Simulation Analysis of the Sugarcane Leaves Cutting Process of the Electric Returning Machine

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Abstract: In order to improve the sugarcane leaves cutting effect of electric sugarcane leaves returning machine, the sugarcane cutting process is modelled and simulated by ANSYS/LS-DYNA software. It shown that in the double-support cutting mode, the cutter roller ensures the multi-layer sugarcane leaves were cut at the rotate speed of 800 rpm. During the cutting process of sugarcane leaves, the stress is mainly concentrated at the incision, and the sugarcane leaves on the side of the blade are subjected to greater stress. The smaller the distance between the rotary blade and the fixed blade of the same combination, the easier the sugarcane leaves are cut off. In the cutting test of sugarcane leaves, the cutting rate was 91.47%, which echoed the simulation results, indicating that modelling and simulation have reference value.

Keywords: Sugarcane leaves returning machine; Sugarcane leaves; Finite element method; Cutting.

1. Introduction
Sugarcane leaves are the main by-product of sugarcane, and its yield is about 75t/hm2, which account for 12%-20% of sugarcane production. The sugarcane leaves are treated by machinery to return to the field, which can accelerate the natural degradation, and can play the role of moisture retention, fattening and yield increase, and sustainable development. However, there are more than 800 medium and large sugarcane harvesters in China. At present, the level of mechanized harvesting in China is very low, and the harvesting method of sugarcane is still based on human harvest [1]. Therefore, after artificially harvesting sugarcane, the sugarcane leaves are still laid on the sugarcane field, which requires the sugarcane cutting and returning machine for subsequent operations instead of the traditional incineration treatment. In China, most of our returning field machines are large-scale machines, mainly based on the tractors, which consume more energy. 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 can easily cause damage to the roots, which will lead to a reduction in sugarcane production in the next season. In addition, there are mainly hilly lands in the south China, where the adaptability 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. 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 [2-3]. An important indicator of the performance of the returning machine is its cutting rate. From the structural point of view, the cutting mode of sugar cane leaves determines the cutting rate. This paper studies the way in which sugarcane leaves are cut through the rotating knives and fixed knives and thrown back to the field. There are few...
examples of cutting simulation of sugarcane leaves. Zhenhua Xu uses ALE algorithm and fluid-solid coupling model to simulate the working process of flexible knife whipping sugarcane leaves [4]. Heyang Huang performed finite element simulation on the flexible strip whipping Gaubau Kender leaves to optimize the structure of leaves picker [5]. We used finite element simulation of ANSYS and LS-DYNA software to analyse the sugarcane leaves cutting process, and establish a simulation model of sugarcane leaf cutting process [6-8]. This paper analyses the cutting condition and state of sugarcane leaves by simulation, with aims to reveal the working principle of sugarcane leaves cutting mode, and provide reference for the structural design of electric sugarcane leaves returning machine. At the same time, the sugarcane leaves have thin and soft characteristics, which are more easily decomposed than other straw wastes, so the way of sugarcane leaves returning field is more suitable for cutting.

2. Cutting Mode and Moving Parameters of the Rotary Blade

2.1. Cutting Mode

The sugarcane leaves have strong toughness, so if the sugarcane leaves are pulverized, the knives need to consume a large amount of power. The cutting method is divided into single-support cutting and double-support cutting. The working mode of the scissors is single-support cutting, as shown in Figure 1. This mode has higher requirements for the distance and accuracy of the movable knives and the fixed knives. Therefore, the electric sugarcane leaves returning machine uses thin blades and adopts a double-support cutting mode with lower requirements for distance and accuracy between rotary blade and fixed blade (as shown in Figure 1). The rotary blades can cut the sugarcane leaves without excessively high speed to save power.

![Figure 1. The single-support cutting (left) and the double-support cutting (right).](image)

2.2. Moving Parameters of the Rotary Blade

While the rotary blades rotate with the blade roll, they also move forward with the whole machine, so the absolute motion of the blades is composed of rotating motion and the forward motion of the whole machine. Normally, the cutting point of the rotary blade is at the end of the trajectory, so the displacement equation and velocity equation of the rotary blade tip can be obtained (Eq. 1 and Eq. 2).

\[
\begin{align*}
\dot{x} &= V_t + R \cos(\omega t) \\
\dot{y} &= R \sin(\omega t)
\end{align*}
\]

\[
\begin{align*}
\dot{V}_x &= V_t - \omega R \sin(\omega t) \\
\dot{V}_y &= \omega R \cos(\omega t)
\end{align*}
\]

