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Design of a Small and Medium-Sized Potato Harvester

Junlin Huang[1,a,*], Tiancheng Huang[1,b], Yanzhe Ni[1,c], Wei Lu[1,d]

[1]*School of Mechanical and Electrical Engineering, Guilin University of Electronic Technology, Guilin, Guangxi, 541004, China*
[a]*1791512826@qq.com*, [b]*1328577132@qq.com*, [c]*1943477021@qq.com*, [d]*lujunqi2001@163.com*
[*]*Corresponding author*

Abstract: *In response to the demand for mechanized potato harvesting among ordinary agricultural households, research was conducted on potato harvesters. The current status and development trends of mechanization reform for small and medium-sized planting scales were analyzed. Consequently, a small and medium-sized potato harvester was designed; the designed harvester mainly consists of the following components: the harvester body structure, soil plowing mechanism, soil breaking and collecting mechanism, conveyor belt mechanism, cleaning mechanism, size sorting and screening mechanism, and towing mechanism, suitable for harvesting potatoes in small and medium-sized plots. The deformation and stress analysis of the key stressed parts of the harvester can optimize the mechanical structure design. Therefore, taking the plough shovel and the soil breaking shovel as examples, the finite element analysis software ANAYS was used to establish a nonlinear finite element model, analyze the stress in the working state, and compare it with the allowable stress of the corresponding structural steel to verify the feasibility of the structure.*

Keywords: *Potato, Harvesting Machinery, Classification and Screening Institutions, Finite Element Analysis*

1. Introduction

In the “14th Five-Year Plan for National Agricultural Mechanization Development”, the Ministry of Agriculture of China explicitly states: “Improve the agricultural machinery equipment innovation system, target the needs of agricultural mechanization, accelerate the advancement of agricultural machinery equipment innovation, and develop various types of agricultural machinery that are suitable for national conditions, meet farmers’ needs, and are advanced and applicable” [1]. Currently, the potato planting area in China has significantly increased, and the level of mechanization in potato planting has improved year by year. However, large machinery still predominates, and there is insufficient attention to small and medium-sized plots. Most regions still rely on manual harvesting, which is inefficient and labor-intensive [2]. Therefore, a potato harvester suitable for small and medium-sized plots has been designed to complete tasks such as soil breaking, harvesting, conveying, cleaning, and sizes sorting in one go.

2. Design of the Harvesting System

2.1. Basic Components

The designed harvester mainly consists of the following components: the harvester body structure, soil plowing mechanism, soil breaking and collecting mechanism, conveyor belt mechanism, cleaning mechanism, size sorting and screening mechanism, and towing mechanism, as shown in Figure 1.

The harvester body includes a potato storage compartment, chassis, four wheels, and axles. Additionally, the body of the harvester serves as the crucial part for mounting the soil-opening and breaking blades, collection blades, conveyor device, and drive wheels, among other equipment. It plays a vital role in fixing and supporting the sowing system.

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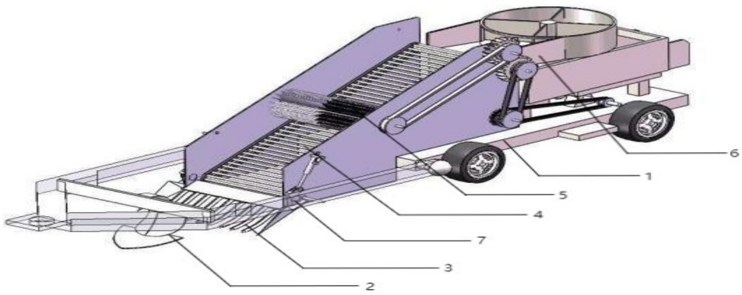
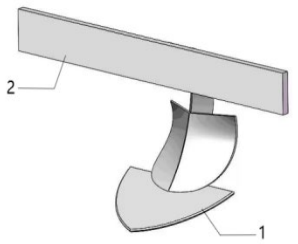


1-harvester body structure 2-soil plowing mechanism 3-soil breaking and collecting mechanism 4-conveyor belt mechanism 5-cleaning mechanism 6-size sorting and screening mechanism 7-towing mechanism

