

Movement Simulation of Sugarcane Harvester Cutter Based on ANSYS/LS-DYNA

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Abstract—By analyzing the working principle of sugarcane harvester cutter, geometric model and finite element model of sugarcane are established. According to the actual working condition, the finite element analysis software was carried out to get the displacement nephogram of stress, cutting force curve and other results. The field cutting of cutter was tested and verified. Experiments show that the model has higher accuracy. The broken rate is the lowest when the speed of cutting disk is 600 r/min, advance speed is 0.5 m/s, the blade edge angle is 18 degrees, and blades for cutting Angle is 20 degrees.

Keywords—sugarcane harvester cutter; design; simulation; experiments

I. INTRODUCTION

China is one of the production of sugar cane country. After Brazil and India, the planting area of sugar cane is 20 million acres in China. Compared with developed countries, low level of agricultural mechanization has become an obstacle to development of our agricultural. Thus to develop and produce high-quality harvesting machinery is crucial, especially sugar cane harvesting machinery. At present, the harvest process of sugar cane is facing a series of problems: majority of our fields, which are located in hilly areas, are small size. However, foreign machinery is large and expensive. Although a number of sugar cane harvesters are manufactured, these machines also exist many problems in the process of harvesting sugar cane. These problems are as follows: high broken rate of sugar cane, high impurity ratio, low efficiency and so on. Sugarcane belongs to perennial plants. Its yield of next year directly depends on the sugarcane cutter cutting quality of this year [1]. Thus broken rate of sugarcane is a major indicator of cutting quality. Sugarcane cutter, as a key component, have an important impact. At present, the research on sugarcane cutter is ongoing, which are concentrated in the life of the cutter, efficiency and broken rate. However, the study is still not perfect, and further studies should be done [2].

II. DYNAMIC SIMULATION OF THE SUGARCANE CUTTER

A. Geometric Model of Sugarcane

There are two general ways to finite element model: the

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model is established in ANSYS; the established model is imported to ANSYS. Taking into account that the second method may cause wrong results [3]. The first method is chosen. Furthermore, without influence on perform of sugarcane cutter, the model can be simplified. Geometric model of sugarcane sees Fig. 1.

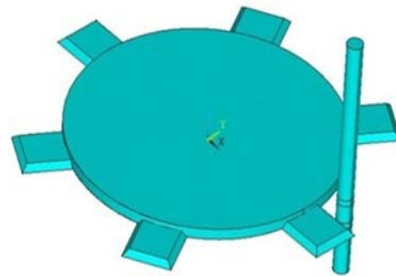


Fig. 1. Geometric model of cutter – sugarcane

B. Material Model

Sugarcane is composed of rind and cane core, which is an anisotropic, nonlinear, heterogeneous viscoelastic material. Taking into account the differences in physical and mechanical properties of the different sugarcane and the axial failure of sugarcane's Incision is low, model of sugarcane is taken as an entirety. And sugarcane is defined as isotropic elastic-plastic material. The plastic Kinematic model is as follows.

$$\sigma_y = \left[1 + \left(\frac{\varepsilon_1}{C} \right)^{\frac{1}{p}} \right] (\sigma_0 + \beta E_p \varepsilon_p^{eff}) \quad (1)$$

In the type: σ_0 stands for initial yield stress; ε_1 stands for strain rate; c and p stand for parameters of strain rate; ε_p^{eff} stands for effective plastic strain.

C. MESHING AND LOADING

Meshing, as the most important part of finite element analysis, directly determines the accuracy and speed of calculation. Hexahedral meshing is used to ensure accuracy. The number of units in the meshing of the cutter is 245810. According to the principle of the meshing, the sugarcane should be divide into three phases: contact zone, transition zone and non-contact area. The meshing of contact area should

be divided into refined, and the size of meshing is 0.2mm; the size of transition zone is 2mm; the size of remaining area is 60mm. The number of units are 168 210. The finite element model of sugarcane cutter sees Fig. 2.

