RESEARCH ON KEY QUALITY CHARACTERISTICS OPTIMIZATION OF POTATO HARVESTER BASED ON METROLOGICAL TESTING

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In response to the key issues affecting the harvesting quality, such as low efficiency, high damage rate and unstable separation effect of existing potato harvesters, this study conducts an optimized design research for a potato harvester from the perspectives of quality and testing. The harvester mainly consists of a digging shovel, a vibrating screen, a transporting wheel, a rotating drum, a height adjustment device, a potato collection box, a frame, and a transmission shaft. When working, a vibrating screen and a rotating separation drum are used to separate potatoes and soil blocks twice, respectively. The potatoes are left in the drum and continue to rise directly above the center of the drum top, falling into the potato collection box, completing the entire potato harvesting process. Based on experimental design and measurement data, by accurately measuring key process characteristics such as shovel surface angle, vibrating screen frequency and amplitude, key component parameters were optimized and designed, significantly improving the overall quality and reliability of the machine. The harvester has excellent performance, small size, low cost, significant cost reduction and efficiency improvement, effectively promoting the modernization of agriculture and rural areas.

Keywords: quality control; potato harvester; vibrating screen; potato soil separation

1. Introduction

Potatoes have high yields, abundant nutrients, and strong adaptability to the environment. They are now widely distributed around the world and have the characteristics of being used as both food and vegetables, as well as being widely

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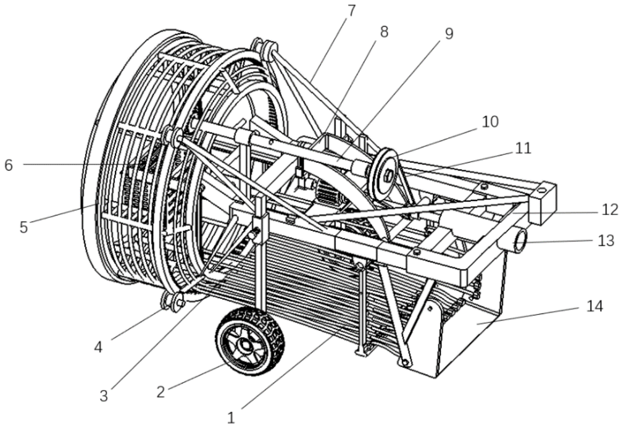
processed. They have become one of the four major food crops in the world, second only to rice, wheat, and corn [1].The potato planting area in China has reached 4.7 million hectares, with a total output of nearly 90 million tons, ranking first in the world. Mainly distributed in Heilongjiang, Jilin, Shandong, Inner Mongolia, Shanxi, and Yunguichuan [2].The development of potato harvesting machinery in foreign countries was earlier, with a high degree of mechanization and rapid improvement in technical level. At the beginning of the 20th century, developed countries in Europe and America began extensive research on potato harvesters and made significant breakthroughs in the 1940s. The potato harvesting equipment developed mainly consists of large-scale combine harvesters. With the development of technology, potato harvesters in European and American countries have evolved from traditional large-scale machinery to more advanced small-scale machinery. This development process has gone through multiple stages from simple excavation to joint harvesting, providing more efficient and accurate services for agricultural production. Countries such as the UK, France, Italy, Japan, and South Korea mainly develop small and medium-sized potato excavators or combine harvesters. These models have the advantages of simple structure, small size, high reliability, and minimal damage, and are mainly suitable for harvesting potatoes on small and medium-sized plots [3-6]. Chinese potato harvesting machinery started relatively late. Currently, potato harvesting machines are mainly small and medium-sized, and domestic potato harvesting is mostly done manually or semi mechanically. The harvesting process begins with a small excavator digging, laying potatoes on the surface and manually picking and bagging them. There are significant differences in potato harvesting methods and crop varieties in China, and the entry of large machinery into some small plots can cause various problems and result in uneven resource allocation. Especially large machinery is difficult to adapt to special planting techniques, resulting in a high rate of potato damage during harvesting, poor separation efficiency, multiple missed and buried potatoes, and severe mechanical damage during transportation and separation [7-10]. Therefore, this paper designs a machine suitable for harvesting potatoes on small plots. By adopting a two-stage separation vibration method, it achieves mechanical operations such as excavation, separation, and collection, effectively improving the efficiency of potato excavation. It focuses on solving the mechanized harvesting problems of individual farmers with small plots, many sloping fields, and small-scale planting, which is of great significance for improving agricultural production efficiency.

