

Research Article

Parametric Modeling and Moving Simulation of Vibrating Screen and Tubers on Potato Harvester

¹Huali Yu, ¹Xiaoshun Zhao, ¹Yongying Sang and ²Tao Wu

¹College of Mechanical and Electrical Engineering, Agriculture University of Hebei, Baoding 071001,

²College of Engineering, South China Agricultural University, Guangzhou 510642, P.R. China

Abstract: In order to overcome the behindhand and inefficient design of potato diggers, feature-based parametric modeling software Autodesk Inventor was used for modeling of potato diggers. The swing sieve, movement simulation with ADAMS was carried out. The complex velocity acceleration and displacement curves were analysed. Collision pressure curves were analysed too. Its velocity is less than or equal to 500 mm/s and its acceleration is more than or equal to 2.5 m/s² and less than or equal to 20 m/s². Test results indicated that Collision pressures of small and medium tubers are 120 Newton and 250 Newton, respectively, which are all smaller than damaging pressure. Potato can be transferred freely and damage rate is less than or equal to 4% when the frequency is 5.5 Hz and the swing is 30 mm.

Keywords: Parametric modeling, potato harvester, swing sieve, simulation

INTRODUCTION

Potato bruising is a serious problem in potato industry. Most of the cost of bruising is eventually passed back to the growers in the form of lower prices, reduced demand and increased storage losses. Bruising is outstanding, especially during the course of harvesting. Further more, the harvesting techniques needs a lot of efforts to be improved in China.

At the beginning of the 20th century, it occurs the change from the ways of using the hand-hoe to dig potatoes to the ways of using livestock to tow in Europe, America, the Soviet Union and some Asian countries (Yang, 2002). From then on, all kinds of potato harvesters were developed, such as the four-row potato combined harvesters in Holland, the combined harvester of KKY-2M, KOK-2 and KKP-2 in the Soviet Union and the small-sized ridge-till harvesters (SP100) in Italy (Liu, 2000). In recent years, some small-sized potato harvesters were produced in Korea and Japan, such as the single row or double row potato and pachyrhizus harvesters in gaoshan Machine Company of Korean.

Currently in China, most potato harvesters are small diggers and designed by traditional ways. There are some disadvantages: a great deal of time is needed and energy is spent to modify designs, design ways are obviously backward with low efficiency; incapable of realizing preparative assembly of parts, fails to carry out interference test of assembly; unable to see 3D shape before producing parts. In western countries, the

Inventor 3D shape and ADAMS simulation methods for the design of potato harvester have been adopted extensively, but it is mainly used to design big powered combine potato harvesters.

4UFD-1400 type potato combine harvester was developed Gansu Agricultural University exhibited better performances and adaptation on the dry land potato harvest, especially for fully-mulching dry land, but its potato damage rate was 4.2% (Wei *et al.*, 2013). A certain potato digger in poke finger's wheel was designed, which performed smoothly in digging, lifting and transporting without any block and potatoes were separated effectively from soil, but damage rate was 4.5% (Wu *et al.*, 2010; Wu *et al.*, 2011). A disc ce-grate type potato digger was designed, which performed smoothly in digging and transporting, the separation effect was efficient, but damage rate was 4.3% (Shi *et al.*, 2012). Moreover, these potato harvesters have not arm equipment and cannot transport the potato to loading trucks. For instance, 4SW-40 style and 4SW-130~150 style potato harvester designed by Inner Mongolia Agricultural University (Yan, 2001; Zhao *et al.*, 2007), CPP-XH-150 potato digger manufactured by Modern Agricultural Equipment Technology Co., Ltd, 4U-1 potato combine harvester and 4UW-120 potato digger designed by Chinese Academy of Agricultural Mechanization Sciences (Zhou, 2004), a new potato combine harvester designed by Gansu Agricultural University (Song and Wang, 2009), 4KU-

Corresponding Author: Tao Wu, College of Engineering, South China Agricultural University, Guangzhou 510642, P.R. Chin, Tel.: 13527789542

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130/150A elevator chain harvester for tuber crops (Zhou, 2008). There are two ways in avoiding collision: one is to add protective covering, gasbag or infrared distance sensor to real time detect the collision to control the elevator; the other is by using position information of feedback device from the pre-descript information in computer to judge whether collisions will happen (Hajime *et al.*, 1999). The potato harvester designed by China Agricultural University can transport potato to truck and the motion collision of potato harvester elevator was researched (Jia *et al.*, 2005; Liu *et al.*, 2009).