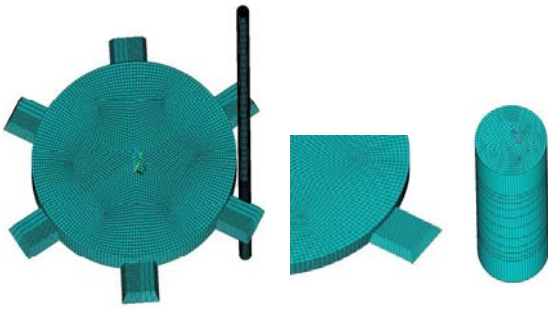


Fig. 2. The finite element model of sugarcane cutter

III. RESULTS OF CUTTING SIMULATION

A. Equivalent Stress Analysis

The stress nephogram of sugarcane cutting process sees Fig. 3.

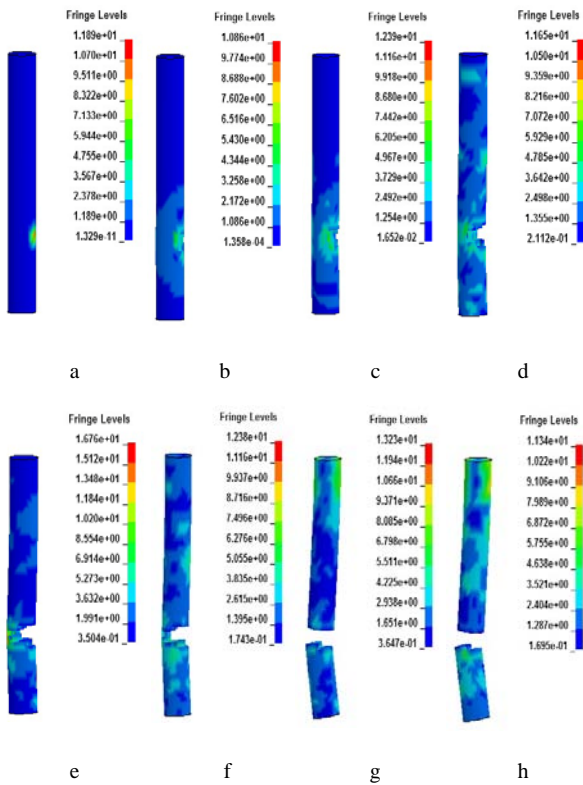


Fig. 3. The stress nephogram of sugarcane cutting process

As we can see in the figure 4, the red zone of stress nephogram represents the maximum stress, the blue area indicates the minimum stress. The Stress during the cutting process is very small, and its maximum equivalent stress is 16.76Mpa. During sugarcane cutting process, when the blade is full in contact with sugarcane, sugarcane suffered the greatest compressive stress. The stress gradually rises, until the sugarcane is completely cut off.

B. Displacement Nephogram of Sugarcane Cutter

The Y-displacement nephogram of sugarcane cutter during the cutting process over time sees Fig. 4.

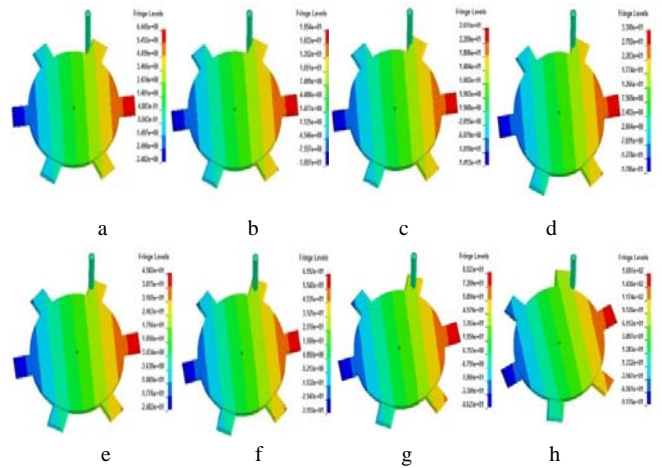


Fig. 4. Y-displacement nephogram of sugarcane cutter

The displacement nephogram of sugarcane cutter mainly shows the process of cutting move and. As what can be seen in Figure 4, the deformation of cutter is small, which indicates that the stiffness of the cutter is sufficient.