Figure 1: The overall diagram of a small and medium-sized potato harvester

2.2. Structural Design

Potato planting methods mainly include flat planting, flat planting with mulching film, ridge planting, ridge planting with mulching film, and intercropping in ridges [3]. During operation, as shown in Figure 2, the soil plowing mechanism utilizes plow blades 1 to dig potatoes out of the soil. The plow head is secured with horizontal iron rods 2, ensuring stability and supporting the plow head to effectively break the soil. After potatoes emerge from the soil and move freely (as depicted in Figure 3), baffles 2 are used to restrict their movement range, thereby reducing potato loss to some extent. To ensure the integrity of potatoes and durability of the machine, the digging and collecting blade 1 is designed with a corresponding curvature, significantly minimizing potato damage during excavation. Linkage rods 3 are used to adjust the pitch angle of the digging and collecting blade. Manual control of this angle allows the blade to be raised or lowered to meet different working requirements effectively.



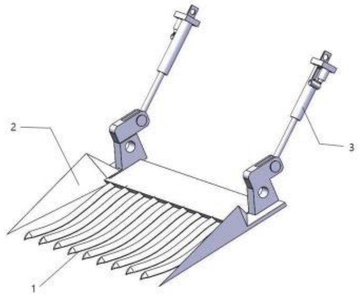
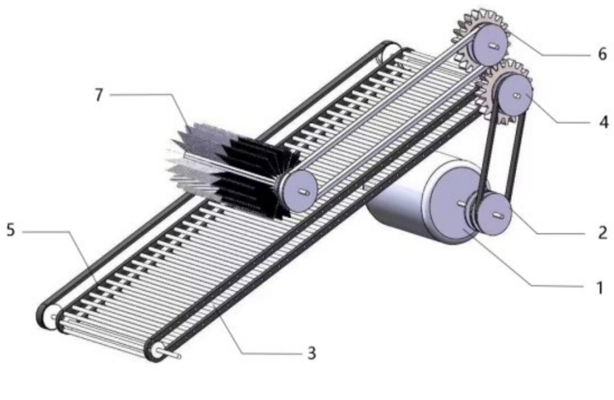


Figure 2: Soil plowing mechanism 1-plough shovel 2-irons (Left)

Figure 3: Soil breaking and collecting mechanism 1-breaking collecting shovel 2-baffle (Right)



1-motor 2-drive wheel 3-drive belt 4-bottom gear 5-conveyor belt 6-drive gear7-brush

Figure 4: Conveyor mechanism

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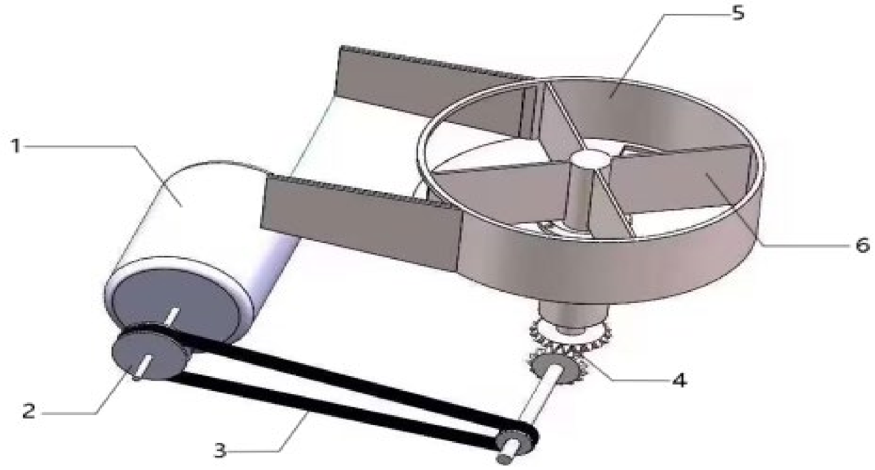

1-motor 2-drive wheel 3-drive belt 4-bottom gear 5-sorting disc 6-fan blade

Figure 5: Classification and screening institutions

The conveying mechanism, as shown in Figure 4, operates with motor 1 driving transmission wheel 2, which in turn drives gear 4 to start the conveyor belt 5. This motion lifts the potatoes upward into the sorting disc. Simultaneously, gear 4 also drives gear 6, causing brush 7 to rotate and clean any soil adhering to the potatoes, effectively cleaning them during transport. The use of transmission belt 3 and motor 1 enhances the automation level of the harvester.

