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KINEMATIC AND DYNAMIC ANALYSIS OF THE MECHANISM OF A SCREENING TYPE POTATO AND ONION SORTING MACHINE

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Abstract
Sorting of potatoes and onions represents a critical technological stage in the production process, where minimizing tuber damage is a key performance criterion. Sorting machines equipped with elastic coatings on working surfaces are widely used to reduce impact-related damage. This study presents a kinematic and dynamic analysis of the drive mechanism in the Tolsma sorting machine, with the objective of evaluating its performance characteristics under real operating conditions in the AGROVER potato cluster (Tashkent region, Republic of Uzbekistan). The methodology focuses on assessing inertial loads that are directly responsible for mechanical damage during the sorting process. The results of graphical analysis of the vertical forces acting on tubers during the screen vibrations of the Tolsma machine indicate that these forces align predominantly with gravity, causing tubers to become lodged in the sieve holes. The limited repulsive force (as indicated by values below the horizontal axis) fails to ensure effective product movement, while the deformation of elastic coatings and the oval shape of tubers contribute to increased risk of bruising and clogging. It is concluded that additional mechanical elements do not sufficiently address productivity loss or tuber injury, as both are primarily driven by inertial forces and suboptimal screen geometry. These findings highlight the need for optimization of machine parameters to enhance sorting efficiency and reduce mechanical damage.

Keywords: calibration, mechanism, kinematics, dynamics, sieve, inertial force, damage.

Introduction

The global demand for high-quality food products continues to grow, accompanied by increasingly strict requirements for the physical and commercial characteristics of agricultural produce. In recent years, several regulatory documents have been adopted that define specific quality standards for crops such as potatoes and onions. These documents provide detailed criteria regarding size, shape, and calibration procedures. For instance, the calibration of potatoes is typically performed by passing the tubers through square holes of predefined dimensions, while onions are sorted based on their maximum transverse diameter [1, 2].

As a result, in Central Asia—particularly in Uzbekistan and Kazakhstan—enterprises and agricultural clusters specializing in the cultivation and processing of potatoes and onions have widely adopted calibration machines from international manufacturers such as Grimme, Schouten, and Tolsma. Among these, Tolsma machines are especially common due to their compact design and operational simplicity. Despite their reliability, these machines are not without drawbacks. A common issue across all types of calibrating machines is the jamming of tubers in square holes. However, a specific problem with Tolsma machines lies in the frequent malfunctioning of the shaft coupling that drives the working unit, along with the rapid wear and tearing of transmission belts [3–5].

Currently, the maintenance of such machines in Uzbekistan is primarily conducted by foreign service providers. To date, no in-depth analysis has been conducted on the structural causes of mechanical failures in these machines, nor has the kinematic structure of their drive mechanisms been thoroughly studied.

Aim of the Study: This article presents a kinematic and dynamic analysis of the drive mechanism responsible for actuating the working unit of the Tolsma sorting machine used in the AGROVER potato cluster located in the Tashkent region of the Republic of Uzbekistan. The results of the analysis offer insights into the interaction between the machine's working surfaces and the tubers.

Materials and Methods

Figure 1 presents the general structure of the sorting machine. The working unit consists of several mutually parallel sieves (five are shown in the figure, though some models may contain three), which are positioned vertically one above the other. Each sieve is connected on both sides to the machine frame via two rocker arms. When the machine is activated, the rockers receive motion from a crank-slider mechanism, causing the sieves to oscillate along with the arms.

Due to the mass of the sieves and their oscillatory motion under acceleration, inertial forces and moments arise within the system. These forces are then transmitted to other components of the machine, influencing both mechanical wear and the dynamics of tuber interaction. Furthermore, the accelerated motion of the sieves complicates the contact behavior between the tubers and the working surfaces, especially in conditions where elastic deformation occurs.

