IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 21, Issue 1 Ser. I (Jan. – Feb. 2024), PP 45-52
www.iosrjournals.org

Design And Test Of Vibration Feeding Device For Seed Potato Cutting Machine

Weilong, Liu ;Hengren,Wang; Xiangyou,Wang
(School Of Agricultural Engineering And Food Science,Shandong University Of Technology, Zibo,255000,China)

Abstract:
In order to realize uniform and orderly feeding of seed potato cutting machine, and effectively improve the operating efficiency and quality of seed potato cutting machine, this paper is based on the electromagnetic vibration principle to set up vibration feeding device, to realize uniform and orderly feeding of seed potato. First of all, through the force analysis of seed potato in the vibration conveying process, to build the relationship between the main operating parameters and the average slip speed, the main factors affecting the performance of the vibration feeding device. Using EDEM simulation software to further explore the working parameters affecting the feeding performance, design a four-factor, three-level orthogonal test, and polar analysis of the test results to determine the optimal parameter combinations: vibration trough vibration amplitude of 1.7mm, vibration frequency of 50Hz, vibration conveying angle of 12 °, vibration direction angle of 20 °. The results of the test results of the bench test verification, the results show that the verification test and simulation error is less than 5%, to meet the seed potato cutting machine continuous and orderly feeding control requirements, the study for the seed potato cutting machine and related materials automatic feeding to provide reference.
Key Word: *Seed potato; Seed potato cutter;Vibration feeding device;Parameter optimization*

Date of Submission: 01-01-2024 Date of Acceptance: 09-01-2024

I. Introduction

Potato is the world's fourth largest staple crop, both food and nutritious, enjoying the reputation of "underground apple". China is an important potato producer and consumer, and the annual planting area increases year by year, so the sustainable development of the potato industry has gradually become an important guarantee of food security [1-2]. In recent years, the whole process of potato mechanization equipment continues to develop, emerging a number of more mature potato modernization machinery, but the research field of seed cutting equipment is still very weak [3-4], the current seed potato cutting to the processing of the assembly line is the main way, this paper designs a device that can realize the seed potatoes in an orderly manner into the material, based on the electromagnetic vibration principle of the feeding device as a research object, the seed potatoes into the vibration ordering process to carry out Force analysis, the main working parameters affecting the operating effect of vibration feeding device. Using EDEM simulation software to carry out feeding simulation test, to further clarify the change trend of each influencing factor, and to determine the optimal feeding effect of the parameter combination, to ensure the success rate and accuracy of seed potato feeding process.

II. Structure And Working Principle of the Feeding Device

1. frame 2 fixing plate 3. connect installation frame 4. rubber baffle 5.V-shaped vibration hopper 6.controllable register 7. electromagnetic vibrator

Fig.1 Overall structure of the vibration feeding device

The main function of potato vibration feeding device can disperse and orderly arrange the accumulated and disorderly potato, which is mainly composed of rack, V-shaped vibration hopper, installation connection frame, fixing plate, electromagnetic vibrator and limit device, etc. The structure of vibration feeding device is shown in Fig.1. In order to meet the uniform and orderly to load device filling potato basic work requirements, using equiometric distribution of V-shaped vibration hopper, potato in vibration forward movement at the same time, and under the action of the limit device makes potato gradually arranged into chain, adjacent potato before and after the head and tail immediately, along the vibration hopper, realize the load device evenly filling the potato material demand.

III. Design and analysis of the key parameters

Key device parameter design

The hopper of the vibration feeding device is equipped with 6 conveying channels, the overall length of the conveying line L_x is 1500mm, the total width of the hopper is 1800mm, the design value of each hopper is 50mm, and the spacing between adjacent V-shaped hopper is 175mm. In order to facilitate the conveying movement of potato materials, the overall dimension of the hopper and the installation diagram are shown in Fig.2.