2. Overall structure and working principle

2.1 Overall Structure

The potato harvester is mainly composed of digging shovel, vibrating screen, rotating drum, frame, height adjustment device, auxiliary wheel, potato collection box, support frame and other main components. The overall structure of the machine is shown in Figure 1.

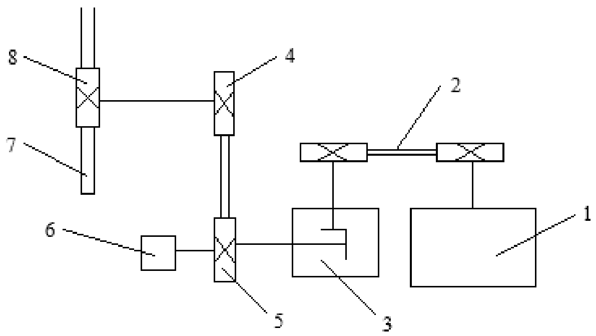


1. Vibrating screen; 2. Transporting wheel; 3. Height adjustment device; 4. Rolling auxiliary wheel; 5. Rotating drum; 6. Collection box; 7. Support frame; 8. Polarization device; 9. Power transmission shaft; 10. Belt pulley; 11. Belt; 12. Frame; 13. Transmission shaft; 14. Digging shovel

Fig. 1. Schematic diagram of the structure of a new hand held potato harvester

2.2 Working Principle

When the harvester is in operation, it is powered by a hand-held tractor. The power transmission route is shown in Figure 2. Firstly, the transmission shaft transmits power to the digging shovel and vibrating screen. The digging shovel excavates the soil and potatoes together and sends them to the vibrating screen behind it. Through the vibration of the vibrating screen, the potato soil is initially separated, and the separated potatoes and residual soil are transported later. Secondly, the power of the transmission shaft is driven by the driving pulley through belt transmission, and the driving gear and the driven pulley are fixed on the same shaft. The driving gear drives the driven circular rack, which in turn drives the rotating drum screen to rotate. As the drum rotates counterclockwise, the soil will pass through the drum screen holes and fall to the ground, while the larger potatoes will be left in the drum and continue to move to the top center of the drum. Under the gravity of the potatoes themselves, they will fall into the collection box, completing the potato harvest. A potato soil vibration separation device was designed based on the principle of connecting rod swing, which initially achieved potato soil separation. A potato soil drum secondary separation and lifting device was designed based on the principle of centrifugal force, which achieved further separation of potatoes and soil and sent them into the potato collection box.



1. Engine ; 2. Belt Drive; 3. Transmission; 4. Active pulley;
5.Passive pulley; 6.The polarization frame; 7. Rotating drum driven circular rack; 8.Rotating drum driving gear

Fig. 2. Power Transmission Route Map

2.3 Technical Parameters

The main technical parameters of the new hand-held potato harvester are shown in Table 1.

Table 1

Main Technical Parameters of the New Hand held Potato Harvester

Technical Parameter	Numerical value
Overall dimensions (length × width × height) / mm	1050×600×1500
Overall quality / kg	560
Supporting power / kW	12
Harvest ridge count	1
Homework width / mm	500
Excavation depth / mm	80-260
Homework speed km/h	2-3
Production efficiency m^2/h	1000-2000

3. Design of Key Components for a new handheld potato harvester

3.1 Overall Structural Design of Digging Shovel

3.1.1 Design of digging shovel

The digging of the new hand-held potato harvester is crucial for the quality of potato harvesting. Fresh potatoes are prone to skin damage during the harvesting process, and when encountering excessively wet soil, the digging shovel is easily blocked by soil blocks and weeds. Therefore, the angle at which the potato digging shovel enters the soil is very important [11-12]. The main design factors for digging shovels include: shovel blade inclination angle γ, shovel face inclination angle α, shovel length L, and shovel width s_1.

