Optimization of Potato Soil Transportation Separation Mechanism Based on Discrete Element Method and TRIZ Theory

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Abstract. In this paper, based on the problem of poor operation of sweet potato harvester, the discrete element method and TRIZ theory are used to optimize the key mechanism. Based on the discrete element method, EDEM software was used to simulate the operation process of the potato soil conveying and separating mechanism, and the optimal combination of working parameters was obtained. The linear velocity of the rod lift was 2.3 m/s, the inclination angle was 18 degrees, and the amplitude was 8 mm. Field experiments were carried out to verify the results. Through the problems in simulation and field experiment, based on TRIZ theory, the improvement scheme is proposed by using physical contradiction, and the two-stage potato soil transport separation mechanism is obtained. The simulation results show that the operation effect is improved obviously. Finally, the optimization of potato soil transport and separation mechanism is completed by determining the optimal working parameters and improving the structure innovation.

1. Introduction

Although China is a big country for sweet potato production and cultivation, its mechanized production technology is very backward, and the harvesting process is prone to problems such as low quality of work [1-3]. As the main operating mechanism of sweet potato harvester, the potato soil conveying and separating mechanism is the key to affect the harvesting effect. At present, the rod-type potato soil conveying and separating mechanism is the most widely used, and the harvesting effect is good. The structure is as shown in Figure 1, which comprises the separating grid rod composed of rods, the driving wheel, the shaking wheel and many more [4]. The working principle is as follows: during the traveling process, the sweet potato harvester excavates the potato soil mixture and transports it back to the rod elevator, and the rod rotates under the driving of the driving wheel and generates vibration effect through the shaking wheel. The soil was broken and screened to the ground, so that the potato pieces were separated from the soil, and the potato pieces were collected by hand to collect the chips.

In this paper, the existing bar-type sweet potato harvester as a reference object, as shown in Figure 2, using discrete element method to simulate the operation process of potato soil conveying and separating mechanism, optimize the parameters of the mechanism, and verify by field experiments[5].
2. EDEM simulation of operation process of potato soil conveying and separating mechanism

2.1. Selection of Particle Contact Model
Particle contact model is an important foundation of discrete element technology. For different simulation objects, different contact models need to be selected. In the process of sweet potato harvesting, sweet potato and soil are separated by collision and contact between lifter and potato-soil mixture. In addition, because of the role of liquid bridge between soil particles and cohesion in the contact area, Hertz-Mindin and JKR Cohesion contact model is adopted. As shown in Figure 3, the contact model is also called "elastic-damping-sliding-friction contact". Mechanics Model.

![Figure 3. The contact model of particles](image)

![Figure 4. Simplified mechanism model](image)

2.2. Establishment of simulation model
The mechanism model is established by referring to the existing sweet potato harvester as shown in Figure 2, and the simplified model as shown in Figure 4 is obtained by using Solidworks. Because of the complex shape of soil particles, the soil is simplified into spheres, which are composed of spheres of different sizes and shapes. The reference object of sweet potato simulation model is Potato 32.

2.3. Setting Discrete Element Simulation Parameters
Through density measurement test and static compression test of sweet potato, ring knife test, direct shear test and triaxial test of soil, the physical and mechanical properties parameters of sweet potato and soil were measured, and the simulation parameters as shown in Table 1. The working parameters of the sweet potato harvester are shown in Table 2. Through the design of single factor simulation test, the speed, inclination and amplitude of the rod line are changed under certain conditions. The optimal working parameters are obtained through the analysis of the simulation results.

| Material   | Parameter        | Density (g·cm\(^{-3}\)) | Poisson’s ratio | Shear modulus (Pa) |
|------------|------------------|--------------------------|-----------------|--------------------|
| Sweet potato |                 | 1.02                     | 0.32            | 1.03×10^6          |
| Soil       |                  | 1.21                     | 0.38            | 1.07×10^6          |
| Steel      |                  | 7.80                     | 0.3             | 7.0×10^{10}        |
Table 2. Working parameter setting

| Factor | Velocity (m/s) | Dip angle (°) | Amplitude (mm) | Bar diameter (mm) | Bar spacing (mm) |
|--------|----------------|---------------|----------------|-------------------|-----------------|
| Level 1| 1.9            | 18            | 8              |                   |                 |
| Level 2| 2.1            | 21            | 10             | 16                | 55              |
| Level 3| 2.3            | 24            | 12             |                   |                 |

