Simulation Analysis and Experimental Study on Strength of Castor Cutting Cutter

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Abstract. Castor oil is an important oil crop. In this paper, the parameter setting of the castor harvesting device cutter head is tested and analyzed. The stress changes of the castor stalks and the cutter head during the cutting process were studied by the simulation experiment. To determine the best working parameters of the knife dish experiment material model for mechanical properties, the shear test of castor stem is done. To determine the castor stem shear modulus and Poisson's ratio, and through the test to determine the castor stem density, castor stem material based on this model is established. In the simulation cutting, on the one hand, cut back and forth on the other hand to establish a three-dimensional model of the blade, the blade parameters of the cut back and forth (blade Angle Cutting speed) for castor stem cutting effect are got. The results of two kinds of cutting way two-factor variance analysis and judgment for cutting the significant influence of various factors are got. By comparing the two types of cutting performance, the best parameters for cutting are accomplished. Finally, the knife dish at work cutting effect is the best parameter selection. The study complete castor harvest machinery for the future provide theoretical basis.

Keywords: Castor, Cutterhead, Ethnical properties, Simulation Analysis, Experimental Study.

1. Introduction
Castor is one of the world's top ten oil crops, castor fruit can be used to extract oil, and castor oil can be used as an important chemical raw material, production of lubricating oil paint surfactant such as hundreds of kinds of chemical products, because of its green harmless characteristics, has been widely used in air defense chemical medicine and mechanical industries, and its renewable nature, called renewable green oil [1]. Domestic research on castor harvest is still in its infancy, and castor harvesting machinery is mostly improved on the basis of corn and rice harvesting machines. Based on the burlap harvester's cutterhead design, it can be used to learn from other plants' cutterheads. Based on optimization and improvement. Weeds and weeding are important parts of orchard plant protection. Due to the high cost of manual mowing and the complex geography of the orchard, the topological optimization method can be used to optimize the design of the mower cutter. The research team of Jiangsu Academy of Agricultural Sciences used the three-dimensional software pro/e to make the digital model of the cutterhead [3], and carried out finite element analysis on the cutterhead to obtain the ultimate resistance before optimization. Then the topology of the cutterhead was optimized by
hyperworks. Jiawei's team from the College of Mechanical and Electrical Engineering of Guilin University of Electronic Science and Technology adopted the orthogonal test scheme [4], and studied the relationship between cutting torque and cutting loss and the rotational speed of the disc cutter, the inclination angle of the disc cutter, the slip angle of the blade. Ramie, ramie fiber is an important textile material, so research on ramie cutting is very important. The Agricultural Machinery and Chemistry Division of Hunan Agricultural University [5], established a material model of ramie, and used the finite element cutting simulation test to study the cutting loss between ramie and the motion parameters and structural parameters of the cutter. In the 1960s, thanks to the RayVenton-designed harvester, the height of the cutter was adjustable, the turning radius of the cutting machine was reduced, the finger feeder was added, and the cut-off beam was bundled. [7].

The relationship between biological characteristics and structure is not the same. In summary, the experimental study and mechanical properties of the mechanical properties of the castor rod diameter are in their infancy, and there is no more theory to support the relevant research. In the process of castor harvesting, the interaction between cutter and castor rod diameter is supported by relevant theory, which provides theoretical basis for the development of ramie harvesting machinery.

2. Castor stem diameter mechanical characteristic test

The castor stalk was tested for elastic modulus. The instrument used in the experiment was mainly a texture analyzer. The shearing maximum stress that the texture analyzer can measure is 1000N. The shear stress variation curve of the castor stem in the shearing process can be seen on the connected computer. The displacement of the castor stem and the maximum shear stress of the castor stem.

The moisture content of the castor stem and the castor are considered in the experiment. Two variables were used to test the stalk cutting position. The cutting parts of the castor stem were divided into three parts: bottom, middle and top. The water content was 20%, 25% and 30%. The curves obtained during the cutting process of castor stalks are roughly the same. The experiment shows that under the influence of different water content and different shearing sites, the stress characteristics of castor stalks have not changed, but only by shearing force. Therefore, the water content is 30%, and the cutting part is the top to study the stress characteristics of the castor stem. It can be seen from Figure 1 that during the shearing process of the castor stem, the maximum shearing force will be obtained at the second peak. And the maximum shear can be obtained in the test. Therefore, subsequent processes can be processed according to these parameters.