The size sorting and screening mechanism, illustrated in Figure 5, is driven by motor 1 through transmission wheel 2, transmission belt 3, and the engagement of bottom gear 4, causing fan blades 6 on sorting disc 5 to rotate counterclockwise. Potatoes are sorted into appropriate slots based on their size, thereby enabling the harvester to perform size classification effectively.

The harvester body is designed with two storage compartments for storing potatoes of different sizes. These compartments are equipped with cover plate components to ensure smooth operation. The cover plates are angled to facilitate the potatoes' smooth entry into the storage compartments.

2.3. How the Harvesting System Works

The operational principle of the harvesting system is as follows: When the drive motor is powered on, it simultaneously activates the conveyor belt, brush, and sorting disc. As the harvester begins its operation and moves forward with the front power source, potatoes are dug up from the soil by the plow blades, collected by the gathering blade, and then systematically fed into the cleaning mechanism for soil separation. After cleaning, the potatoes proceed into the final sorting mechanism, where the rotating disc separates and collects potatoes of different sizes into designated compartments or bags.

Once the harvesting process is complete, the user only needs to start the motor and engage the towing device to facilitate the harvesting operation.

3. The Working Principle of the Key Part and the Relevant Parameters

3.1. Working Principle and Calculation of Transmission System

The transmission system of the potato harvester, as shown in Figures 6 and 7, employs two types of transmission: gear and belt drive. The design of each transmission component is coordinated based on the speeds required by the conveyor belt and sorting mechanism. There are two pulleys mounted on the motor. In Transmission System 1 (Figure 6), pulley 1 drives gear 2, which in turn rotates the conveyor belt via the fixed small pulley 2. Gear 2 also drives gear 3, connected to cleaning brush 5 via a belt.

In Transmission System 2 (Figure 7), pulley 2, driven by the motor, rotates gears 3 and 4, which engage to drive sorting mechanism 1. The motor speed can be manually adjusted based on the quantity of potatoes being harvested, allowing for changes in conveyor belt speed to increase harvesting efficiency. The conveyor belt of the potato harvester supports a load of approximately 50 kg, operates at a speed of 30 m/min, has rollers with a diameter of 60 mm, achieves an overall efficiency of 75%,

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with a friction coefficient of 0.2, and a safety factor of 1.8 [4].

$$F = \mu mg \tag{1}$$

$$P = F \cdot \nu \cdot \kappa / \eta \tag{2}$$

$$N = V/2\pi r \tag{3}$$

F - conveyor belt load, N;

P - power required for operation, kw;

v - conveyor belt speed, m/min;

k - safety factor;

η – total efficiency;

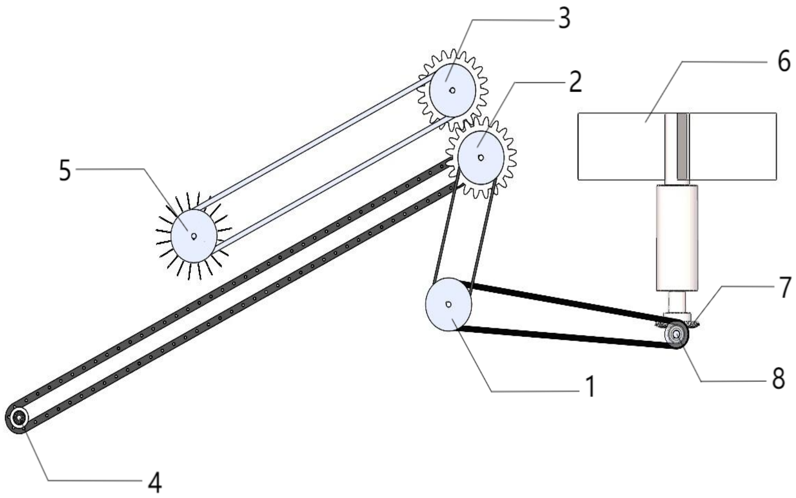
μ – coefficient of friction;

N - conveyor belt speed, r/min;

r - roller radius, mm.

