Journal of Engineering Mechanics and Machinery (2025)
Clausius Scientific Press, Canada

DOI: 10.23977/jemm.2025.100112
ISSN 2371-9133 Vol. 10 Num. 1

Design and simulation analysis of leaf removal mechanism of lettuce

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Keywords: Lettuce; Defoliate; Simulation analysis

Abstract: Lettuce leaf removal is an important part of mechanized harvesting of lettuce, and it is also one of the main functions of lettuce harvester. An adaptive Angle opening and closing mechanism for leaf removal of lettuce was designed in this paper. The size and type of the defoliating mechanism were determined based on the external characteristics of lettuce, and its reliability was analyzed by simulation. In addition, the blade resistance and the driving power required during operation are calculated, and the minimum power of the motor required is determined.

1. Introduction

Lettuce is an annual or biennial herb of lettuces of Compositae family, which is one of the main vegetable crops in China, and its planting scale is very huge, but at present, the leaves of lettuce in China are harvested manually, and the process of manually removing leaves of lettuce is very tedious, requiring long-term repeated bending, high labor intensity, low labor efficiency, and high labor cost [1]. The research of mechanized harvesting lettuce is still in the theoretical stage, and the precision of leaf removal cannot be realized. Smart agriculture is the development trend of agriculture in the future. As a part of the vision of smart agriculture, automated harvesting and leaf removal of lettuce is an inevitable path to realize the intelligence of various production links in agricultural production through a new generation of information technology [2].Most of the research work of vegetable harvesting machines is still in the initial stage, and the leaf removal machine of lettuce can not be automated and intelligent. Due to the brittle texture of the stem of lettuce [3], the extrusion or collision of external forces in the process of leaf removal will cause damage, and the strength and speed of leaf removal need to be controlled in the mechanical process of leaf removal. In order to solve the problem of precise leaf removal of lettuce, an adaptive opening and closing Angle leaf removal mechanism was designed to achieve efficient leaf removal and recycling of lettuce, reduce waste, and help farmers solve the dilemma of manual leaf removal.

2. Defoliating mechanism design

Leaf removal mechanism is the main device of lettuce leaf removal, the most important is the design of leaf removal claw, in order to adapt to different sizes of lettuce roots, the claw piece inner ring curvature, grasping force size analysis and design, the design of the main harvest object for the maturity of higher lettuce (usually growth time of about 60-90 days, lettuce is highly concentrated in 31~45cm,The average height was 38cm, the diameter of the stem was concentrated in 4.01~4.5cm, the average diameter was 4.25cm).Stem diameter and plant height of lettuce can be used as reference for defoliating system design. According to the way of manual leaf removal, the imitation human hand leaf removal claw is designed. A three-dimensional model of the mechanism is shown in Figure 1.

The lettuce is placed on the limiting convex and the supporting convex, and the movement of the lettuce is restricted by the limiting convex. After the mechanical claw is grasped at the supporting convex end, the lettuce leaves are pushed away by the screw drive to the limiting convex end [4].The mechanism imitated the manual leaf removal process design, for different sizes of lettuce by detecting the size of the current generated when the steering gear rotation to monitor the size of the gripping force, so as to achieve dynamic control of lettuce.