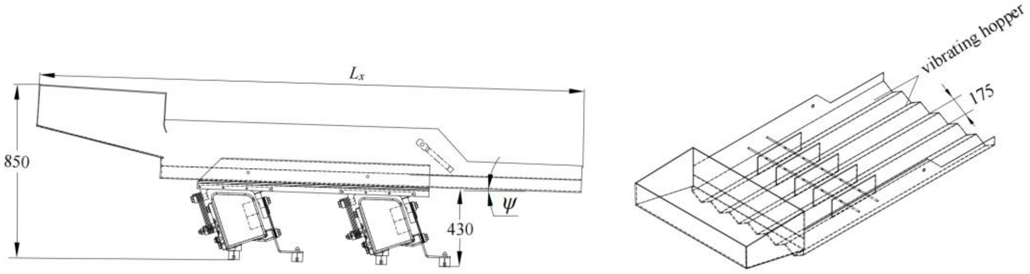


Fig.2 Size and installation diagram of vibration hopper

Analysis of vibration transmission force and motion of seed potato

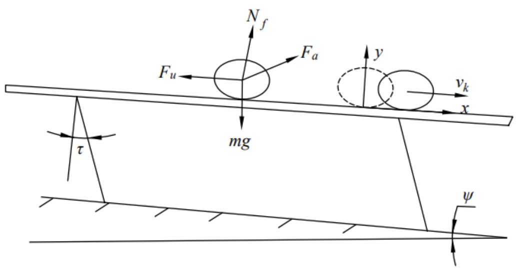


Fig. 3 Analysis of potato stress and motion

In order to make the vibration feeding device better meet the operation requirements of seed potato transportation, the working parameters of the vibration conveying device should be reasonably designed according to the material characteristics of seed potato.

Potato material in the V-shaped vibration hopper by a certain frequency of small reciprocating vibration, so as to realize the orderly forward transmission movement of potato, and evenly and continuously delivered to the feeding device at a certain transmission speed, to meet the demand of orderly feeding [5-6]. The potato was simplified into an ellipsoid rigid body with mass m and uniform distribution, and the force and motion of the single potato materials were analyzed in the hopper. As shown in Fig. 3, the force of potato on the hopper is simplified to its own gravity mg, reverse support force N_f, friction F_u and shock force F_a. The vibration direction Angle is τ, including the Angle between the inertial force direction and the inclined plane of the potato, and ψ is the tilt Angle of the hopper slope, that is, the vibration transmission Angle.

Let the amplitude of the vibration hopper be A, and the vibration angle frequency be ω_k. After time t, the displacement of potato material along the slope s, the vibration speed v_k, and the vibration acceleration a_k can be expressed as

$$\begin{cases} s = A\sin(\omega_k t) \\ v_{\mathrm{k}} = A\omega_k \cos(\omega_k t) \\ a_{\mathrm{k}} = A\omega_k{}^2 \sin(\omega_k t) \end{cases} \quad (1)$$

Given that the acceleration relative in the hopper slope, the dynamics of the potato in two directions is

$$\begin{cases} m\ddot{x} = F_a\cos\tau + mg\sin\psi \pm F_u \\ m\ddot{y} = N_f + F_a\sin\tau - mg\cos\psi \\ F_u = u_{\mathrm{k}} N_f \\ F_a = ma_{\mathrm{k}} \end{cases} \quad (2)$$

Where : μ_k *is* the friction factor between potato material and hopper slope

Potato is relatively static, sliding and throwing in the vibration hopper. In order to achieve smooth transportation of potato, it should slide relatively down along the slope of the hopper and no throwing movement occurs. At this time, it should meet $\ddot{y}$ =0. The joint vertical formula (1) and (2) can get the acceleration of potato relative to the vibration hopper is

$$\ddot{x}_1 = (\cos\tau + \mu_{\mathrm{k}}\sin\tau)A\omega_{\mathrm{k}}^2\sin\omega_{\mathrm{k}}t + (\sin\psi - \mu_{\mathrm{k}}\cos\psi)\mathrm{g} \quad (3)$$

When the potato slides downward relative to the vibrating hopper, the critical condition is $\ddot{x}$ =0,let the phase Angle be ϕ_1

$$\phi_1 = \arcsin\left(\frac{(\mu_k\cos\psi - \sin\psi)g}{(\mu\sin\tau + \cos\tau)\omega^2 A_{\mathrm{k}}}\right) \quad (4)$$

To make the potato downward slide down, ϕ_1 should be a solution, can get

$$\frac{(\mu_k\cos\psi - \sin\psi)g}{(\mu\sin\tau + \cos\tau)\omega^2 A_{\mathrm{k}}} \le 1 \quad (5)$$

Here A_k should meet

$$A_k \ge \frac{(\mu_k\cos\psi - \sin\psi)g}{(\mu\sin\tau + \cos\tau)\omega^2} \quad (6)$$