The function of the shovel blade inclination angle γ should ensure good soil breaking ability and a certain self-cleaning ability when entering the soil. The shovel blade inclination angle γ should meet the following requirements [13]:

$$\gamma < 90° - \varphi \tag{1}$$

In the formula, φ - the friction angle of soil on steel, taken as 30° to 36°;

γ - shovel blade inclination angle. According to the law of friction, the smaller the inclination angle of the shovel blade γ, the stronger the soil cutting ability. However, when the inclination angle of the shovel blade γ is too small, it is easy to cause damage to the potato chunks, so γ is generally taken as 40° to 50°. According to the above theoretical basis, the inclination angle of the shovel blade is taken as 40° [13-14].

The inclination angle of the shovel surface is the angle between the excavation device and the ground level during the excavation operation.The function of the inclination angle α of the shovel surface is to cut open the soil ridge, allowing the mixture of potatoes and soil blocks to be smoothly transferred back. In general, the smaller the α, the less resistance the shovel is subjected to by the soil blocks. Through force analysis of the mixture of potatoes and soil blocks on the shovel surface, as shown in Figure 3, it can be concluded that:

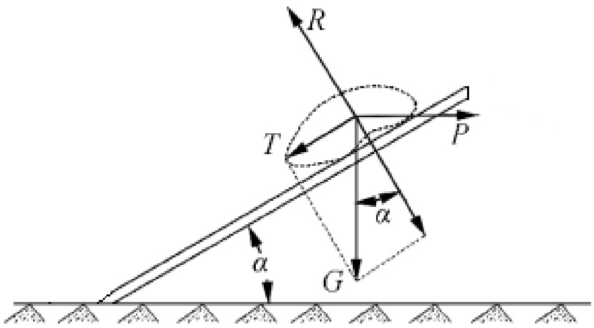


Fig. 3. Force analysis of potatoes on excavation shovel surface

$$\begin{cases} P\cos\alpha - T - G\sin\alpha = 0 \\ R - G\cos\alpha - P\sin\alpha = 0 \end{cases} \tag{2}$$

In the formula, P- represents the force required for the shovel to excavate the material, N;

T-the reaction force of the shovel body on the soil sliding along the shovel surface, N;

R-the reaction force of the shovel on the soil, N.

Simplifying the derivation yields:

$$\alpha = \arctan\frac{P-\mu_1}{\mu_1 P + mg} \tag{3}$$

$$\mu_1 = \tan\varphi \tag{4}$$

In the formula, μ_1-friction coefficient between soil and shovel surface.

Based on the above analysis, the inclination angle α of the shovel surface to some extent determines the resistance during excavation operations. However, if the inclination angle of the shovel surface is too small, the excavation performance will be affected. Considering the adjustability of the later inclination angle of the shovel surface, theoretically, the inclination angle α of the shovel surface should not exceed 24°. To ensure the efficiency of potato operation and reduce the loss rate, the inclination angle α of the shovel surface is designed to be 22°.

From experience, it can be concluded that the width of the digging shovel is related to the underground distribution distance of potato tubers, the deviation of working travel, and the distance of potato planting. In order to ensure that both potatoes and soil blocks are dug, the design of the digging shovel should consider the width of potato planting. The formula for calculating the width s_1 is:

$$S_1 = M + B + 3\sigma + 2C \tag{5}$$

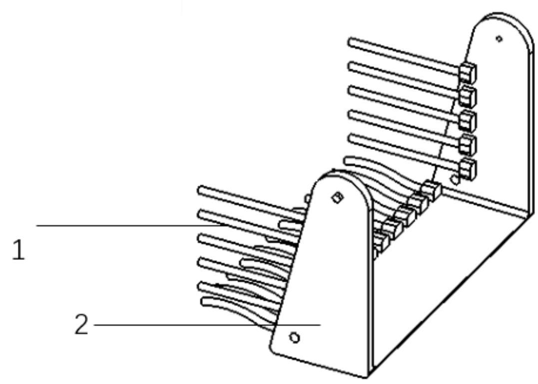
In the formula, M- represents the average line spacing, mm;