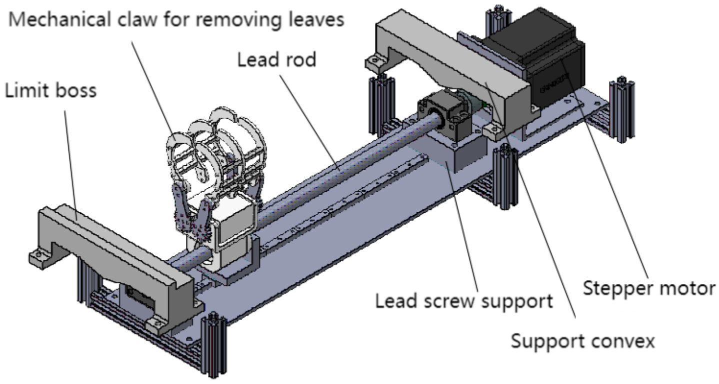

Figure 1. 3D model of defoliating mechanism

2.1 Structural design

The leaf removing mechanism mainly includes a limit boss, a support boss, a lead screw, a leaf removing mechanical claw, a stepper motor and other components. The lettuce to be removed is placed on a limit boss and a support boss. The two bosses limit the displacement of the lettuce during the removal of leaves. Leaf removal mechanical claw imitation artificial leaf removal design is circular, by adjusting the gripping Angle to adapt to different sizes of lettuce, in the circuit design of the mechanical claw drive steering gear current size monitoring, through feedback control of the steering gear opening and closing Angle to prevent lettuce from being damaged by extrusion or the lack of gripping Angle can not complete the leaf removal. The stepper motor drives the screw to pull off the lettuce leaves after the mechanical claw is grasped. In the working process, the support is installed with a sliding rail slider, connected with the screw nut holder, to provide support for the smooth operation of the mechanical claw in the process of leaf removal, to ensure the stability of the mechanism.

2.2 Motor drive power

Screw thread rise Angle during operation:

$$\alpha = \tan^{-1}\left(\frac{L}{\pi D}\right) \tag{1}$$

In the formula: is the value of the lead of the screw, the unit is mm; Is the outside diameter of the lead screw, the unit is mm.

The corresponding size parameters are substituted into the above formula to calculate α≈5.71°

Calculation of the thrust required by the lead screw during operation [5]:

$$F = F_{\text{叶}} + \frac{F_N}{\cos\alpha} + \mu F_N \tag{2}$$

The load on the lead screw base is indicated in the formula, unit N, represents the additional thrust required to overcome the friction force, unit N, friction coefficient of 0.25.

Add the data and calculate $F=35.1N$

The formula for calculating the minimum drive power required by the motor is

$$P_{\min} = F * \frac{nL}{60} \tag{3}$$

Based on the above analysis and formula, $P_{min}=438.75W$ is calculated

3. Simulation and optimization of defoliating claw

3.1 Integral simulation analysis

Leaf claw is the key to leaf removal. The blade is pulled away by hand [6], and the inside of the blade is designed as an arc. The diameter of mature lettuce is between 4.01~4.5cm, and the average value of 4.25cm in the claw plate is obtained. The stress displacement analysis can optimize the structure and improve the reliability of the design. The finite element analysis model in Solidworks uses SolidWorks Similation to carry out finite element analysis of its stress and displacement under working conditions [7], and compares it with different materials to select the material with the best analysis result as the final processing material. Before the analysis, the four holes at the bottom of the claw were restricted. Through investigation and reference, it was understood that the stem of asparagus lettuce has the characteristics of crisp and tender, soft and easy to break off the leaves, and about 10N force is required to remove the leaves, so a uniform force of 15N is applied to the upper part of the claw, so as to determine whether the claw can complete the required strength of removing the leaves.

The calculation results are shown in Figure 2, Figure 3, Figure 4, Figure 5, Figure 6 and Figure 7, through the 15N force on aluminum alloy 1060-H14; The analysis and calculation results of ductile iron and 201 annealed stainless steel on the claw plate of three different materials can be seen that the 201 annealed stainless steel has the smallest displacement in the working state, which is 0.31mm. The allowable stress of aluminum alloy 1060-H14 is close to the ultimate stress of the claw plate, there are safety risks, the allowable stress of ductile iron is far beyond the ultimate stress, resulting in a waste of material performance, 201 annealing stainless steel allowable stress and limit stress difference close to one-third of the allowable stress, to meet the principle of material selection. In summary, the selection of 201 annealed stainless steel meets the strength requirements required by the work and the economy is good.