When the critical condition is $\ddot{y}$ =0, N_f =0,get by formula (2)

$$A_k\omega_k^2 \sin\omega_k \sin\tau - gcoa\psi = 0 \quad (7)$$

At this time the phase angle is ϕ_2 , from this solution

$$\phi_2 = \arcsin\frac{g\cos\psi}{A_k\omega_k^2\sin\tau} \quad (8)$$

For the potato not to have a throwing motion, ϕ_2 should be no solution, which leads to

$$\frac{g\cos\psi}{A_k\omega_k^2\sin\tau} > 1 \quad (9)$$

At this point, ϕ_2 should satisfy

$$A_k < \frac{g\cos\psi}{\omega_k^2\sin\tau} \quad (10)$$

In summary, when the potato slides down the vibrating hopper and no throwing occurs, then A_k should satisfy the condition

$$\frac{(\mu_k\cos\psi - \sin\psi)g}{(\mu_k\sin\tau + \cos\tau)\omega^2} \le A_k < \frac{g\cos\psi}{\omega_k^2\sin\tau} \quad (11)$$

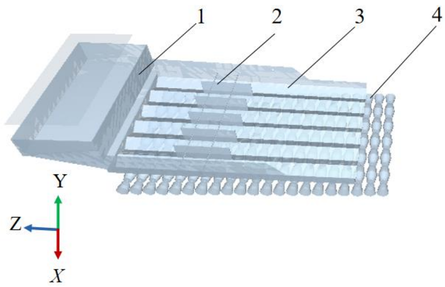
From the equation (3) is known to the potato stable downward sliding and no throw acceleration, the x-direction acceleration integration twice, to find each cycle of motion displacement, divided by a vibration cycle interval set ts for a cycle of motion at the beginning of the moment, set te for a cycle of motion at the beginning of the moment, to get a cycle of motion of the average speed is

$$\bar{v} = \frac{g}{4\pi\omega}(\sin\psi - \mu_k\cos\psi)(\phi_e - \phi_s)^2 - \frac{A\omega_k}{2\pi}(\cos\tau + \mu_k\sin\tau)(\sin\phi_e - \sin\phi_s) + \frac{A\omega_k}{2\pi}\cos\phi_s(\cos\tau + \mu_k\sin\tau)(\phi_e - \phi_s) \quad (12)$$

In order to make the potato along the vibrating hopper has a more stable and uniform sliding speed, to set the vibration parameters reasonably, from the formula (11), (12) can be seen, in u_k certain conditions, the amplitude size A_k, vibration frequency ω_k, vibration conveying angle ψ and vibration direction angle τ and prototype conveying performance is closely related to the increase in the amplitude size, vibration frequency, vibration conveying angle and vibration direction angle can make the potato is more favorable for the ownward sliding, but too large vibration angle frequency and amplitude will lead to potato jumping relative to the material trough slope, usually the amplitude size and vibration angle frequency through the adjustable regulated DC power supply adjustment, usually the larger the voltage, the faster the conveying speed.

IV. Simulation and analysis of the vibration feeding process

Simulation model building



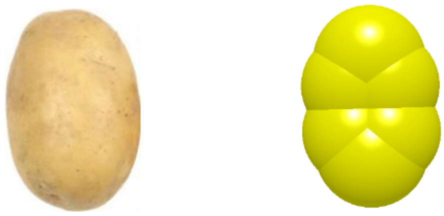
1.storage hopper 2.limit device 3.vibrating hopper 4.round table roller set

Fig.4 Simplified model of potato vibratory feeding

In this paper, the vibration feeding mechanism is mainly driven by electromagnetic vibrator hopper for seed potato material arrangement, the receiving device for uniform rotation and uniform forward movement of the circular platform roller group, in practice, the potato by the vibration feeding device continuous and uniform delivery to the receiving device, in order to explore the potato vibration feeding device performance, the use of Solidworks software for three-dimensional modeling model, and will be simplified model into the EDEM to generate the computational model, as shown in Fig.4, through the change of different working parameters in the software to simulate the simulation of the vibration feeding process of potatoes.

Modeling of potato particles

There are many varieties of potato, this paper statistics of the Netherlands 15 potato triaxial size, in order to more closely simulate the shape characteristics of the potato, the establishment of six particles unit potato discrete meta-model as shown in Fig.5 [7-8], its length size, width size, height size average value of 84 mm, 59 mm, 53 mm, respectively, the shape of the oval shape, due to the quality of the potato size of 140 ~ 210 g also There is variability in the size of the potato, the volume scale factor of this potato was set to 1.1, 1, and 0.9 in the particle factory, which accounted for 12%, 78%, and 10% of the overall size, respectively.