B - Average distribution width of potato chunks, mm;

C - Machine travel deviation, generally taken as 50-80 mm;

σ - Comprehensive standard deviation, mm;

The digging shovel is mainly composed of a grid bar and a flat shovel, as shown in Figure 4. Based on the above analysis and the commonly used materials in agricultural machinery, alloy steel is used as the material for the shovel. The shovel needs to be strengthened to enhance its strength and stiffness. The grid bar should be welded to the bottom of the shovel surface by welding, and the steel bar welded to the side cannot be bent. To prevent potatoes from falling during movement, it is also necessary to achieve separation between potatoes and soil blocks. The use of alloy steel can enhance the hardness, wear resistance, and corrosion resistance of excavation shovels under the same conditions, and improve the service life of excavation shovels when working in some wet soils. After investigation, it was decided to use steel bars with a diameter of 7 mm for the grating. The digging shovel is connected to components such as a diagonal rod and a polarizing frame (as shown in Figure 5) to achieve power transmission [15].



1. Fence bar; 2. Flat shovel

Fig. 4. Digging shovel structure

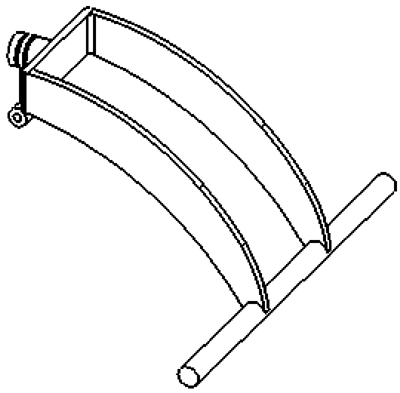
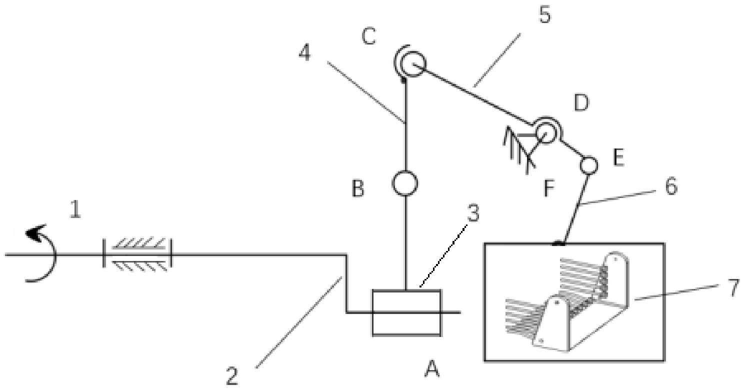


Fig. 5. The polarization frame



1. Rack; 2. Eccentric wheel; 3. Connecting sleeve; 4. Articulated arm; 5. Vibration frame; 6. Connecting plate; 7. Digging shovel

Fig.6. Transmission diagram of vibration digging shovel principle

The working process of the excavator shovel is shown in Figure 6, and the power passes through six motion pairs during the transmission process. During the transmission process, power first reaches frame 5 through eccentric wheel 2. The vibration frame is welded onto the frame using welding technology. Connect the excavator shovel 7 through the connecting plate 6 to achieve reciprocating swing. The digging shovel swings back and forth into the soil, digging up the soil and potatoes from the ground, and then transporting them backwards. The bars on the digging shovel can separate the potatoes from the soil, allowing the soil to leak into the lower part of the bars and continue to transport potatoes and other impurities backwards. The remaining potato and soil chunks move along the grid towards the vibrating screen for further separation. This design structure can greatly improve the ability of excavation shovels to break soil, allowing soil blocks to form small soil particles and reducing power consumption for subsequent processes.