Inventor software is used to design 3D model of potato digger and then by ADAMS software, simulation analysis of screen and potato tuber movement is done to get the compound speed, acceleration and displacement of swing screen and the collision force of potato tuber. To find the optimisation movement parameters of swing screen to decrease collision force and reduce of damage rate of potato tuber.

FEATURE-BASED PARAMETRIC MODELING OF THE VIBRATING SCREEN

New vibrating screen was designed by Inventor on the foundation of the digger vibrating screen design. The Classification and Structure of the Vibrating Screen is: curving shaft, screen frame, suspended arm, tail screen axes, screen strip and the screen axes bracket, as shown in Fig. 1. The curving shaft revolves to arouse the screen body to do a to-and-fro swing. Tubers are spread on the transfer belt irregularly (Yang *et al.*, 1999).

Subdivide the vibrating screen into the series characters and save it in the characteristic database. Each character has technique parameters such as size and benchmark etc. Take the screen frame as an example to build up parts model: get a needed character according to the screen frame shape, including stretch and drill, the length of the screen frame is 400 mm, width is 600 mm, the immobility bore diameter of the tail screen axes is 10 mm. Inputting parameters to build up entity model, by which only the parameter value is needed to modify while modifying the model. The geometry restriction relation of size is formed while establishing model, restriction relation and design intent keep constant when modifying model.

The assembly function of software is used to assemble each part. Generally, each part contains 6 freedom degrees; the assembly process is to analyze the function of each part and the freedom degree of 6 directions firstly, then to choose the appropriate assembly method, lastly to fix parts. It carries on the interference test after the assembly body is created, make sure of rationality of accessories design and match (Wang and Chen, 2003).

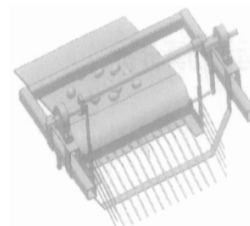


Fig. 1: Simulation model of swing sieve of potato harvester



Fig. 2: Bruise type1-skinning

The motion simulation of vibrating screen:

Set up the model of simulation: Vibrating screen is installed on the rear end of the digger. It works as the second separation section to the materials from the web and place tubers in strips behind the digger. Vibrating screen is normally the last working part of the digger, which processes the exhuming materials (Wang *et al.*, 2002). Most of the materials on the vibrating screen are tubers, there have no enough soil to protect the tubers and so there are close relations between the tuber damage and the parameters of vibrating frequency and swing. The movement rule of the vibrating screen is determined by the cam parameters and so the simulation model of the vibrating screen and cam is needed to be set up and the dynamic parameters is made according to simulation result. The data form of inventor entity is transformed into Parasolid form and is guided into ADAMD system by ADAMS/Exchange entrance and then the model is reset up perfectly.

Potato bruise types: There is four major types of potato bruise damage: skinning, black spot, shatter bruise and pressure bruise.

The first three types result from potato hitting objects, such as equipment clods, rocks or other handling operations.

Skinning or “feathering” often results from handling of immature potato tubers, resulting in the skin being scuffed and rubbed off. Tubers with skinned areas threat have turned dark as a result of exposure to wind, sunshine, or dry air (“scald”). It is as shown in Fig. 2.

Black spot bruise occurs when the impact of a potato tuber against an object damages cells in the tissue just beneath the skin without actually breaking the skin. Within 24 to 48 h the damaged tissue turns dark gray to black in color, but can be seen only after peeling the potato.

Table 1: Size-time relationship

Position	Left, right suspended arm axis	Left, right jointed short axis	Left, right suspended arm	Left, right of tail screen
Types	Revolution joint	Revolution joint	Revolution joint	Revolution joint

Shatter bruise results when impacts cause cracks or splits in the potato tuber skin. The cracks may extend into the underlying tissue. Diseases such as Fusarium dry rot, early blight and bacterial soft rot easily invade tubers that have shatter bruise.

