THEORETICAL ANALYSIS OF SEPARATION OF POTATO TUBERS FROM SOIL IN A BELT-ROD ELEVATOR

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Abstract. In this study, the mechanism of operation of the belt-rod elevator of a small-sized potato digger and the efficiency of separating tubers from the soil were studied. The main factors influencing the characteristics of the separation of tubers from the soil were obtained on the basis of a theoretical analysis of the tilt angle of the elevator, the linear speed of the belt-rod elevator and the speed of movement of the digger. As a result, the optimal parameters were obtained: equal elevator tilt angle of 18°, linear elevator speed of 1.4 m/s and forward speed of the digger of 0.80 m/s.

Key words: potatoes, digger, pulley, belt, soil; damage to tubers; tilt angle, speed, elevator, rod.

Introduction. Potatoes are of strategic importance as the fourth non-grain food crop in the world [1]. The world, including our country, pays great attention to the complete mechanization of the potato industry. Currently, most of the research on the separation of potato tubers from the soil in developed countries is carried out using a potato digger, which digs up tubers in a small-circuit area.

Many scientists have conducted theoretical analysis and experimental research on mechanical harvesting of potatoes. Al-Dosary et al. [2] studied the effect of forward speed of the combine and digging depth on damage to potato tubers during field trials. Zhou et al. [3] developed a self-propelled potato harvester, and conducted field tests. Li Wang et al. [4] studied the effect of the design and operating parameters of an inclined elevator on the damage of potato tubers using a test bench. Wu Huang et al. [5] optimized the parameters of a potato digger for wet soils. However, most of the research on devices for separating tubers from the soil when harvesting potatoes was carried out in bench tests. Experiments with harvesters in the field most directly reflect post-harvest tuber damage and residual soil, but it is not easy to study the process of soil sifting and potato damage.

In recent years, with the development of computer technology and the rapid development of the discrete element method, many scientists have used the discrete element method to study and analyze agricultural machinery [6-10]. Research on mechanical harvesting using the discrete element method is also increasingly being carried out for root crops. Wei Z. et al. [11] analyzed the influence of the structure and operating parameters of wave-shaped separation on the process of separating tubers from soil based on the discrete element method and determined the form of separation and the corresponding combinations of parameters. Park D. [12] studied and tested the forces of influence on potato tubers in a potato harvester using EDEM software. Both Li B. et al. [13] and Gao G. et al. conducted research on the separation process of potatoes and soil using EDEM software and optimized the parameters. However, most of the above studies were carried out only using discrete element modeling, and most of them were designed for potato diggers. Fewer studies have been conducted on modeling and optimizing the parameters of the potato-soil separation process in a potato harvester. To summarize, we can say that there are several works on the use of the discrete
element method in mechanical harvesting of potatoes, sweet potatoes, garlic and other crops, but most of these studies were focused on potato harvesters, and little research was done on no extensive digging was reported. In this study, a small-sized potato digger was selected as a prototype, and a belt-rod separator of tubers and soil was selected as a research object, and then modeling and research of the characteristics of separation of tubers and soil during the harvesting process was carried out. Theoretical analyzes were carried out on the movement of the elevator during the process and the separation of the tuber-soil mixture from the tubers. The factors influencing the characteristics of the separation of tubers from the soil on a belt-rod elevator have been identified. The load on potato tubers during harvesting and the efficiency of separating tubers from the soil were used as reaction indicators. A simulation model with an EDEM-RecurDyn coupling was constructed to study the influence of the elevator angle, elevator linear speed and digger speed on the efficiency of separating tubers from the soil. The optimal parameters were obtained using the Box–Behnken method. This article examines the characteristics of the separation of tubers from the soil, taking into account the design and operating parameters of the separation device of a small-sized potato digger.

**Research materials.** Design and operating principle of a strip-rod separator. The main function of the belt-rod separator is to separate the tubers in the tuber-soil mixture transported by the elevator. The separator consists of a frame, supporting belt pulleys, rods, drive shaft and guide pulleys (Fig. 1). The rods are attached directly to the belts using rivets. The upper pulley supports the belt in such a way that there is a difference in angles ($\beta$) between the front and rear pulleys of the belt. The gear on the drive shaft meshes with the rod and drives the belt rod. During harvesting, the excavated mixture consists of three main components: fine-grained soil, large soil lumps and potato tubers. When transporting the mixture to the separator, most of the fine-grained soil is sifted out, and potato pieces and larger lumps are moved along with the elevators. During vibration, collisions and bouncing, large soil lumps, as well as soil attached to the surface of the tubers, fall off and are separated; the rest of the potatoes and soil lumps are then transferred to subsequent processing.

![Figure 1. 3D model of a belt-rod potato separator: 1- support belt pulley; 2-frame; 3-guide pulley; 4-rod; 5-drive shaft.](image)

Main design parameters of a strip-rod type separator. Based on preliminary research and in accordance with the requirements for the length of the separator, it was determined to be 1450 mm. The width was determined to be 560 mm in accordance with the actual shape of the potato planting ridge. The total calculated radius of the rod is 5-6 mm, so 5 mm was chosen. Depending on the shape of the potato tubers, the distance between the rods is 42 mm, and the number of teeth of the corresponding gear is 12.
Research methods and results: theoretical analysis of the process of separating potatoes from the soil. The separator is driven by a combination of gears and belt pulleys. The gear is the active pulley, and the belt pulley is the driven pulley. The trajectory of the elevator during operation can be divided into two sections. The elevator comes into contact with the potato-soil mixture and performs screening operations in area A-B-C, but in area C-D-E-A the elevator is not processed. The elevator position (v) can be determined in the horizontal direction (vx) and vertical direction (vy). The gear speed is equal to ω. The angle between the tape-rod and the ground is equal to α. The angle between AB and BC is equal to β, as shown in Figure 3.