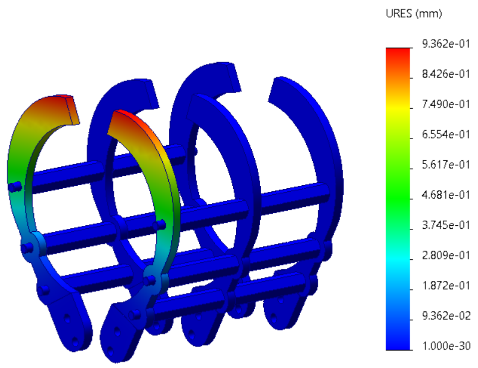

Figure 2 Displacement diagram of aluminum alloy 1060-H14 as material

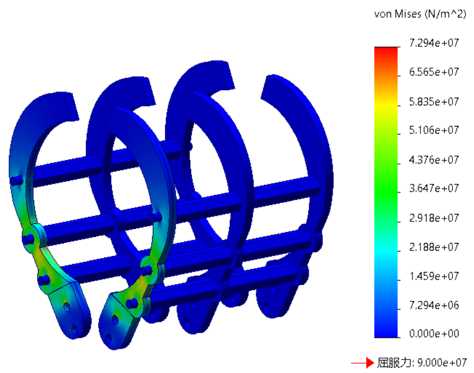

Figure 3 Application diagram of aluminum alloy 1060-H14 as material

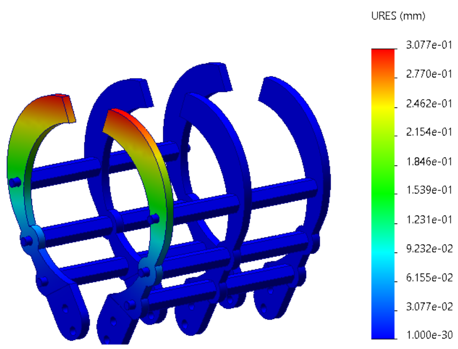

Figure 4 201 Annealed stainless steel as a material displacement diagram

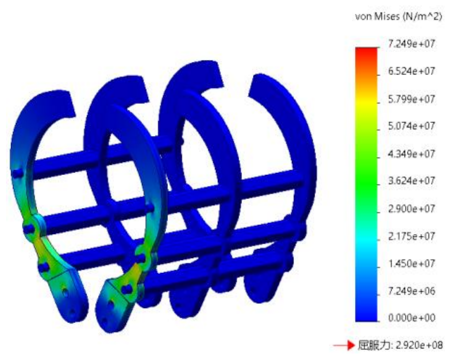

Figure 5 201 Annealing of stainless steel as a material diagram

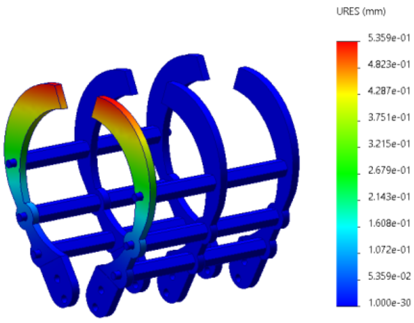

Figure 6 Displacement diagram of ductile iron as a material

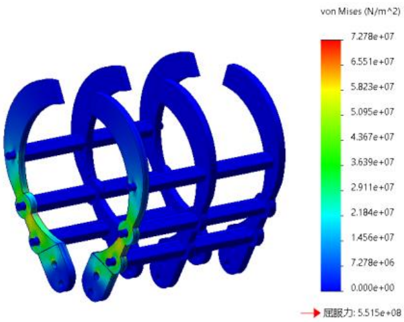

Figure 7 Stress diagram of ductile iron as a material

The analysis of the stress state of the claw of 201 annealed stainless steel can be seen that the stress is concentrated between the middle connection pin hole and the bottom connection pin hole. When the claw plate is stressed, the upper half of the claw plate bends and displaces, and produces a concentration of stress in the outer outline of the middle connecting pin holes. As the center, the stress on the outside of the claw plate is relatively small, and the maximum and minimum stress are more than ten times different, which has a certain impact on the structural uniformity of the defoliating claw. In addition, the contact area between the jaw and the connecting pin will affect the transfer of force, resulting in the support role of the rear connecting pin and the jaw. The action of removing leaves mainly relies on the internal outline of the claw blade imitation hand to pull off the leaves, and the lack of strength of the claw blade may lead to fracture in the process of removing leaves, which not only affects the process of removing leaves, but also destroys the lettuce body.

Based on the above analysis, the following improvements are made to the structure: (1) On the premise of ensuring the working ability of the mechanism, lightweight design is carried out on the parts with low force strength; (2) Increase the contact area of the claw piece and the connecting pin, so that the rear connecting pin and the claw piece share part of the force; (3) The rounded corner of R4 is carried out at the circular arc connection of the outer contour of the claw plate for transition to avoid the occurrence of stress concentration, so that the force generated by the defoliation is evenly distributed on the claw plate.