F=0.2*50*10=100 N, P=100*1.8*0.5/0.75=0.12 kw, N=30/2/3.14/0.03=159 r/min.

If the motor input speed is 100 r/min, the motor torque T=P*9.55/1500=120*9.55/1500=19 N.m, and the reduction ratio I=input rotational speed(100r/min)/output rotational speed(159r/min)about 1.59.



1-pulleys 2 and 3-bevel gears 4-small pulleys 5-cleaning brushes 6-fan blades 7 and 8-bevel gears

Figure 6: Transmission system

3.2. Calculation of Parameters of the Ground breaking Collection Mechanism

The analysis of the forces on the potato-soil mixture in the X and Y directions is shown in Figure 7, and the equations are shown in (4) - (8).

$$R - P \cdot \sin \alpha - G \cdot \cos \alpha = 0 \tag{4}$$

$$P \cdot \cos \alpha - F_f - G \cdot \sin \alpha = 0 \tag{5}$$

$$F_f = \mu_0 R \tag{6}$$

$$G_0 + G_1 = G \tag{7}$$

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$$\alpha = \operatorname{arctg}\frac{p-\mu(G0+G1)}{\mu P+G0+G1} \tag{8}$$

In the above equation (4)~(8), v - machine forward speed, m/s;

H1-excavation depth, mm;

H2-shovel bottom height, mm;

R-the supporting force of the shovel body on the soil, N;

P- the force required to move the ascending object N;

α -shovel face inclination angle, ◦;

Ff -friction of the digging shovel on the soil, N;

G-total gravity of potato per plant and soil, N.

The soil density is generally 2.55 ~ 2.85 g·cm-3 , and the soil density selected in this paper is 2.65 g·cm-3 . The gravity per cubic centimeter of soil is calculated by the density equation as 0.0265 N. The inclination angle of the shovel surface is closely related to the excavation depth, and the integrity of the potato after excavation should be ensured to avoid cutting the potato [5]. Therefore, the digging depth is about 30mm greater than the potato depth. The excavation depth h1 is 190 mm, and the calculated shovel inclination α is 25.7   [6].

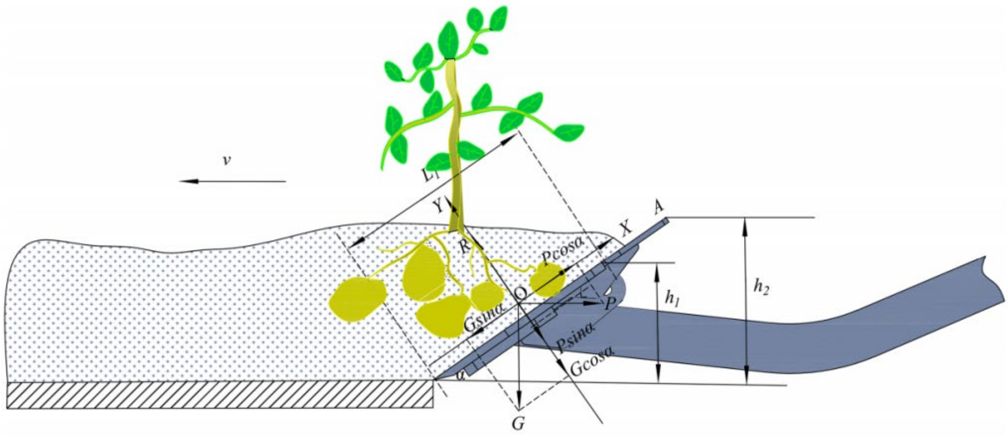

Figure 7: Force diagram of excavation analysis

4. Deformation and Stress Analysis of Key Components

It is of great significance to give the correct material properties to the test during the simulation process for the authenticity of the simulation results, and it also has a non-negligible impact on the calculation results of the data [7]. The deformation and stress analysis of the key stressed parts of the harvester can optimize the mechanical structure design and improve the reliability and rationality. Therefore, taking the plough shovel and the soil breaking shovel as examples, the finite element analysis software ANAYS was used to establish a nonlinear finite element model, analyze the stress in the working state, and compare it with the allowable stress of the corresponding structural steel to verify the feasibility of the structure [8].