![Shear force variation diagram](image)

Figure 1. Shear force variation diagram

Since there is no elastic modulus in the data obtained by texture analyzer, it is necessary to calculate the elastic modulus.

$$G = \frac{\tau}{\gamma}$$
\[ \tau = \frac{F}{S} \]  \hspace{1cm} (2)

The formula of shear modulus obtained by simultaneous equation (2-1) (2-2) is \( G = \frac{F}{S \cdot \gamma} \). Because the shear force obtained by shear test of castor stems varies with displacement, and the work done by cutting tools in this process can be measured by texture analyzer in this process, the shear force in the formula can be regarded as equivalent. If the average shear stress is \( F = W / L \), the original formula can be transformed into \( G = \frac{W}{S \cdot L \cdot \gamma} \), and the cutting area of castor stalk xylem is 62.31 mm. After simplification, the shear modulus of castor stalk xylem can be obtained.

**Table 1. castor stalk shear data**

| Work by shear force W \((N*mm)\) | Strain \(\gamma\) | Work distance \((mm)\) | modulus of rigidity \((MPa)\) |
|----------------------------------|-----------------|----------------------|-----------------------------|
| A1 729.91                       | 0.16            | 4.10                 | 18.41                       |
| A2 1329.77                      | 0.16            | 4.20                 | 31.97                       |
| A3 1006.60                      | 0.15            | 3.90                 | 28.06                       |
| B1 879.66                       | 0.14            | 3.70                 | 27.25                       |
| B2 1047.66                      | 0.15            | 4.00                 | 27.77                       |
| B3 1015.14                      | 0.15            | 3.90                 | 28.30                       |
| C1 1026.45                      | 0.14            | 3.70                 | 31.79                       |
| C2 867.68                       | 0.14            | 3.80                 | 25.48                       |
| C3 952.97                       | 0.16            | 4.20                 | 22.91                       |

Among them, A, B, and C have water content of 30%, 25%, and 20% respectively. The numbers 1, 2, and 3 respectively represent the loading position as the top, middle, and bottom positions. After processing the data, the shear modulus of the xylem of the castor stalk G1=26.88MPa can be obtained. According to the calculation method of the xylem of the castor stem, the shear modulus of the fiber part of the castor stem can be determined as G2=8.08MPa.

The maximum shearing force, when the water content is 30%, 25%, the maximum shearing force is exhibited as the shearing portion is lowered. The trend of increasing go first and then decreases; when the water content is 20%, the maximum shearing force decreases first and then increases with the decrease of the shearing part. When the shearing position is located at the middle and bottom, the maximum moisture content decreases. The shear force is continuously reduced; when the shear position is at the top, the maximum shear force increases as the water content decreases.

Due to the limited test conditions, the Poisson's ratio of castor stems could not be obtained through experiments. Therefore, the xylem Poisson's ratio of castor stalks was only \(\nu=0.314\), and the fiber partial Poisson's ratio was \(\nu=0.467\). The density of the stalk can also be obtained through experiments. The density formula \(\rho=m/V\), the quality of the castor stem can be obtained by the balance. Since the volume of the castor stem is not a regular geometry, it can only be obtained by the drainage method. The volume finally obtained the density of castor stems is 180kg / m3. The diameter of the castor stalk can be measured by Vernier calipers, the castor stalk is obtained. The diameter D=26.42 mm, wherein the thickness of the xylem portion and the fiber portion are 5.67 mm and 1.1 mm, respectively. The result is shown in table 2.
3. Tool Design Simulation

3.1. Design of Parameters for Rotary Cutter Head

Since the existing machinery does not have the cutter head parameter design of the ramie harvesting machine, the existing parameters of the cutter disc are studied by referring to the materials, and combined with the structural characteristics of the existing ramie stalk, the cutter head is designed. The 3D cutter parameters for two different numbers of teeth are shown in Figure 2.