2.4. Analysis of simulation results

The simulation results show that the interaction force between sweet potato and soil is negligible. It can be concluded that the damage of sweet potato is mainly caused by the collision force between sweet potato and machine. Therefore, the damage degree of sweet potato is defined by comparing the relative magnitude of collision normal force under different working parameters, as shown in Figure 5. Combining with the simulation conveying efficiency, the optimum working parameters are finally selected, that is, the linear velocity of the rod lift is 2.3m/s, the inclination angle is 18 degrees, and the amplitude is 8mm.

![Figure 5. Sweet potato stress diagram under different working parameters](image)

![Figure 6. Commissioning site](image)

3. Field test verification

Field test refers to "NYT 648-2002 Technical Specification for Quality Evaluation of Potato Harvester" to provide quality evaluation index, test method and evaluation rules for field test of sweet potato harvester. In order to observe the change of potato-soil mixture material and the movement of sweet potato more clearly in the working process of potato-soil conveying and separating mechanism, a high-speed camera was used to record the working process of potato-soil conveying and separating mechanism, as shown in Figure 6.

In this field experiment, the linear velocity of the elevator was taken as the variable, and the casualty rate and the bare rate of the experimental results were calculated and compared with the simulation results. The field test results are shown in Table 3.

Table 3. Field test results

| Factor (v) | Potato injury rate (%) | Bare potato rate (%) |
|------------|------------------------|----------------------|
| 1.9m/s     | 5.9                    | 98.3                 |
| 2.1m/s     | 5.1                    | 97.7                 |
| 2.3m/s     | 6.4                    | 96.4                 |

The results showed that there was no linear relationship between wounded rate, bare rate and linear velocity. When the linear velocity is 2.1m/s, the casualty rate and the bare rate of potato are better than the other two working conditions. The experimental results are consistent with the simulation results, which proves the feasibility of using discrete element method to simulate the operation process of potato soil conveying and separating mechanism.
4. Innovative design of potato soil conveying and separating mechanism

The optimal working parameter combination of the potato soil transport separation mechanism was
determined in the previous paper. However, during the simulation test and field experiment research
analysis, it was found that the damage of sweet potato mainly occurred in the collision between the
cone and the lift, and the sweet potato rolled. The state is random and uncontrollable, so there will still
be some probability of damage during the harvesting process. In order to further reduce the damage
rate of sweet potato and enhance the stability of the transport separation process, it is necessary to
carry out innovative design of its structure to improve the research.

Therefore, this section will reduce the casualty rate of potato soil transport and separation
mechanism, enhance the stability of operation as the optimization objective, use TRIZ theory to carry
out system function analysis, and find the key issues, combined with the separation principle of
physical contradictions in TRIZ theory, put forward a new optimization scheme[7-9].

4.1. System component analysis

Component analysis is to summarize and classify the components contained in the potato soil
conveying and separating mechanism system and the supersystem, list and analyze the components.
The main elements of the technical system include rods, side plates, driving wheels, driven wheels and
dithering wheels, elements of soil and sweet potatoes interacting with the mechanism, auxiliary tool
elements such as rack, shovel, reducer and belt, and component analysis is shown in Table 4.

| Engineering system | Component | Supersystem Component |
|--------------------|-----------|-----------------------|
| Potato soil conveying and separating mechanism | Transportation and Separation of Potato Soil | Frame Digging shovel |
| | Bar | Jitter wheel |
| | Side panel | Driving wheel |
| | Driving wheel | Driven wheel |
| | Sweet potato | Soil |
| | Frame | Tractor |

4.2. Establishment of Functional Model

Based on the interaction between the above components, the total functions of the system and the sub-
functions of each component of the system, the implementation of the functions and whether harmful
effects are produced are defined, as shown in Figure 7.