Where \( V_t \) is the forward speed of the machine; \( R \) is the radius of gyration of the rotary blade tip; \( \omega \) is the rotational speed of the rotary blade; \( t \) is time. When the rotational speed of the blade roll is 800rpm and the forward speed of the whole machine is 0.5m/s, the absolute linear velocity of the blades tip obtained by the formula is 6.7m/s, which is smaller than the existing large sugarcane leaves returning machine. It can be seen that the double-supported cutting mode consumes less kinetic energy than the unsupported cutting mode, and is more in line with the operation of the small-scale returning machine to achieve energy saving. In this paper, ANSYS/LS-DYNA software simulation is used to study the cutting process of sugarcane leaves in double-support mode.
3. Sugarcane Leaves Cutting Model

3.1. Sugarcane Leaves Model
The length of mature sugarcane leaves is about 80~150 cm, and the width of leaves is mostly 4~5.39 cm. Sugarcane leaf are composed of vein and blade, with a vein in the middle and blade on both sides of the vein \[9\]. In order to simplify the model, the crescent shape of the vein section is simplified to a semicircle with a radius of 0.24 cm, the leaf section is simplified into a rectangle with the thickness of 0.4 mm, as shown in Figure 2 In the simulation process, the accuracy of the mechanical properties of the sugarcane leaves is crucial, which is related to the rationality of the simulation. The mechanical parameters of sugarcane leaves refer to the existing research literature \[10\]. In this paper, we select the experimental data of dried and middle sugarcane leaves, and calculate the failure strain value of sugarcane leaves for simulation, the specific parameters can be seen in Tab.1.

![Figure 2. Sectional dimensions of the sugarcane leaf model.](image)

| Composition of sugarcane leaves | Elastic Modulus (MPa) | Shear modulus (MPa) | Tensile strength (MPa) | Shear strength (MPa) | Poisson's ratio | Failure strain value |
|--------------------------------|----------------------|---------------------|-----------------------|---------------------|----------------|---------------------|
| Vein                           | 1281                 | 493                 | 33                    | 5.7                 | 0.29           | 0.01                |
| Blade                          | 716                  | 272                 | 22                    | 7.8                 | 0.31           | 0.02                |

3.2. Model Simplification and Assumptions
The following assumptions are made in finite element modelling: 1)To limit the modelling scale and consider the influence of adjacent tool combinations, the model only establishes three sets of rotary blades and fixed blades; 2) When the sugarcane leaves are pushed to the cutting area, their linear velocity is very low with respect to the rotational speed of the blade roll, so the sugarcane leaves are set to a stationary state of being free; 3) The rotation of the blade roll will inevitably produce a self-excited wind field, but the influence of the wind field is ignored in the modelling for limiting the modelling scale; 4) Relative to the deformation of sugarcane leaves, the deformation of the rotary blades, the fixed blades, the blade roll and the frame is very small, so other models besides the sugarcane leaves are set as rigid bodies.

3.3. Parameter Setting and Simulation
A simulation model of sugarcane leaves cutting was established by SolidWorks and imported into the Explicit Dynamics module of ANSYS Workbench software for pre-processing. The model is divided into 25,407 nodes and 49,511 elements by free meshing. The initial speed of the blade roll is defined to 800 rpm, and the boundary condition is that the square tube is set to a fixed constraint. The simulation calculates the k file and imports it into LS-DYNA software.
Figure 3. Meshing and loading of the simulation model.

The model sets the material parameters by LS-DYNA software, in which the square tube is Q235, the blade roll is made of stainless steel, and the blades is made of high carbon steel. The sugarcane leaves are defined as the plastic kinematic material. When the tensile strain or shear strain of the sugarcane leaves reaches the limit value, the sugarcane leaves model elements will be invalid, and the sugarcane leaves will be cut off in the form of deletion, the specific material parameters are referred to Tab.1. The rotational speed of the blades roll is set as 800 rpm. The sugarcane leaves and blades, the sugarcane leaves and the square tube are added contact relationship to avoid penetration. The simulation time is set to 0.02 s and the calculation is performed.

3.4. Analysis of Simulation Results

Through simulation, the whole cutting process of the sugarcane leaf was 120 ms. The post-treatment can observe the cutting process of the sugarcane leaves, which is difficult to observe in actual experiments. The sugarcane leaf cutting model presents different states at different time (0.4 ms, 34 ms, 64 ms, and 110 ms). At \( t=0.4 \) ms, the blades contact the vein, and the stress is concentrated on the vein. At \( 0.4\sim34 \) ms, the incision of the sugarcane leaf gradually become larger and the stress is distributed on both sides of the incision. At \( 34\sim110 \) ms, with the continuous rotation of the blade roll, the sugarcane leaf is finally cut into four segments, and the stress is gradually reduced.