3.1.2 Digging shovel vibration direction angle δ

The vibration angle of the excavator shovel plays a crucial role in the movement of materials on the shovel [16]. By adjusting the vibration direction angle δ and motion parameters $r\omega^2$, the motion posture of potatoes and soil blocks on the shovel can be controlled. The vibration direction angle δ is the angle between the shovel surface and the vibration direction line (X) [17], as shown in Figure 7.

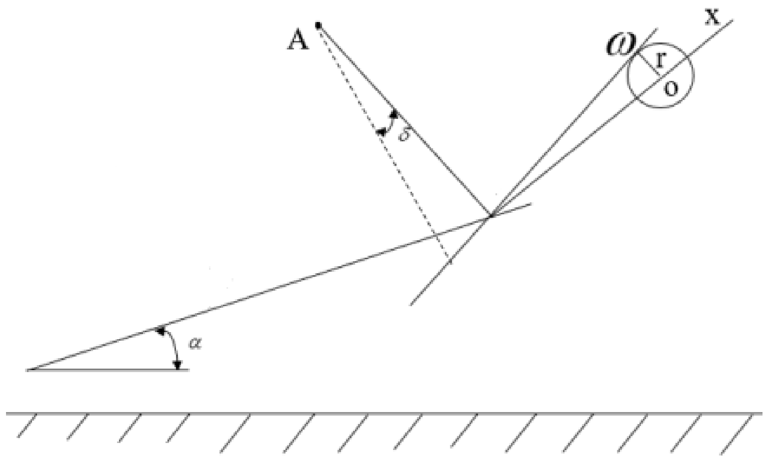


Fig. 7. Working principle diagram of vibration digging shovel

According to the principle of the shovel:

$$\frac{1.7\cos\alpha}{sin\,\delta} < \frac{\omega^2 r}{\mathrm{g}} < \frac{2.6\cos\alpha}{\sin\delta} \quad (6)$$

In the formula, ω - crank angular velocity, rad/s;

R - crank radius, mm;

α - burial angle, °;

δ- vibration direction angle,°.

According to the information [18], the vibration direction angle δ is taken as 10° to 15°; here the vibration direction angle δ is taken as 12.5° and r is taken as 20 mm, then the number of vibrations n of the vibrating excavator shovel is $561<n<694$.

3.1.3 Calculation of vibration amplitude

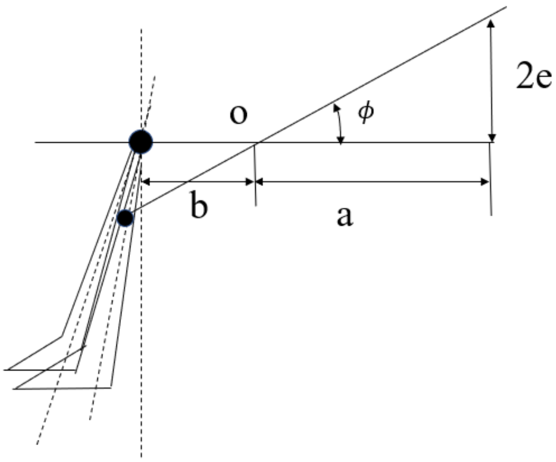


Fig. 8. Diagram of amplitude calculation

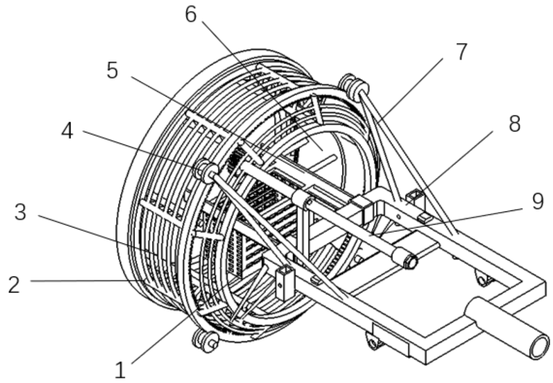
The vibration mode of the digging shovel is shown in Figure 8. The eccentric wheel drives the digging shovel to perform periodic circular motion. The amplitude of the vibrating digging shovel can be calculated based on the eccentricity *e*, the center O of the connecting rod, and the lengths *a* and *b*.