Pressure bruise develops in storage, causing a flattened or depressed area on a potato tuber. It usually results from tuber dehydration (water loss) caused by low soil moisture before harvest and/or by inadequate humidification of ventilation air in storage.

Restriction types and force adding: Torque is transferred to screen axis by drive axis of back drive chain on the digger and cam make screen swing to-and-fro driven by screen axis. The suspended arm and screen frame are jointed by a joint pin. The movement of restriction position is revolution and restriction type is revolute joint. The screen restriction is listed in Table 1.

The power from Gear-box is transferred to the driving axis of the web chain, one side drives conveyer chain revolution and the other side transfer power to vibrating screen axis by belt and screen axis drive suspended arm to revolve and then vibrating screen begins to swing. Adding revolution drive to left and right suspended arm axis and make turning direction and rotate at same speed.

The design request of vibrating screen: The analysis of the material's movement rule on the screen is premise for selecting dynamic parameters of screen rationally, it is as shown in Fig. 3. According to the working demands, the distance to screen entrance is bigger than that of screen inside under the condition of no tuber jumping:

- **Vibrating frequency and swing:** Different selection of frequency and swing will make different capability of getting across the screen. Dynamic parameters of screen are related to movement state of materials. Normally, the velocity of vibrating screen should be less than 600 mm/s and the swing should be in the range of 15 mm and 35 mm for the aim of tuber bruising less than 5%.
- **Acceleration of screen:** According to the calculating models, in order to avoiding tuber skin damage during transportation, the distance to screen entrance is bigger than that of screen inside under the condition of no tuber jumping. According to the force analysis of tuber on the screen, the acceleration of the tuber sliding forward, backward and jumping should meet the conditions as in the formula (1), (2) and (3):

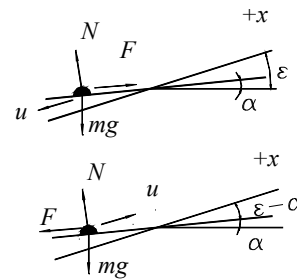


Fig. 3: Force analysis of potato on the swing sieve

Forward, as in:

$$\omega^2 r > \sin(\varphi - \alpha)g / \cos(\varepsilon - \alpha + \varphi) \quad (1)$$

Backward, as in:

$$\omega^2 r > \sin(\varphi + \alpha)g / \cos(\varepsilon - \alpha - \varphi) \quad (2)$$

Jumping, as in:

$$\omega^2 r < \cos(\alpha)g / \sin(\varepsilon - \alpha) \quad (3)$$

Here:

- ω = The angle speed of brace, rads/s
- r = Rotating radius of cam, m
- g = Acceleration of gravity, m/s²
- α = Obliquities of screen face, (°)
- ε = The angle of vibrating direction, (°)
- φ = The friction angle between materials and screen face, (°)

According to the relative design parameter, the scope of acceleration is 2.5 m/s² and 20 m/s².

Analysis of simulation result: In ADAMS system, the movement initial condition can be only translation joint and revolution joint, rpm is the initial movement condition of vibrating screen, so drive force could be added on the center of suspended axis. Figure 4 to 6 show, respectively the compound speed, acceleration and displacement of screen centric can be gotten by simulation analysis of screen and tuber movement.

From the following figures, it is known that the speed is less than 500 mm/s, which meets the request of potato skin damage rate; acceleration range is in 2.5 m/s² and 20 m/s², acceleration ratio can be got for the range, which meets the formula (1), (2) and (3). The materials can be carried to screen entrance successfully; displacement waves between 75 mm~135 mm and swing is 30 mm, both of them meet request.