To fully understand and evaluate these effects, both kinematic and dynamic analyses of the machine mechanism are required. Given that all sieves are structurally identical and symmetrically mounted to the frame, the initial analysis focuses on a single representative sieve. This simplification allows for detailed evaluation of motion parameters, inertial loading, and force transmission, which are critical for predicting overall machine performance and identifying structural weak points.

a) b)

Fig.1. A grading machine produced by Tolsma

Figure 2 shows a schematic representation of the drive mechanism that transmits motion to the machine's sieve, along with the trajectories of its moving components.

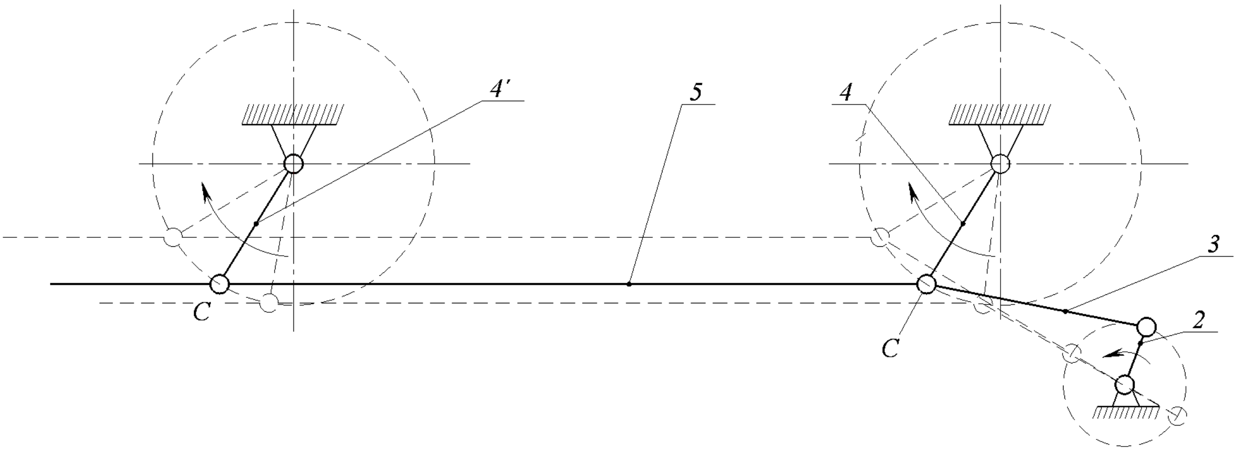

Fig.2. Plan of the positions of the mechanism for transmitting motion to the screen of the sorting machine: ***2– crank, 3- rod, 4, 4′-rocker, 5- screen***

Механизм обладает степенью подвижности, равной 1, то есть состояние механизма можно выразить через положение кривошипа.

В механизме рабочим звеном является грохот. Грохот, из-за его прикрепления с обеих сторон к опоре через два коромысла одинаковой длины, расположенные под одинаковым углом относительно вертикали, совершает возвратно-поступательное движение. Для кинематического анализа движения грохота достаточно изучить движение произвольной точки, принадлежащей ему. Кинематику точки С, которая относится к грохоту (поскольку точки сопряжения коромысел и грохота расположены друг над другом, и эти точки обозначены одной буквой С на рис. 2)., будем анализировать с использованием аналитического метода (метод замкнутых контуров вектора) (рис.3).

$$\varphi_4 = \arccos\frac{l_3^2 - l_2^2 - l_1^2 + 2l_1 l_2\cos\varphi_2 - l_4^2}{2l_4\sqrt{l_2^2 + l_1^2 - 2l_1 l_2\cos\varphi_2}} - \arctan\frac{l_2\sin\varphi_2}{l_1 - l_2\cos\varphi_2}\,. \qquad (1)$$

Since taking the first and second derivatives of expression (1) with respect to the generalized coordinate φ₂ is analytically complex, and the primary goal of the kinematic analysis of point C is to understand the nature of inertial forces, the motion of point C will be examined using a graphical method. The motion law of this point will then be reconstructed using interpolation techniques..