(a)physical seed potato (b)particle model

Fig.5 Physical object and particle model of seed potato

Simulation parameter model determination

Tab. 1 Material parameters setting

Material	Parameter	Value
potato	Poisson ratio	0.47
	Shear modulus /Pa	1.34×10^{6}
	Density/(kg·m^{-3})	1092
304 Stainless steel	Poisson ratio	0.332
	Shear modulus /Pa	7×10^{6}
	Density/(kg·m^{-3})	8000
urethane rubber	Poisson ratio	0.47
	Shear modulus /Pa	2.9×10^{9}
	Density/(kg·m^{-3})	940

Tab.2 Setting of each contact parameter

Material	Parameter	Value
potato-potato	Recovery coefficient	0.791
	Static friction coefficient	0.453
	Rolling friction coefficient	0.0246
potato-304 stainless steel	Recovery coefficient	0.685
	Static friction coefficient	0.714
	Rolling friction coefficient	0.156
potato-polyurethane rubber	Recovery coefficient	0.675
	Static friction coefficient	0.423
	Rolling friction coefficient	0.259

Simulation of the movement process, assuming that the parameters of the model quality distribution is uniform, in the movement process of potato main contact contact material for 304 stainless steel and polyurethane rubber, through the review of the relevant literature [9-10], to determine the simulation model of the various parts of the material properties of the parameters shown in Tab.1, potato and the simulation model of the material properties of the parameters of the contact material as shown in Tab.2, and set up the contact model for the Hertz-Mindlin with bonding.

In the EDEM simulation is also completed before the model motion parameters are set to vibration hopper to add vibration motion characteristics, and a single roller group were added to the linear and rotational motion composite characteristics, set the moving speed of 0.03m/s-1, rotational angular velocity of 3rad/s, a total of 21 group design, and set the roller group in the beginning of the movement of the 15s to simulate the vibration of filling into the process of generating potato The particle speed is 0.5Kg/s, and the total simulation time is set to 40s.

Design and result analysis of the simulation test

Motion simulation simulation of potato feeding process, through theoretical analysis and single-factor test, selected vibration hopper vibration amplitude range of 1.5 ~ 1.9mm, vibration frequency range of 45 ~ 55Hz, vibration conveying angle range of 6 ~ 12 °, vibration direction angle range of 16 ~ 24 °, the construction of four-factor three-level orthogonal simulation test , the simulation process as shown in Fig.6, when the potato When stabilized, the feeding success rate is defined as the evaluation index of feeding effect by counting the number of potatoes in the nest eyes of adjacent rollers, and the calculation formula is

$$W = \frac{m_1}{m_0}\times100\% \quad (13)$$

Where: m_1 is the number of rollers occupying a potato in the fossa of the roller；
m_0 is the total number of fossae in the neighboring roll group.

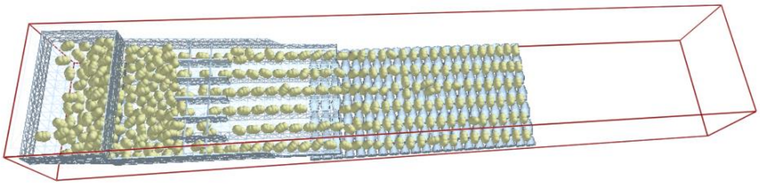


Fig.6 The EDEM simulation process

In order to reduce the number of tests, and at the same time accurate prediction of the test data, this paper selects the vibration amplitude, vibration frequency, vibration conveying angle, vibration direction angle of the four parameters as the influencing factors of the success rate of feeding, and each factor selects three levels, and designs a four-factor, three-level orthogonal test, and the simulation test influencing factors and the levels of each factor are shown in Tab.3.

Tab. 3 Simulation test factor level

		Factor		
oding level	Amplitude	Frequency	Conveyor angle	Orientation angle
	A/(mm)	B/（Hz）	C/（°）	D/（°）
I	1.5	45	6	16
II	1.7	50	9	20
III	1.9	55	12	24

A four-factor, three-level test was conducted according to the above, and a total of nine groups of simulation simulation tests were conducted with five repetitions at each level, and the simulation test design and simulation results are shown in Tab.4.

