layer feeding, the spatial posture of the billet at the moment of the sugarcane is cut off at the cutting blade is generally upturned, a small part of the billet is inclined downward far from the end of the cutting blade under the action of its own gravity,that is sagging state, and a part of the billet remains inclined posture when feeding, which is consistent with the theoretical analysis. Under the action of lower-layer support, the upturned billets are less and less obvious in the multi-layer feeding than the single-layer feeding, while the inclined posture is more complete and the distribution is more regular.Therefore, it can be inferred that the shorter length of the sugarcane cut section, the less obvious effect for billet under its own gravity.What is more, the inclined posture and the number of billet is more complete and large, while the sagging billet will be reduced or not obvious and its distribution is more regular.

*3.4 Two-factor Test of Throwing Velocity*

In order to meet the length of the billet, avoid the blockage of the feeding channel, satisfy the production efficiency of the harvester and the quality of the fracture during the harvesting operation of the sugarcane chopper harvester, the chopper of the harvester needs a relatively high rolling speed. The high-speed rotating cutting blade not only has the ability to cut the sugarcane into billet, but also has a good throwing capacity for the billet. And the interaction between the billet and the cutting blade is a relatively complicated process at the moment of the billet is thrown away by the cutting blade, which brings great difficulty to know the initial velocity of the billet when was thrown out. Therefore, in order to simplify the study, the interaction between billet and the cutting blade at the moment of disengagement ignores the air resistance, and only considers the thrust of the cutting blade, the self-gravity of billet, the velocity of the billet obtained during the process of the whole stalk sugarcane being cut by the b lade and the velocity of billet slip along the blade before it slip away the cutting blade[18, 19]. Therefore, the force situation of the billet is shown in Figure 6, the relationship between the throwing velocity and the thrust of the billet by the law of conservation of momentum is as Eq. (5)

$$mv_p - m\,(v_0 + v_h) = \int(t) \quad (5)$$

where $v_p$ is throwing velocity of the billet , m/s; $V_0$ is liner velocity of the cutting blade, m/s; $V_h$ is the slip velocity of the billet slip along the cutting blade, m/s; $F_t$ is the thrust of the cutting blade , N.

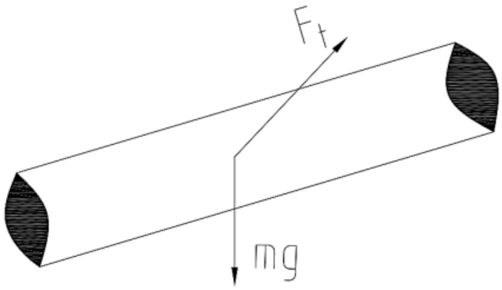



**Figure 6.** Force diagram of billet and cutting blade in the instant of separation

According to the field test of the harvester, the speed of the cutting blade and throwing angle of the chopper are the two main factors,which would affect the throwing velocity. Therefore, in order to further explore the influence of the cutting speed of the cutting blade and the throwing angle of the chopper on the throwing velocity, the equivalent coefficient ζ of the throwing velocity of the billet is introduced, so that $v_p = \zeta(v_0 + v_h)$, then the formula (5) can be shown as Eq. (6)

$$m\,(\zeta - 1)\,(v_0 + v_h) = \int(t)t \quad (6)$$

Therefore, it is necessary to obtain the throwing velocity through high-speed photography test, and to determine the effect of the throwing angle of the chopper and the speed of the cutting blade on the throwing velocity of billet at the moment of the throwing, and then analyze and obtain the equivalent coefficient of the throwing velocity.

*3.4.1 Test Design*

Based on the above analysis, the test selects the throwing angle and the rotational speed of the cutting blade as the test factor, and the throwing velocity as the test measurement index for the two-factor test. The test factors and levels are shown in Table 1. According to the mathematical relationship between the length of the cutting section in [20] and the parameters of the chopper and the conveying device, the length of the billet at different cutting speeds is guaranteed to be about 250 mm(Figure 7a). Two high-speed cameras were used to shoot the marked points on the billet in parallel when the billet is thrown out by cutting blade. In order to avoid the wrong tracking of the marked points caused by excessive overlap of the billet, a single layer whole stalk sugarcane which has marked points was fed in the test.