C. Curve of Cutting force

X-force represents the radial cutting force; Y-force represents the axial cutting force; Z-force represents circumferential force. The curves of X direction, Y direction and Z direction see Fig. 5.

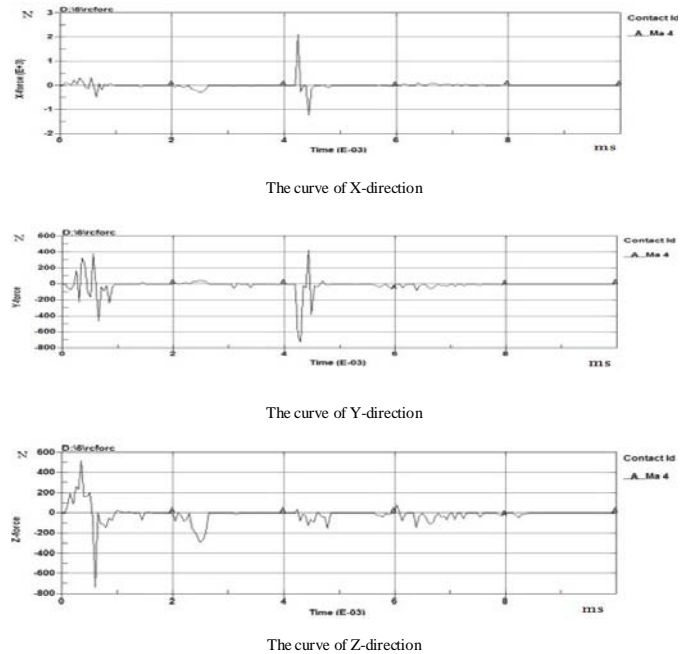


Fig. 5. The curve of cutting force

In Figure 5, the maximum radial cutting force is 2N; the maximum axial force is 415N; the maximum circumferential force is 30N; and the negative number indicates the rebound of

the cutter in the process of cutting process. During the normal process of cutting, the radial cutting force and circumferential cutting forces are small, Y- axial cutting forces is the main cutting force.

The cutting process is dynamic, changing from zero to the maximum, and then from the maximum down to zero. The results of analysis show that there are two place, the connection of axis and cutter and parts of the cutter edge, should be strengthened in the design because of the maximum stress.

IV. TEST OF CUTTING

A. Program of Cutting Test

The method of quadratic regression orthogonal is used to optimal design of sugarcane cutter.

Factors of the test: x_1 (r/min) stands for the speed of the cutter; x_2 (°) stands for the edge angle; x_3 (m/s) stands for the speed of the harvester; x_4 (°) stands for cutting angle.

Indicator of the test: Y (%) stands for broken rate.

$$n = m_c + 2p + m_0 \tag{2}$$

In the type: n stands for number of the test; $m_c = 2^p$, p stands for number of the factors; m_0 stands for number of center point test

$$\frac{n(m_0 p + 2r^4)}{(p + 2)(m_c + 2r^4)^2} = 1 \tag{3}$$

In the type: $p = 4$, $r = \sqrt[4]{m_c} = 2$; $m_0 = 24$ ($m_0 \geq 0$), $n = 48$.

Coding of each factors are as follow.

$$x_{0j} = \frac{x_{rj} + x_{-rj}}{2} \tag{4}$$

$$\Delta_j = \frac{x_{rj} - x_{-rj}}{r} \tag{5}$$

$$z_j = \frac{x_j + x_{0j}}{\Delta_j} \tag{6}$$

Coding table of factors sees table 1.

Table 1 Coding table of factors

Level	Factor x_1	Factor x_2	Factor x_3	Factor x_4
Upper asterisk (+2.215)	800	21.5	1.2	25
Upper level (+1)	750	18	1	16

Zero level (0)	650	14	0.8	12
Under level (-1)	550	10	0.5	5
Under asterisk (-2.215)	450	6	0.2	0
Δ_j	75	3.75	0.2	6.5

B. Experimental Procedure

Each test 100 sugarcane was selected, then observe the broken rate. The results of the test see in Table 2 [4].