After optimization, the maximum equivalent stress of the 3D model is 36.9MPa, which is one-tenth of the yield stress of the material, which is mainly concentrated on the connecting pin hole at the top of the first claw plate and the pin and claw plate after the first claw plate, so that the stress is evenly distributed on the entire defoliating mechanism. The resulting displacement is 0.025mm, one-twelfth of what it was before optimization. Both the displacement and the maximum equivalent stress are far less than the limit value of the material, so the strength requirements are met.

The optimized model increases the end area of the supporting column at the joint of the reamer and the supporting column, so that the load is mainly distributed on the connecting supporting column, and most of the load is shared by the supporting column through force transmission. When there is no rounded corner transition, the maximum equivalent stress is 72.5MPa, which is mainly concentrated at the two circular arc joints. Stress concentration does not occur after rounded corner transition. The stress displacement diagram of the optimized model is shown in Figure 8, and the stress distribution diagram after stress is shown in Figure 9.

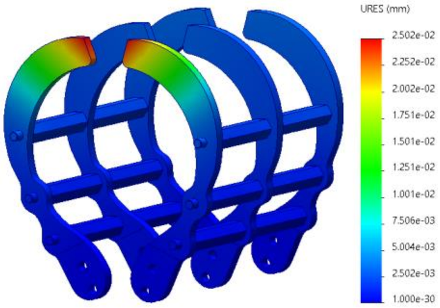

Figure 8 Force displacement diagram of the optimized model

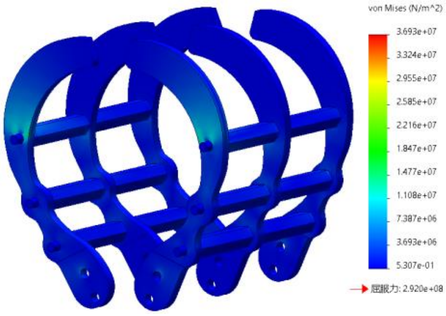

Figure 9 Stress distribution diagram of the optimized model after stress

3.2 Claw separate simulation analysis

We through relevant methods, carry out a separate force analysis on the claw plate, analyze the force situation of the claw plate under full load, and check whether there is a risk of fracture or serious deformation of the claw plate. In Solidworks finite element analysis model, analyze its stress distribution and displacement in the working state. The calculation results are shown in Figure 10 and Figure 11. Through the force analysis of the 15N force, it can be seen that the maximum equivalent stress is 26.02MPa and the maximum displacement value is 1.393mm, which is lower than the allowable stress of 201 annealed stainless steel material and the deformation degree is small, meeting the strength requirements required by the work.

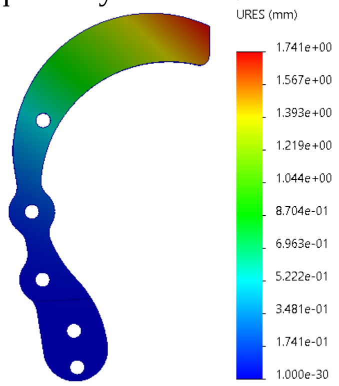

Figure 10 Displacement diagram of the claw plate after stress

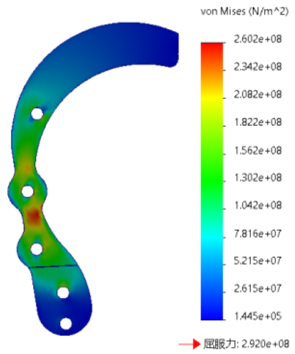

Figure 11 Stress distribution diagram after the claw plate is stressed

4. Conclusions

The adaptive opening and closing Angle of leaf removal mechanism designed in this paper is optimized through mechanical structure design and simulation analysis. The way of leaf removal of artificial lettuce is not only low efficiency and labor intensity, but also difficult to ensure the quality of leaf removal. The adaptive Angle of opening and closing of lettuce defoliation mechanism not only solves the problems of defoliation efficiency, cost and labor intensity, but also effectively guarantees the quality of defoliation of lettuce due to its structural characteristics, effectively solves the problem of lettuce growers on defoliation of lettuce, has broad market prospects, and also provides reference and experience for the research and development of agricultural machinery.

Acknowledgement

This project is supported by the Innovation and Entrepreneurship Training Program for college students of Guilin University of Electronic Science and Technology, project number: 202410595029.

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