If the eccentricity of the transmission shaft is *e*, the vibration amplitude of the connecting rod is 2*e*, and the maximum swing angle obtained by moving around the middle connection point o is $\phi = \arctan\frac{2e}{a}$, The amplitude is $A=b\tan\Phi$. In the formula, *e* is 10 mm, *a* is 210 mm, and *b* is 160 mm. After calculation, it can be obtained that Φ=6.9°, *A*=15 mm.

3.2 Overall structural design of drum screen

3.2.1 Design of drum screen

The drum screen mechanism can achieve secondary separation of potatoes and soil, and its structure also plays a crucial role in the transportation of potatoes in space [19]. As shown in the Figure 9, the potato drum screen device mainly consists of a drum, a frame, a collection frame support frame, a lifting mechanism, etc. The rotating drum is mainly composed of square steel bent into a circle and 7 mm steel bars, with a spacing of approximately 30 mm between the steel bars. The square steel and steel bars are connected together by welding to achieve the working process. The rotating drum operates through four fixed guide wheels distributed on the frame. At the front of the separation drum is a vibrating screen, which receives potato tubers and soil from the vibrating screen. Through the rotation of the drum, a centrifugal force is applied to the potato chunks and soil chunks. Under the action of centrifugal force, some fine soil chunks and other debris are thrown out, and the potato chunks are transported into the collection box through the lifting device to complete potato harvesting [20-21].



1. Collection frame; 2. Square steel; 3. Grid bar; 4. Rolling wheel; 5. Collection frame support frame; 6. Lift plate; 7. Support frame; 8. Rack; 9. Drive shaft

Fig. 9. Rotating roller mechanism

3.2.2 Determination of drum radius R

The potato planting method selected in this paper is ridge cultivation. By referring to the planting mode of Dutch potato variety 15, the width is set to 900 mm and the ridge height *h* is set to 250 mm. As shown in Figure 10, D and R are the diameter and radius of the potato drum screen, respectively. It can be clearly seen that the soil cross-section of the ridge cultivation method is roughly an isosceles trapezoid, the width *a* of the ridge covering the top surface of the soil is 250 mm, the width *b* of the ground is 500 mm, and the horizontal distance *c* between adjacent ridges is 900 mm [22].

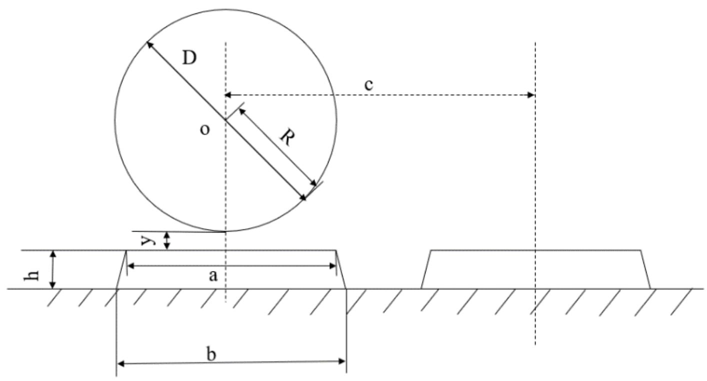


Fig. 10. Schematic diagram of drum screen diameter

Referring to the data related to the planting mode of potatoes, the diameter D of the potato drum sieve can be obtained. When the potato harvester works in the field, the drum should have a certain height with the ground to avoid friction between the drum and the ground, which may cause wear on the mechanical structure. So the drum screen should be kept at a certain distance of y=100 mm from the ground, and at the same time, the digging shovel in front should be deep into the soil to ensure that all potatoes are dug out. The calculated drum radius *R* is:

$$R = \sqrt{(\frac{b}{2})^2 + (h + y)^2} = 430\,mm \tag{7}$$

In the formula, *R*- the radius of the drum screen, mm.