![Figure 2. Cutter block diagram](image)

1. Moving knife; 2. holding device; 3. castor stalk.

The material of the cutter head is set to 65Mn, the material property is set according to the material property of 65Mn, the density is $7.81 \times 10^3$ kg/m$^3$, the elastic modulus is 198 Gpa, and the Poisson's ratio is 0.3. These material properties will be entered into the software as tool material properties for the cutter head in subsequent tests.

![Figure 3. Blade device](image)

Table 2. Model parameters of stem materials of castor stalks

| Material | Modulus of rigidity (MPa) | Poisson ratio | Thickness (mm) |
|----------|---------------------------|---------------|----------------|
| xylem    | 26.88                     | 0.31          | 5.67           |
| Fiber    | 8.08                      | 0.47          | 1.1            |

| Table 3. The knife dish parameters |
|-----------------------------------|
| **Thickness (mm)** | **Bore (mm)** | **Flute Length (mm)** | **Neutral** | **Velocity of approach (m/s)** | **Material of knife dish** |
|---------------------|---------------|-----------------------|-------------|-------------------------------|--------------------------|
| The dish a           | 4             | 200                   | 35          | 8                             | 0.8                      | 65Mn                     |
| The dish b           | 4             | 200                   | 35          | 12                            | 0.8                      | 65Mn                     |

3.2. Design of Parameters of the Round-trip Cutting Blade

The reciprocating cutting mode is mainly to set the parameters of the movable knife and the clamping device, which plays the role of fixing and supporting the castor stalk in the cutting process, and the movable blade plays the role of cutting the castor stalk. Because the cutting speed and the edge angle of the blade have certain influence on the cutting process, the reciprocating cutting test can be simulated by setting the cutting speed and the edge angle of the blade. The parameters of the reciprocating cutting blade are set by consulting the parameters of the same type of sugarcane and ramie, so the parameters of the reciprocating cutting blade are designed as follows:
Table 4. The blade parameters

| Sliding cutting angle (°) | Top Thick (mm) | Flute Length (mm) | Rank Angle of Cutter (°) |
|--------------------------|----------------|------------------|--------------------------|
| Blade                    | 20             | 3                | 120                      | 0                        |

The blade is composed of a clamping device and a moving knife. The advance speed of the blade is 0.8 m/s, the material of the blade is 65Mn, the density is $7.81 \times 10^3$ kg/m³, the elastic modulus is 198 GPa, and the Poisson's ratio is 0.3. The clamping device draws on the structure of the clamping portion of the corn harvesting machine, and on this basis, simplifies the growth of the restrained castor stalk, wherein the blade is shown in Figure 5.

3.3. Strength Check of Blade

The reciprocating cutting motion and the rotary cutter cutting movement have very high requirements on the strength of the blade and the cutter head. It is necessary to ensure that the maximum stress of the blade and the cutter disc during the cutting process does not exceed the yield strength of 65Mn. The static analysis section of Simulation is checked.

Because the maximum shear force is different in the shear test of the ramie stem, the maximum shear force $F=748\text{N}$ is taken during the blade stress check. As the load force received by the blade, the specific part of the force is shown in Figure 6. During the static stress analysis process, the material property of the blade material 65Mn is input into the database and applied, and the bottom of the blade is restrained. The system naturally generates the mesh according to high precision, and obtains the equivalent stress and deformation map of the blade in the later stage of the test, and can Obtaining the maximum equivalent stress experienced by the blade can be used as a basis for later strength check analysis. The test results are shown in Figure 4 and Figure 5.