Table 2: Force of damaging potato

Tuber size	Length/mm	Width/mm	Thickness/mm	Weight/g	Area/mm ²	Force limit/N	Pressure/(N/cm ²)
Small	40~50	40~45	40~45	40~50	1650	576	30.6
Medium	50~60	45~50	45~50	60~70	2130	792	37.2

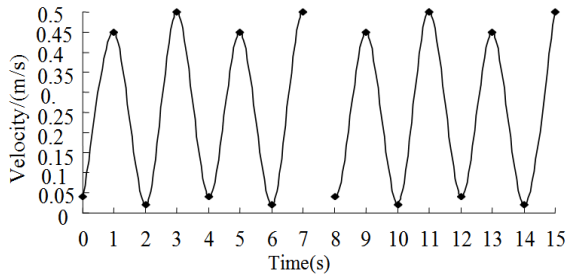


Fig. 4: Velocity

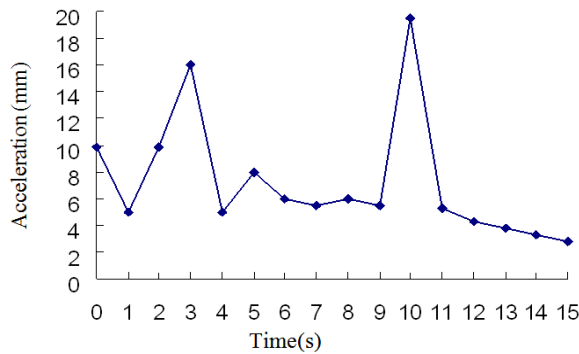


Fig. 5: Acceleration

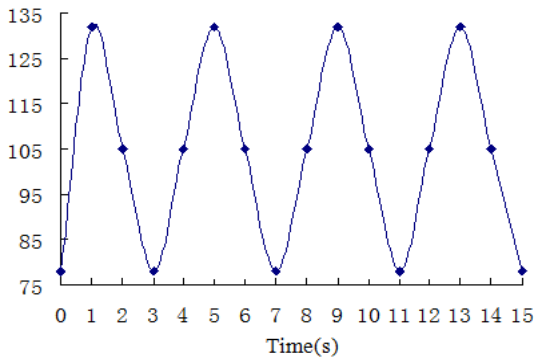


Fig. 6: Displacement

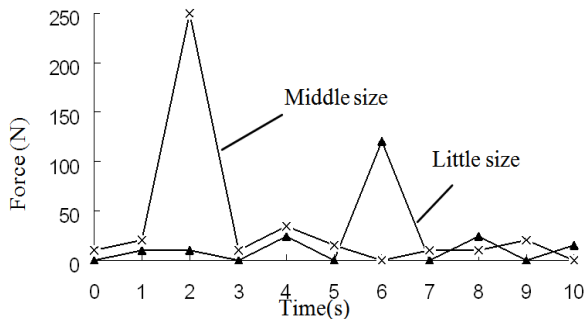


Fig. 7: Collision force of potato

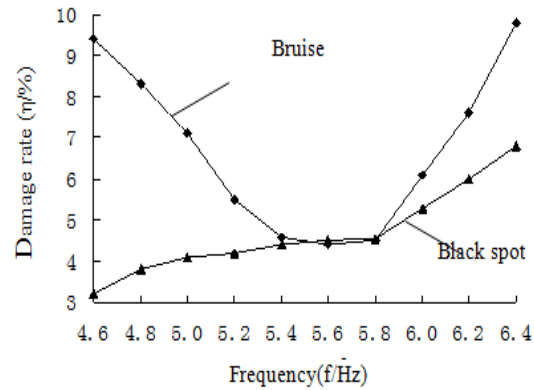


Fig. 8: Relation between frequency and damage rate

Analysis of tuber collision simulation: Force is measured during tuber movement by studying the small and medium tubers, normally, average length 40~60 mm, width 40~50 mm and thickness 40~50 mm. To avoid bruising potato, the collision force which tubers drop down from web chain to screen should be less than the limited data of Table 2. The simulation result is shown in Fig. 7. The maximum forces of small and medium tubers are all less than limited data, which is, respectively 120 N and 250 N; both of them meet the request.

Figure 8 shows the relations between frequency and damage rate of screen. It is obvious that the damage rate is less than 4% when the frequency is 5.5 Hz; it meets the request of design.

CONCLUSION

The feature-based parametric modeling software Autodesk Inventor, which is used to model potato digger parts, has enhanced the agricultural machinery modification design and the serialized design efficiency and so as to insure the higher design precision and the working capability.

This analysis does not consider the elasticity, root tension and air resistance of the tubers, which needs to be deeply studied in future because practical factors are much more complicated.

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