Figure 4. Changes in the incision during sugarcane leaf cutting.

The nodes forces of vein on both sides of the blade are shown in Figure 5 and Figure 6. The four nodes are subjected to the impact force, so that the nodes reach the failure value, and is represented in the deleted form as being cut by the blade. After 5 ms, the nodes are not affected by the force, because the vein is cut by the blade. In addition, it can be seen that the forces acting on the node 1014 and node1019 are significantly greater than the forces acting on the other two nodes, indicating that the nodes are more stressed on the cutting edge side of the blade, which is beneficial for the sugarcane leaves to be cut. Therefore, when the rotary blade is match with the fixed blade, the cutting edge of rotary blade is close to one side of the fixed knife to increase the shearing force.
3.5. Influence of Sugarcane Leaves Stacking

The sugarcane leaves may be in a superimposed state, and be cut by the rotating blades. Therefore, it is necessary to simulate the cutting process of different layers of sugarcane leaves and analyze whether the rotary blades can cut off them. This paper will simulate 2–4 layer sugarcane leaves cutting model. To facilitate simulation and modelling, it is assumed that the sugarcane leaves are flat stacked, and the rotary blade cut the sugarcane leaves layer by layer, as shown in Figure 7. The parameters and constraint settings of this simulation model are the same as the previous simulation model, and the only difference is the number of sugarcane leaves, the simulation results are shown in Figure 8. From the simulation results, the sugarcane leaves can be basically cut off, and there is a little connection on one side of the sugarcane leaves, which is mainly because the cutting area of the blades is narrower than the width of the sugarcane leaves. This does not affect the cutting of the cane leaves in the actual work, because the sugarcane leaves model are modelled according to unfolded state, and in practice the sugarcane leaves are rolled up and narrowed due to the loss of moisture. In actual work, the initial position of the sugarcane leaves being cut is random, so that a part of the sugarcane leaves may be cut off by the blades after enter the cutting zone, and however, the sugarcane leaves that have not been completely cut off also achieve the effect of accelerating natural degradation. Besides, the returning machine can perform two or more cutting operations on the sugarcane leaves to increase the cutting rate.
Figure 7. The simulation stacking form of sugarcane leaf.

a. Two layers sugarcane leaves  b. Three layers sugarcane leaves  c. Four layers sugarcane leaves

Figure 8. The Cutting model of sugarcane leaves of different layers.

4. Test Verification

4.1. Test Equipment and Site
In order to test whether the sugarcane leaves meet the design requirements of the returning field machine in the double-support cutting mode, the machine needs to perform the cutting sugarcane leaves test, as shown in Figure 9. In order to the benefit of the test and statistical analysis, the machine will be carried out on uneven soil. The remaining test instruments include electronic scales, meter scales, tachometers, and computers.

Figure 9. Test site.

4.2. Test Performance Indicators and Methods
The cutting rate of sugarcane leaves is determined by the weighing method, which is the percentage of the weight of the sugarcane leaves that meets the cutting length to the total weight of the test sugarcane leaves (Eq. 3).

\[ \eta = 1 - \frac{m_2}{m_1} \times 100\% \]  

(3)

Where the \( \eta \) is the cutting rate of the sugarcane leaves returning machine, the \( m_1 \) is the total weight of all materials in the test, \( m_2 \) is the weight of the sugarcane leaves material that does not meet the standard.
The yield of sugarcane leaves is 7.5 t/hm², which mean that the yield of sugarcane leaves of per square meter is 0.75 kg [11-12], so when the test, the sugarcane leaves are laid on an area of 2 m², where the length is 2 m and the width is 1m, and the total weight of the sugarcane leaves is 1.5 kg. During the test, the machine is debugged to the best condition. The pickup mechanism collects the sugarcane leaves off the ground and pushed it to the cutting area, and then rotating blades cut the sugarcane leaves. In order to avoid the influence of the leakage rate of the pickup mechanism on the cutting off rate statistics, the leakage rate is controlled to 0% during the test.

4.3. Analysis of Test Results
The test materials were collected from Xintai Sugar No. 22, which is widely planted in China. The test carried out five sets of data collection, as shown in Tab.4. The average cutting off rate in the table is 91.57%, which satisfies the working requirements of the sugarcane leaves returning machine. It can be seen that the sugarcane leaves cutting mode can meet the requirements of machine, and the simulation of sugarcane leaves cutting model can give the theoretical reference and analysis for the design of returning machine.