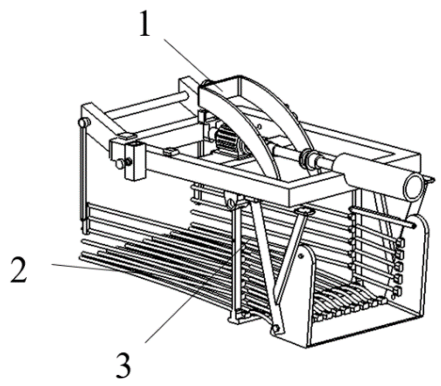
3.2.3 Determination of drum speed n

The rotational speed of the drum is the angular velocity at which the drum rotates during the separation process. The rotational speed of the drum has a significant impact on the effectiveness of potato soil separation and the rate of potato damage. The rotation speed of the drum screen is too low, and some large soil blocks are not crushed into small ones due to certain impact, making it impossible for them to pass through the screen and leak out; However, if the rotation speed is too fast, the number of impacts and collisions of potatoes in the drum will increase, resulting in greater damage [23]. Therefore, determining an appropriate rotational speed for the drum screen is crucial. During the rotation of the drum, it is driven to rotate by four auxiliary wheels. According to the formula for centripetal force, the threshold for the rotational speed *n* is obtained as follows:

$$n = \frac{30}{\pi}\sqrt{\frac{g}{R}} = 45.6\,r/min \tag{8}$$

3.2.4 Design of vibrating screen

The vibrating screen mechanism is a key mechanism in the process of separating potatoes and soil blocks. By using the vibrating screen, some large soil blocks are quickly broken into small ones, thus achieving the effect of potato soil separation [24]. The vibrating screen uses steel bars with a diameter of 7 mm and parallel intervals of 30 mm welded together, as shown in Figure 11. The vibrating screen mechanism is fixedly connected to the polarizing device, and the polarizing device vibrates up and down to drive the vibrating screen to move forward and backward. The vibrating screen mechanism is connected to the excavator shovel through two connecting rods, thereby also transmitting the vibration to the excavator shovel.



1. Polarization device; 2. Vibration screen; 3. Connecting rod

Fig. 11. Vibrating screen mechanism

4. Conclusion

This study designed a new type of hand-held potato harvester. It can complete the integrated operation of potato excavation, potato soil separation, transportation, and collection in one go, realizing the mechanization of potato harvesting and solving the problem of manual secondary potato picking. By designing and analyzing the structure of the vibrating digging shovel and drum screen, the inclination angle of the digging shovel blade is determined to be 40°; the inclination angle α of the shovel surface is designed to be 22°. The radius of the drum screen is 430 mm, and the drum speed is 45.6 r/min. The digging shovel can penetrate deep into the soil layer to scoop potatoes onto the vibrating screen. The vibrating screen adopts a grid format device and is designed using the principle of linkage swing. With mechanical vibration, it separates the potato soil for the first time, allowing the potatoes to enter the potato soil separation drum at the rear. The potato soil separation drum is also designed using a grid format device and the principle of centrifugal force. It can perform secondary separation and lifting of potato soil, achieving further separation of potato soil and sending potato chunks into the potato collection box. Due to the large spacing between the barriers separating the rollers of the drum, the soil blocks will be crushed by the gravity during ascent. The harvester uses a vibrating screen and a rotating separation drum to achieve thorough separation of potatoes and soil; Using plastic separation components to reduce potato skin damage and improve harvest quality; After potato excavation and soil separation, clean potatoes are directly sent to the potato collection box, solving the problem of manual secondary picking and packing. The research and development of new potato harvesting methods have significant economic and social benefits in reducing labor costs, improving work efficiency, and increasing productivity.

Acknowledgments

This work was supported by the General Project of Shandong Natural Science Foundation (ZR2021ME173), the Science and Technology Project of Shandong Institute of Metrology and Testing (No.2021KJ29), and the Tai'an Science and Technology Innovation Development Project (No. 2021ZC515).

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