Figure 3. Movement of the chewer during separation of tubers from the soil

The pulley on the shaft contacts the belt rod and engages when the drive shaft rotates. The impact of the engagement causes elastic deformation of the belt. The strain is transmitted in the opposite direction to the direction of engagement, causing the belt to oscillate and the rod to vibrate up and down. The switching process during operation is similar to that of a chain drive. Based on existing studies related to chain drives [14-16], the impact engagement process was analyzed. During operation, the forces at both ends of the rod are distributed symmetrically, and the resulting moment is zero, so it was possible to analyze the forces on both sides of the rod at the center of mass. The mechanical model of the interaction between the gear and the rod was simplified as follows. The belt between the rods is installed in the form of a spring of a certain stiffness. The gear teeth are installed in the form of a cylinder with a certain mass to act on the rod at a relative speed, as shown in Figure 4.

Figure 4. Simplified mechanical model for engaging a gear with a rod

The total kinetic energy (Ez) at the moment before engagement is the kinetic energy of the gear relative to the axis. A collision occurs, as a result of which the relative speed of the gear teeth decreases, and the speed of the gear increases. That collision ends when the velocities of the two objects are equal (v0). At this moment, part of the total kinetic energy is converted into kinetic energy of the rods and gear teeth, and the other part is converted into deformation energy (Eb). The total kinetic energy (Ez) can be represented as:

\[
E_z = \frac{1}{2} m_e v_e^2 + \frac{1}{2} m_c v_c^2 + \frac{m_c \rho^2 v_c^2}{4R_0^2} + E_b = \frac{1}{2} J \omega^2
\]  

(1)
where the mass of the rod is equal to \( mg \), the mass of the gear teeth is equal to \( mc \), the mass of the gear is equal to \( M \), the rotational inertia is equal to \( J \), the radius of the meshed gear teeth is equal to \( \rho \), and the distance between the center of the circle of the gear and the center of the rod is equal to \( R_0 \).

The corresponding strain energy can be obtained by differentially transforming the relationship between contact strain and stress, and then substituting it into the equations of elastic contact theory and generalized integration. The result of the calculation looks like this:

\[
E_0 = \int \sigma ds = \frac{F^2}{4b} (\alpha_0 \ln F + 2\beta_0) \tag{2}
\]

where \( \sigma \) is the contact stress, \( s \) is the contact strain, \( b \) is the contact length, \( \alpha_0 \) and \( \beta_0 \) are constants that are affected only by shape and material, and \( F \) is the maximum impact force during engagement, which is calculated as follows:

\[
F^2 (\alpha_0 \ln F + 2\beta_0) = \frac{2\alpha^2 bm_g \cdot M \cdot \omega^2 \cdot \sin^2 (\frac{\pi}{2} + \lambda)}{2m_g + M} \tag{3}
\]

where \( a \) is the distance between the rods, \( \omega \) is the angular velocity, \( z \) is the number of gear teeth and \( \lambda \) is the degree of the tooth angle.

From the above equation it is clear that the maximum impact force generated by the meshing is related to the shape and material of the gear and belt rods. Different speeds also affect the separation process. Each engagement causes the belt to vibrate. This causes the strip bar to move up and down in a reciprocating motion. The vibration period (\( T \)) is affected by the rotation speed of the drive shaft.

\[
T = \frac{2\pi}{\omega \cdot z} = \frac{\pi}{6\omega} \tag{4}
\]

The amplitude of vibration is affected by the actual installation and material of the belt, and the amplitude was measured to be about 2 mm according to the actual operation of the bar without load in the previous test. Based on the above analysis, a simple harmonic motion perpendicular to the cross-section of the motion path of one rod is applied to the entire potato soil separation mechanism driven by a belt pulley in the RecurDyn software. Its equation of motion is \( 2\times\sin(2\pi\times \text{time}/T) \). In this way, the vibration created by the gear during real operation is simulated. A rod whose initial position is at point B is selected to analyze its speed. \( v \), \( v_x \) and \( v_y \) indicate a housing without vibration, and \( v', v_x' \) and \( v_y' \) indicate a housing with additional vibration, as shown in Figure 5.
When vibration is applied, the speed of the rod fluctuates as it moves. The range of oscillation is around the speed when vibration is not applied, and the range of oscillation of the speed component in the horizontal direction (vx) is small, while the speed component in the vertical direction (vy) is large. Both have slight fluctuations in speed during the interaction process. The effect of the presence or absence of additional vibration on the change in the position of the rods is small, and numerically it is somewhat more obvious in the y direction. Sx and Sy indicate the change in position of the rods when the vibrator is connected to the separating device, as shown in Figure 6.

Figure 5. Effect on the change in speed of an individual rod with and without additional vibration

Figure 6. The influence of the presence or absence of additional vibration on the change in the position of the rods

LITERATURE