**Table 1.** Test factors and level tables

| Level | Factor | |
|---|---|---|
| | A. Throwing angle （°） | B. Cutting speed of cutting blade（r/min） |
| 1 | 32 | 370 |
| 2 | 34 | 420 |
| 3 | 36 | 470 |

a. length of billet b. marked point

**Figure 7.** Tracking billet and marked point of the test

*3.4.2 Test Results and Analysis*

The motion information of the billet recorded by two high-speed cameras simultaneously in the test was imported into the TEMA software, then the billet which has clearly marked point (Figure 7b) and separated from the cutting blade at the moment was tracked, after that, the throwing velocity information of the billet was obtained. The velocity of the billet with sudden change in velocity was taken out, and the average value of the initial velocity of the six representative billet was taken as the throwing velocity of the billet at the moment when it separated from the cutting blade. The test results are shown in Table 2.

**Table 2.** Test Design Results Table

| Test number | Factor | | Test index |
|---|---|---|---|
| | A | B | Throwing velocity(m/s) |
| 1 | 1 | 1 | 5.46 |
| 2 | 1 | 2 | 6.00 |
| 3 | 1 | 3 | 6.92 |
| 4 | 2 | 1 | 5.90 |
| 5 | 2 | 2 | 6.20 |
| 6 | 2 | 3 | 6.70 |
| 7 | 3 | 1 | 5.57 |
| 8 | 3 | 2 | 6.32 |
| 9 | 3 | 3 | 6.79 |

The results of the two-factor test were analyzed by SPSS for variance analysis. The results are shown in Table 4. It can be seen from the table that the sum of the squares of the throwing angle of the chopper is 0.031, the degree of freedom is df=2, and its F=0.415, Sig.=0.686>0.05. Therefore, the effect on the throwing velocity of the billet is not significant in the 95% confidence interval for throwing angle of the chopper. But as for the cutting speed of the cutting blade, the sum of the squares is 2.023, the degree of freedom is df=2, and its F=26.907, Sig.=0.005<0.01. So that, the effect on the throwing speed of the billet is extremely significant in the 99% confidence interval.

From the variance analysis of the throwing velocity, it is concluded that the throwing velocity of billet is only related to the cutting speed of the cutting blade of chopper, and has no correlation with the throwing angle.Therefore, the average values of the three throwing velocities corresponding to the cutting speeds of the three horizontal blades in Table 2 are taken as the throwing velocities at that level, and the mathematics relationship between the linear velocity of circular motion and the angular velocity (Eq.(7))

$$v_0 = 2\pi nR \quad (7)$$

where $v_0$ is Linear velocity of blade edge of cutting blade, m / s; $n$ is the cutting speed of the cutting blade, r/s.

The corresponding linear velocity of blade edge of cutting blade were obtained at different cutting speeds according to the above mathematical relationship. And the results are shown in Table 5. A linear regression analysis is performed on the throwing velocity and linear velocity of the blade edge without introducing a constant term coefficient, and the curve equations of the linear velocity and the throwing velocity are obtained as Eq. (8)

$$y=1.058x，R^2=0.999 \quad (8)$$

The significant difference of model variance analysis is sig=0.000<0.001,which indicates that the linear relationship between the throwing velocity of the billet and the cutting blade edge linear velocity is significant, which further indicates that the time of the billet slipping along the cutting blade is very short or there is no relative slip process. The slip velocity can be negligible, that is, the initial throwing velocity of the billet can be simplified as Eq. (9)

$$v_p = \zeta v_0 \quad (9)$$

Therefore, the coefficient of the regression curve equation can be approximated as the throwing velocity equivalent coefficient $\zeta$, that is, $\zeta=1.058$, which indicates that the thrust of cutting blade on the billet is relatively small when the billet is separated from the cutting blade. Therefore, the initial throwing velocity of the billet is mainly obtained by the cutting blade in the cutting and the follow-up process, and its size mainly depends on the cutting speed of the cutting blade.