Table 2. Test data.

| test number | m₁/kg | m₂/kg | cutting off rate (%) |
|-------------|-------|-------|----------------------|
| 1           | 1.5   | 0.1236| 91.76                |
| 2           | 1.5   | 0.1153| 92.31                |
| 3           | 1.5   | 0.1207| 91.95                |
| 4           | 1.5   | 0.1331| 91.13                |
| 5           | 1.5   | 0.1398| 90.68                |

5. Conclusion
Through the finite element software, the sugarcane leaves cutting process of different number layers is simulated and the following conclusions can be made:
1) The analysis results show that the blade roll with 800 rpm can cut off the multilayer sugarcane leaves.
2) During the cutting process of the sugarcane leaves, the stress on the sugarcane leaves on the blade edge is much larger than that on the other side, indicating that the smaller the distance between the rotary blade and the fixed blade is, the more favourable the sugarcane leaves to be cut off.
3) The cutting off rate of the electric sugarcane leaves returning machine is 91.47%, which verifies the correctness of the modelling and simulation of the sugarcane cutting process, and provides theoretical basis for the research of the sugarcane leaves returning machine.
4) In the future, the electric returning machine can be further studied from the aspect of intelligence such as route planning and automatic driving.

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References
[1] Lin Xiao. 2019. The development of the sugarcane harvesters in China. Agricultural Engineering, vol9, No1, pp 7-9.
[2] Graham M H, Haynes R J and Meyer J H.2002. Soil organic matter content and quality: effects of fertilizer applications, burning and trash retention on a long-term sugarcane experiment in South Africa. Soil Biology and Biochemistry, vol34, No1, pp93-102.
[3] Ming Li, Jinli Wang, Yiguo Deng, Hui Huang and Jin Zhang. 2008. Structural design and experiments on sugarcane leaf shattering and returning machine. Transactions of the Chinese Society of Agricultural Engineering, vol 24, No 2, pp121-126.
[4] Xu Zhenhua. 2016. *Simulation Research on Working Process of Flexible Cutter of a Sugarcane Leaf Cutting and Returning to Field Machine* (Guangzhou: South China Agricultural University Press) pp19-75.

[5] Heyang Huang, Yuxing Wang, Jing Wang, Lixin Zhao, Zhenhua Xu and Jiaxian Lu. 2015. *After Inserting Vegetable Transplant Transplanting Mechanism Dynamics Analysis and Simulation*. *Journal of Agricultural Mechanization Research*, vol37, No2, pp87-90+97.

[6] Guohe Li, Minjie Wang and Chunzheng Duan. 2007. Finite element simulation of the process of orthogonal metal cutting based on the ANSYS/LS-DYNA. *Transactions of the Chinese Society for Agricultural Machinery*, vol38, No12, pp173-176.

[7] Handong Huang, Yuxing Wang, Yanqin Tang, Feng Zhao and Xiangfa Kong. 2011. Finite element simulation of sugarcane cutting. *Transactions of the Chinese Society of Agricultural Engineering*, vol 27, No2, pp161-166.

[8] Junfang Xia, Xiaowei He, Shuisheng Yu and Yong Zhou. 2013. Finite element simulation of soil cutting with rotary knife roller based on ANSYS/LS-DYNA software. *Transactions of the Chinese Society of Agricultural Engineering*, vol29, No10, pp34-41+293.

[9] Huiqing Yang, Ximei Xing and Jian Chen. 1997. The study on Leaf Width of Sugarcane Varieties. *Jiangxi Agricultural Science & Technology*, No6, pp21-23.

[10] Yuanwei Ye. 2012. *Key Technique Research about Pretreatment Pulp Machine of Sugarcane Leaves' Fermentation* (Haikou: Hainan University Press).

[11] Qing Liao, Guangpo Wei, Guifen Chen, Bin Liu, Dongliang Huang and Yangrui Li. 2011. Effect of Trash Returning on Microbial Communities, Physical and Chemical Properties of Soil and Plant Growth of Sugarcane. *Southwest China Journal of Agricultural Sciences*, No2, pp658-662.

[12] Xiongwei Cui, Yuebin Zhang, Jiawen Guo, Shaochun Liu and Jingmei Dao. 2010. Effects of Different Patterns of Sugarcane Leaf Returning Field on Soil Moisture and Sugarcane Yield. *Sugar Crops of China*, No4, pp21-23.