**Figure 7.** Functional Model of Potato Soil Transport and Separation Mechanism System
In the function diagram, the arrow points to the active object, the straight line indicates the normal function, the broken line indicates the insufficient function, the wavy line indicates the harmful function, and the straight line plus the vertical short line indicates the excessive function.

4.3. Problem description and analysis

4.3.1. Defining physical contradictions Based on the description of the above problems, the physical contradiction is put forward: the ability of crushing and screening of potato soil conveying and separating mechanism is both large and small. Higher screening capacity of crushed soil is to ensure a higher rate of bare potatoes, while smaller screening capacity is to ensure that sweet potatoes can be protected by soil and reduce the rate of wounded potatoes. It is difficult to achieve this at the same time for the current potato soil transport and separation mechanism.

4.3.2. Solving Physical Contradictions According to the problems that need to be solved in the actual design of potato soil conveying and separating mechanism, the above inventive principles are screened and analyzed. Finally, the separation principle is selected as the guiding idea for the innovative design of potato soil conveying and separating mechanism.

According to the principle of partition, the original potato soil transport and separation mechanism is innovatively designed. As shown in figure 8, the two-stage potato soil transport and separation mechanism is designed, which separates the functions of soil crushing, potato soil separation and transportation. The first and second stages of potato soil transport and separation mechanism respectively accomplish the above two functions.

![Figure 8. Two-stage potato soil conveying and separating mechanism](image-url)

Among them, the first stage of potato soil transport and separation mechanism mainly completes soil crushing and transfers the mixture of potato soil to the second stage of potato soil transport and separation mechanism. Its operation process ensures that the soil is crushed while not being sifted in large quantities, so that the sweet potato can be effectively buffered and protected in the transport process. According to the previous research, the working parameters are set as follows: the rod linear velocity is 2.3m/s, the amplitude is 8mm, and the inclination angle is 18 degrees. However, in order to ensure that the soil is not sifted out in large quantities, the rod spacing of the first potato soil conveying and separating mechanism is reduced from 55mm to 35mm, and the rod diameter is 14mm. In addition, the effective length of the working face is reduced to about 3/4 of the original length, i.e. 1.2m, according to the photography and analysis of the working process of the potato soil conveying and separating mechanism by the high-speed camera. At the same time, the problem of the overall longitudinal size growth caused by the two-stage structure is avoided to some extent.

The second stage of potato soil conveying and separating mechanism mainly completes the soil sieving and the backward transportation of sweet potatoes. Its operation process does not need soil crushing. Therefore, the shaking wheel is replaced by the pulley to keep the working face running...
smoothly, thus avoiding the damage of sweet potato caused by collision. In order to further reduce the damage of sweet potato, rubber sleeve was wrapped on the outside of the rod. Its outer diameter was 16 mm, the clearance of the rod was 55 mm, and the length of the working face was 0.8 m.

4.4. Feasibility verification of improved scheme based on discrete element method

Based on the simplified model and working parameters, the discrete element simulation of the two-stage potato soil conveying and separating mechanism was carried out to verify the actual effect of the new scheme. Through the analysis and comparison of the simulation results before and after the improvement, it can be seen that the operation effect of the improved two-stage potato soil conveying and separating mechanism has been improved obviously, the relative damage probability of sweet potato has been greatly reduced, the average loss rate of the first stage operation mechanism is as high as 73.9%, and the average loss rate of the second stage operation mechanism is 11.0%, which verifies the feasibility of the improved scheme.

5. Conclusions

Based on the discrete element method, the optimal working parameters of the potato soil transport and separation mechanism are obtained, that is, the linear velocity of the rod elevator is 2.3 m/s, the inclination angle is 18 degrees, and the amplitude is 8 mm. At the same time, the simulation results are verified by field experiments, which verifies the accuracy and feasibility of the simulation. Based on TRIZ theory, the mechanism was innovatively designed, and a two-stage potato soil conveying and separating mechanism was obtained. The simulation results show that the relative damage probability of sweet potato is greatly reduced. The average loss rate of the first stage operation mechanism is 73.9%, and that of the second stage operation mechanism is 11.0%.

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