**Table 3.** Main parameter settings of the high-speed camera

| Resolution | Exposure Time(μs) | Sample Rate(fps) | Aperture | Exposure index | focal length（mm） |
|---|---|---|---|---|---|
| 1280×800 | 300 | 2000 | f5.6 | 1600 | 37 |

a double-layer feeding

b three-layer feeding

**Figure 8.** Sugarcane multi-layer feeding

**Table 4.** Variance analysis of throwing velocity

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Corrected Model | 2.055a | 4 | .514 | 13.661 | .013 |
| Intercept | 346.704 | 1 | 346.704 | 9220.862 | .000 |
| Cutting Speed of Cutting Blade | 2.023 | 2 | 1.012 | 26.907 | .005 |
| Throwing Angle | .031 | 2 | .016 | .415 | .686 |
| Total | 348.909 | 9 | | | |
| Corrected Total | 2.205 | 8 | | | |

a. R Squared = .932 (Adjusted R Squared = .864), Dependent Variable: Throwing Velocity

**Table 5.** Regression Analysis Data Sheet

| Linear velocity of cutting blade edge ($m.s^{-1}$) | Throwing velocity($m.s^{-1}$) | | | Average velocity of throwing($m.s^{-1}$) | Standard error |
|---|---|---|---|---|---|
| 5.15 | 5.46 | 5.90 | 5.57 | 5.64 | 0.229 |
| 5.85 | 6.00 | 6.20 | 6.32 | 6.17 | 0.162 |
| 6.55 | 6.92 | 6.70 | 6.79 | 6.80 | 0.111 |

## 4. Conclusion

In this paper, the spatial posture of the billet at the moment when the whole stalk sugarcane was cut off into billet at the cutting blade and the interaction between the billet and the cutting blade at the moment when they are separated were studied by analyzing the working mechanism of the chopper, and then the high-speed photography technology is used to test and analyze on the self-made test bench. The results are as follows:

Through the high-speed photography test and theoretical analysis, it is obtained whether the single-layer or the multi-layer feeding sugarcane, the spatial posture of the billet at the moment of the sugarcane is cut off at the cutting blade is upturned, maintaining the feeding inclined posture and sagging three kind of space posture. It provides a reference for the later analysis of the throwing trajectory of the billet.

(1) The instantaneous interaction between billet and cutting blade was analyzed theoretically and verified by high-speed photographic test.

(2) The instantaneous throwing velocity of billet was obtained by high-speed photography.

(3) The two-factor test analysis showed that the cutting speed of the cutting blade had a very significant influence on the throwing velocity, and the throwing velocity of billet increased with the increase of the cutting speed of cutting billet, which showing a strong linear correlation, but the throwing angle has no significant effect on it. The linear regression analysis shows that there is a strong linear relationship between the throwing velocity and the cutting speed of the cutting blade, and the equivalent coefficient of the throwing velocity is 1.058, which indicates that the thrust of cutting blade on the billet is relatively small when the billet is separated from the cutting blade. Therefore, the initial throwing velocity of the billet is mainly obtained by the cutting blade in the cutting and the follow-up process, and its size mainly depends on the cutting speed of the cutting blade.And the formula for calculating the throwing velocity is $v_p = \zeta v_0$.

## Acknowledgements

Thanks to the finical support of the National Key R&D Program of China (Grant No. 2018YFD0701105), the Science and Technology Program of Guangzhou(Grant No. 201807010084), the Guangdong Provincial Team of Technical System Innovation for Sugarcane Sisal Industry (Grant No. 2019KJ104-11) and the Sugar Industry Technical System Post Project of China (Grant No. CARS-170402). The authors gratefully acknowledge all members of Mechanization Research Office of National Sugar Industry Technology System.