Extreme difference analysis of the test results, as shown in Tab. 5, in the orthogonal test with feeding success rate as the evaluation index, the strong and weak degree of the influence of each factor on the feeding success rate is as follows: vibration direction angle > vibration amplitude > vibration frequency > vibration conveying angle, and the vibration direction angle has the greatest influence on the feeding performance. The extreme difference data show that the best combination of the parameters of each factor is A2 B2 C3 D2, i.e., when the vibration amplitude is 1.7mm, the vibration frequency is 50Hz, the vibration conveying angle is 12°, and the vibration direction angle is 20°, the combination of feeding effect is the best. Fig.7shows that: with the increase in vibration amplitude, vibration frequency, vibration direction angle increases, feeding success is the first to increase and then reduce, can be seen in a certain range to increase the vibration amplitude, vibration frequency, vibration direction angle is conducive to improve the feeding effect, but too fast vibration amplitude increase, vibration frequency, vibration direction angle will make the speed of matching effect with the material receiving mechanism will be worse, resulting in a single roller eye filled with multiple Potato material.

Tab.4 Simulation test and results

序号	Factor				Feeding success rate
	A	B	C	D	/%
I	1.5	1.5	6	16	85.21
II	1.5	50	9	20	97.23
III	1.5	55	12	24	90.74
IV	1.7	45	9	24	94.35
V	1.7	50	12	16	95.58
VI	1.7	55	6	20	97.67
VII	1.9	45	12	20	96.36
VIII	1.9	50	6	24	92.71
IX	1.9	55	9	16	90.87

Tab. 5 Extreme variance analysis results

Performance indicators		A	B	C	D
Feeding success rate	K_1	91.06	91.97	91.86	90.55
	K_2	95.87	95.18	94.15	97.10
	K_3	93.31	93.10	94.23	92.60
	Extreme variance	4.81	3.21	2.37	6.55
Preferred combination		$A_2B_2C_3D_2$			

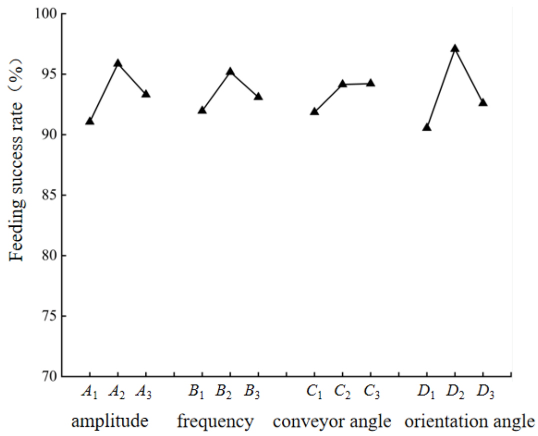


Fig.7 Extreme variance analysis results

Test validation

Test validation under the better parameter combination conditions, repeated three times, and the average, potato delivery status shown in Fig.8, the test results as shown in Tab. 6, the average success rate of feeding is 96.81%, the verification test and simulation error is less than 5%, meet the requirements of continuous and orderly filling of potato block cutting machine.


Fig.8 Verification test

Tab. 6 Verification test result

Test serial number	I	II	III	Average value
Feeding success rate	97.65	96.31	96.47	96.81
Error value	＜5%			

IV. Conclusion

(1) Designed a kind of electromagnetic vibration feeding device for seed potato cutting machine, adopting the principle of electromagnetic vibration to drive the hopper to realize the orderly arrangement of seed potato, completing the parameter design of the main structure, and theoretically analyzing the vibration conveying process of the seed potato, making it clear that the main factors affecting the success rate of feeding are the amplitude of vibration, frequency of vibration, angle of vibration conveying, and angle of vibration direction.

(2) Using EDEM simulation software to simulate the feeding process, and design a four-factor three-level simulation test, with the feeding success rate as the response value, the test results of the extreme difference analysis, to determine the optimal combination of parameters: vibration amplitude of 1.7mm, vibration

frequency of 50Hz, vibration conveying angle of 12 °, vibration angle of 20 °, the optimal parameters of the experimental validation, the results show that potato feeding The result shows that the success rate of potato feeding is 96.81%, and the error between test and simulation is less than 5%, which meets the requirement of continuous and orderly feeding of seed potato cutting machine.

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