Before the finite element analysis of the selected model can be performed, the corresponding constraints must be added according to the actual situation in order for the analysis results to be convincing and reliable. The plot suitable for cultivating potatoes has the characteristics of loose soil, good permeability, rich organic matter content and flat terrain, so the reaction force of the soil can be taken 300N when the plow is carried out the ridge work. According to the ANSYS analysis of the plowshare, as shown in Figure 8 and Figure 9, the maximum deformation is 0.084278mm, and the maximum equivalent stress is 107.27Mpa, which is lower than the allowable stress of the structural steel, and the design scheme is reasonable.

After the ploughshare ridge is opened and the soil crushing work is carried out, the soil is generally

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in the form of broken blocks, so the force of the covering plate is less when the covering work is carried out, and 50 N can be taken. After adding the corresponding fixed and force conditions to the model, ANSYS force analysis was carried out, and the analysis results are shown in Figure 10 and Figure 11, the maximum displacement at the front end is 0.17297mm, and the maximum stress is 8.3268Mpa, which is less than the yield limit. Under normal working conditions, the groundbreaking collection shovel will not cause deformation due to the excessive reaction force of the land, so the structural design is reasonable [9].

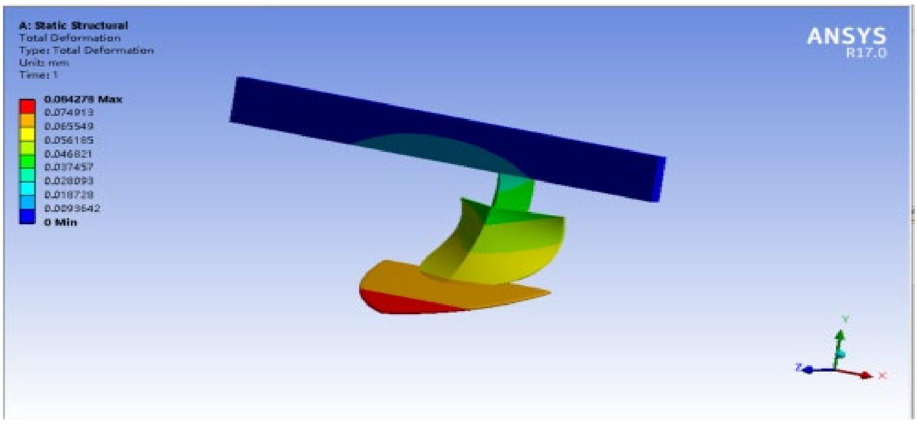

Figure 8: Maximum deformation of plough mechanism

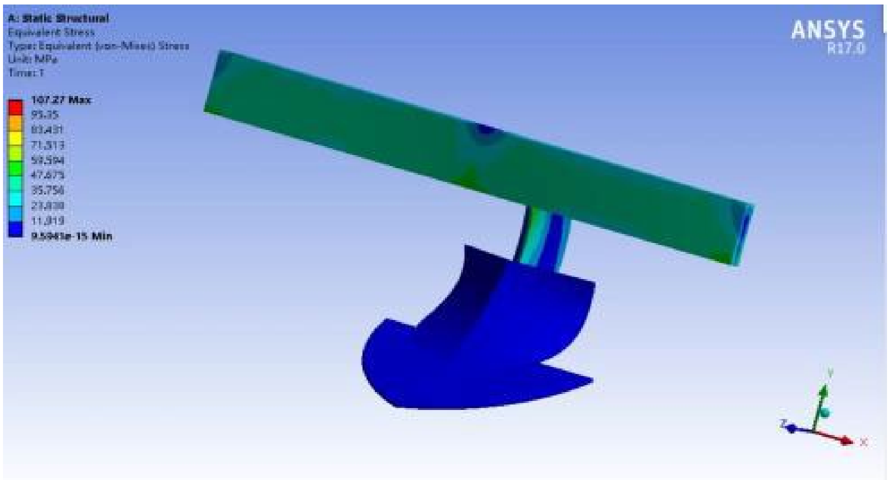

Figure 9: Maximum equivalent stress of plough mechanism

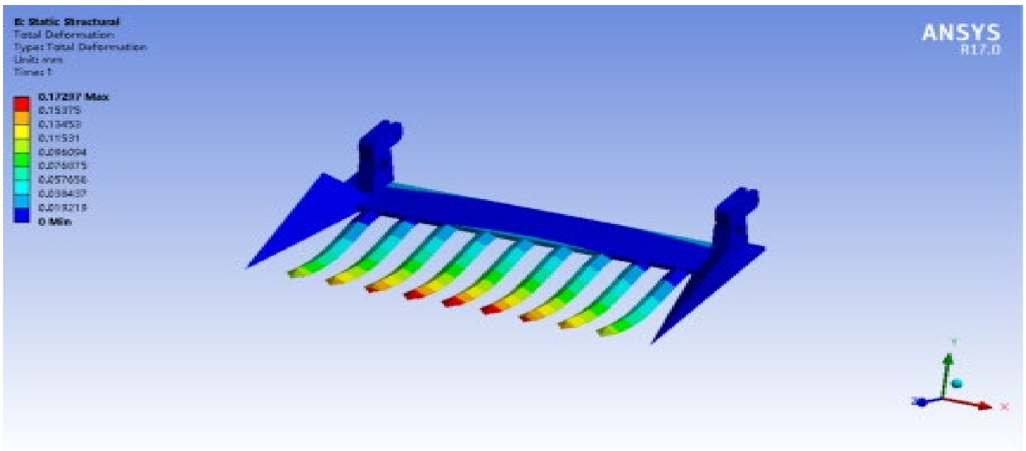

Figure 10: Maximum displacement of the groundbreaking collection mechanism

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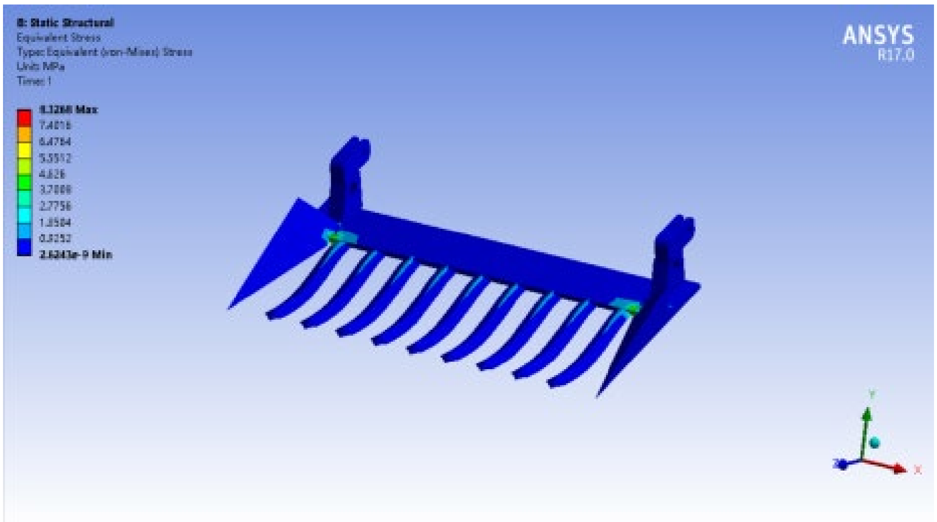

Figure 11: Maximum stress of the groundbreaking collection mechanism

5. Conclusion

To sum up, the method of manually harvesting potatoes is not only inefficient, costly, and intensive, but also time-consuming and labor-intensive. Small and medium-sized potato harvester solves the problems of harvesting efficiency, harvesting cost and labor intensity, and has moderate volume and complete functions, which is very suitable for the use of potato planting self-employed individuals with small and medium-sized plots in rural areas, and has great development potential.

Acknowledgement

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