## References

[1] Dennisl, Determination of the air and crop flow behavior in the bowing unit and spout of a pull-type-forage harvester, Saskatchewan,University of Saskatchewan, Saskatoon:2005.

[3] Lisowski, K. Swiatek, J. Klonnwski, et al. Movement of chopped material in the discharge spout of forage harvester with a Flywheel chopping unit: measurements using maize and numerical simulation, Biosystems Engineering 111 (2012) 381–391.

[4] K.J. Shinners, R.G. Koegel, P.J. Pritzl, et al. Band lubrication to reduce friction loss in forage blowers, Transactions of the ASAE 34 (1991) 1962–1966.

[5] P.S. Chattopadhyay, P.S. Pandey, Influence of knife configuration and tip speed on conveyance in flail forage harvesting, Agricultural Engineering Research 78 (2001) 245–252.

[6] Z.P. Zhai, Y.M. Wu, C.G. Wang, Dynamic simulation and high-speed camera analysis on materials moving along throwing impellers, Transactions of the CSAE 28 (2012) 23–28.

[7] Z.P. Zhai, B. Gao, Z.Y. Yang , et al. Power consumption and parameter optimization of stalk impeller blowers Transaction-s of the CSAE 29 (2013) 26–33.

[8] H.T. Chen, A. Li, N.Y. Shi,et al. Kinetics Modeling and Experiment of Lateral Throwing of Corn Straws, Transactions of the CSAM 49 (2018) 76–83.

[9] Hockings P R, Davis, Improving the Performance of Chopper Systems in Cane Harvester, BSES Report, 1999.

[10] F.J. Liu, X.J. Yang, X.F. Fang, et al. Design and Experime-nt of Chopper Device in Sugarcane Harvester, Transactions of the CSAM 49 (2018) 90–95.

[11] F.J. Liu. Mechanism and Experimental Study on the front-load Chopper in Sugarcane Harvester, China Academy of Agricultural Machinery Science, Beijing, China 2018.

[12] J.W. Zhou, The Influence of the Relative Position Between the Cutting Blades of the Sugarcane Harvester on the Cutting

[2] P.S. Chattopadhyay, K.P. Pandey, Impact cutting behavior of sorghum stalk using a flail-cutter-a mathematical model and its experimental verification, Journal of Agriculture Engineering Research 78 (2001) 369–376.

Quality, South China Agricultural University, Guangzhou, China, 2017.

[13] Kroes, S, The Splitting Energy of Sugarcane. Proceedings of the Australian Society of Sugar Cane Technologists 1998, 20 (1998) 349–356.

[14] C P Norris, R J Davis, P R Hockings. Improving the performance of chopper systems in cane harvesters, SRDC Final Report SD99019,1999.

[15] L.X.Xie, J.Wang, S.M.Cheng, at el .Performance Evaluation of a Chopper System for Sugarcane Harvester, Sugar Tech 21 (2019) 825–837.

[16] J.W. Zhou, Q.T. Liu, T. Wu, Q. Lai, J.C. Luo, The influence of the relative position between paired blades on the cutting quality of sugarcane harvester. Journal of Agricultural Mechanization Research 8 (2018) 111–117.

[17] J.M. Feng, Research and Design on Feeding and Conveying Device of HN4GDL-91 Sugarcane Harvester, South China Agricultural University, Guangzhou, China, 2013.

[18] R.Q. Hu, The Motive Analysis of Particle Which is on the Blade of Plane Type, the Blade Rotate Round a Horizontal Axle with Constant Angular Velocity, Transactions of the CSAM 4 (1980) 62–72.

[19] R.Q. Hu, The Simplification of motive equation of Particle which is on the blade of plane tpye, the blade rotates rounda horizontal axis with constant angular velocity, Inner Mongolia Ancient Agriculture and Animal Husbandry College 1 (1983) 126–133.

[20] Handbook of Agricultural Machinery Design, China Academy of Agricultural Machinery Science, Beijin, China (2007) 1125–1126.