![Figure 4. Blade Angle of 25° stress situation](image)

![Figure 5. Blade Angle of 22° stress situation](image)
From the results of the static stress analysis of the blades in Fig. 6 and Fig. 7, it can be seen that the force on the blade is mainly concentrated at the cutting edge and the stress on the other parts is small, so the blade is the most easily worn part in the cutting process. The notches in the figure above are shown, but from (f) and (c) diagrams, the deformation of the blade is very small, and the maximum is 0.005mm. When the blade inclination is 22° and 25° respectively, the equivalent stress of the blade in each part is approximately the same, and the maximum equivalent stress is known from (b) and (e) diagrams respectively. It is 158.7 MPa and 159.7 MPa, and both are less than 430 MPa of the yield limit of the blade. Therefore, the blade can be considered to meet the strength standard in the cutting process.

3.4. Strength Check of Cutter Plate
The strength check of the cutter head can be compared with the strength check of the insert. By analyzing the stress conditions of the two in the strength check, it can be used as an indicator to compare the cutting performance of the two. The static stress analysis process setting of the cutterhead is approximately the same as that of the insert. Take the maximum shear force \( F = 748 \text{N} \) as the load force of the cutter head, load the constraint and mesh, and input the material property of 65Mn into the cutter head. After the parameter setting of the static stress of the cutter head is completed, the analysis process is started. The equivalent stress and deformation diagram of the cutter head are obtained in the later stage of the test. As a reference index in the process of analyzing the strength of the cutter head, the results obtained in the test are as follows in Figure 6 and Figure 7.

![Figure 6. Stress of the number of cutter teeth](image)
According to the results of the static stress analysis of the cutter head, the stress of the cutter head is mainly concentrated on the edge teeth of the cutter head, that is, the most easily worn part. From the figures (g) and (k), it can be seen that the number of teeth of the cutter head has little effect on the stress of the cutter head, and the stress distribution of the cutter head is roughly the same; from the figures (h) and (m), it can be seen that the number of teeth of the cutter head is 12 and 8 respectively in the cutting process. The maximum equivalent stress of the cutter head is 40.3MPa and 40.4MPa respectively. It is less than the yield limit 430MPa of the cutter head, so it can be considered that the designed cutter head accords with the strength index.

1. When the cutter head is subjected to the maximum shear force, the deformation amount of each part of the cutter head is larger than the deformation amount of the insert.

2. The maximum equivalent stress received by the cutter head during the strength check process is less than the maximum equivalent stress received by the insert, and the maximum equivalent stress of both is less than the yield limit of 65Mn, so it can be considered that the two meet the cutting strength.

The second is to divide the mesh of the castor stem and the blade. Due to the complicated force of the contact part, the element size of the blade in the contact part of the sizing is set to 4 mm, and the element size of the cylinder of the contact part is 10 mm. The element size of the blade of the non-contact portion is 4 mm, and the castor stem is 4 mm. Considering the complexity of the calculation, the smoothing is set to the medium degree. The cutting speed of the blade is set to the test variable, which is set to three values of 1 m/s, 1.5 m/s, 2 m/s, and 3 m/s, respectively. The lower end of the castor stem and the holding device are fixed, and the post-processing equivalent is inserted. Stress (equivalent stress) and shear stress are indicators of post-processing data. Finally, solve begins to simulate the simulation cutting process.
4. Conclusion
In this paper, the research is carried out according to the relevant requirements, and the cutting performance of castor rod diameter is studied. Firstly, the material model of castor stalk was established. The process of reciprocating cutting and rotary cutting of the cutterhead was simulated by Ansys display dynamic cutting simulation. The following conclusions were obtained by comparing the later test data:

1. During the reciprocating cutting process, the cutting speed and the blade inclination have a significant influence on the shear stress, but the interaction between the two has little effect on the shear stress; at the same time, the cutting speed and interaction have a significant influence on the reaction stress. However, the influence of the blade inclination on the reaction stress is not significant.

2. During the rotary cutting process of the cutter head, the influence of the inclination angle and the number of teeth of the cutter head on the shear stress and the reaction stress is not significant, but the interaction between the two has a significant influence on the reaction stress.

3. During the round-trip cutting process, the best working parameters of the blade are cutting speed 2m/s and blade inclination angle 25°; during the rotary cutting process of the cutter head, the optimal working parameter of the cutter head is the cutter head inclination angle 15°. The number of teeth of the cutter head is 8.

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