Table 2 Test results data tables

	x_1 (r/min)	x_2 (°)	x_3 (m/s)	x_4 (°)	Broken rate (%)
1	650	14	0.8	12	3.145
2	650	14	0.5	5	5.234
3	650	10	0.8	5	4.326
⋮	⋮	⋮	⋮	⋮	⋮
48	800	21.5	1.2	25	10.383

C. Regression Analysis

There are four parameters according to the study. To execute the regression analysis of experimental data, the interaction between the two factors considered.

$$\hat{y} = b_0 + \sum_{j=1}^p b_j x_j + \sum_{k=1}^{p-1} \sum_{j=k+1}^p b_{kj} x_k + \sum_{j=1}^p b_{jj} x_j^2 \tag{7}$$

In the type: p stands for number of variables; $j = 0, 1, 2, \dots, p$, $i = 0, 1, 2, \dots, p - 1$.

The correlation coefficient can be determined through curve fitting toolbox of Matlab. According to the results of the data analysis, the optimal regression equation is:

$$F(x_1, x_2, x_3, x_4) = 42.328 - 0.179x_1 + 10.125x_3 - 4.516x_2x_3 + 1.468x_2x_4 + 1.328 \times 10^{-4} x_1^2 - 1.058x_3^2 - 2.68 \times 10^{-2} x_4^2 \tag{8}$$

V. OPTIMIZATION PARAMETERS

A. Mathematical Model

According to the constraints of the objective function formula $F \geq 0$, the mathematical model formula is:

$$F(x_1, x_2, x_3, x_4) = 42.328 - 0.179x_1 + 10.125x_3 - 4.516x_2x_3 + 1.468x_2x_4 + 1.328 \times 10^{-4} x_1^2 - 1.058x_3^2 - 2.68 \times 10^{-2} x_4^2$$

$$\begin{cases} \text{MINF} \\ 600 \leq x_1 \leq 800 \\ 16 \leq x_2 \leq 19 \\ 0.4 \leq x_3 \leq 0.8 \\ 14 \leq x_4 \leq 18 \end{cases} \quad (9)$$

The minimum of the broken rate is $F = 2.376 \times 10^{-3}$, and the optimization parameter of the four factors are: $x_1 = 650$, $x_2 = 18$, $x_3 = 0.5$, $x_4 = 17$.

B. Experimental Verification of Optimal Results

According to the previous optimized data, re-create a set of blades for verification. The number of trials is 20 times, and the number of sugarcane in each trial is 100. The average of the broken rate is 1.325%, which shows that the mathematical model of the optimization is right. The results of verification test see Table 3.

Table 3 Results of Experiment

	$x_1(r/min)$	$x_2(^{\circ})$	$x_3(m/s)$	$x_4(^{\circ})$	Broken rate (%)
1	650	18	0.5	17	1.325

VI. CONCLUSION

Based on the method of virtual design and virtual simulation technology, the cutter of sugarcane harvester was

design. The structural parameters of cutter (blade edge angle, blade cutting angle) and motion parameters (cutting speed and forward speed) were simulated and tested. Experiments show that the model has higher accuracy. It also has certain theory and application value to improve the cutting quality of the cutter, and to reduce the rate of breaking of the sugarcane.

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REFERENCES

- [1] Y. Lv, "Simulant kinematics analysis on mechanism study of the affecting factors of cutting capability of single base cutter of sugarcane harvester", Nanning: Guangxi University, China, pp. 10-28, 2007.
- [2] X. Lai, S.P. Li, and Z.W. Qin, et al, "Simulation and Experiment Study on a New Sugarcane Cutting Device", Journal of Agricultural Mechanization Research, China, vol. 02, pp. 102-105, 1955.
- [3] Y.H. Qiao, "Kinematic simulation research on affecting incision quality of the dual base cutter of a sugarcane harvester", Nanning: Guangxi University, China, pp. 42-48, 2007.
- [4] J.G. Chen, "Experiment research and mechanism analyse of affecting factors on the rate of broken biennial root of the single base cutter of a sugarcane harvester", Nanning: Guangxi University, China, pp. 10-28, 2007.