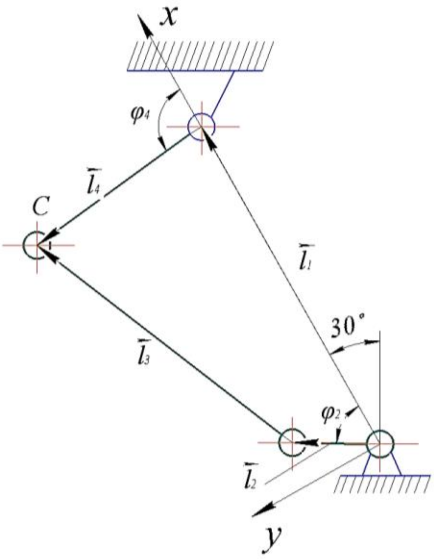

Fig.3. Closed counter of vectors

Considering that in the diagrams in Figures 2 and 3 the initial position of the crank is taken with a difference of 30º, we obtain the following expressions:

$$\upsilon_C = 78\sin(\varphi_2 - 30), \tag{2}$$

$$a_C = 78\cos(\varphi_2 - 30). \tag{3}$$

The main objective of the kinematic analysis of the mechanism is to determine the magnitude and direction of the inertial forces at its key points that have mass. We will designate the mass of the machine screen and the products processed on it as m and take it as a concentrated mass at point C, at which we will determine the forces acting on it. The following forces act on point C (Fig. 4):

gravity

$$\vec{F}_{og'} = m\vec{g}\ , \tag{4}$$

force directed opposite to normal acceleration - centrifugal force

$$\vec{F}_n = m\vec{a}_n = m\frac{\vec{\upsilon}_C^{\,2}}{l_4} = m\frac{6084\sin^2(\varphi_2 - 30)}{l_4}\ , \tag{5}$$

inertial force directed opposite to tangential acceleration

$$\vec{F}_i = m\vec{a}_\tau = m\vec{a}_C = m78\cos(\varphi_2 - 30). \tag{6}$$

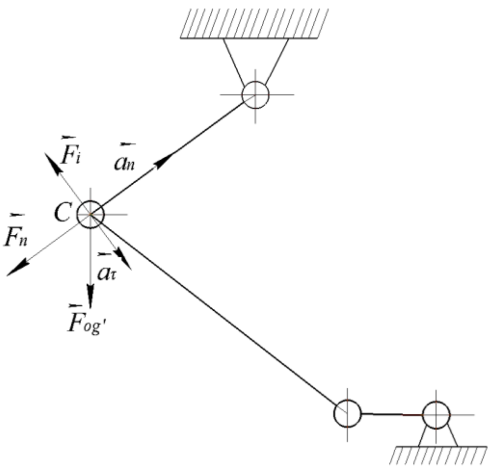

Fig.4. Forces acting on point *C*

It is known that in reciprocating motion all points of the body have the same kinematics. The above forces also act on the elements (i.e. tubers) located on the working surface. Let us determine the forces acting on the tubers in the vertical direction. The vertical component of the inertial force, arising due to tangential acceleration, will be as follows:

$$\vec{F}_{itv} = 78m\cos(\varphi_2 - 30)\cos(\varphi_4 - 60). \qquad (7)$$

The vertical component of the inertial force arising due to normal acceleration will be:

$$\vec{F}_{ntv} = m\frac{6084\sin^2(\varphi_2 - 30)}{l_4}\cos(150 - \varphi_4). \qquad (8)$$

The total vertical force acting on the tuber in the vertical direction is determined as follows:

$$\vec{F}_{tv} = \vec{F}_{itv} + \vec{F}_{ntv} + \vec{F}_{og'tv}. \qquad (9)$$

Results and Discussion

Based on the following geometric and kinematic parameters of the sorting machine, a graph of the variation in vertical force as a function of the crank angle φ_2 was obtained (see Fig. 5):
$l_1 = 0.4$ m, $l_2 = 0.09$ m, $l_3 = 0.3$ m, $l_4 = 0.2$ m, $\omega_2 = 25$ rad/s, and $0 \le \varphi_2 \le 2\pi$.

As illustrated in Figure 5, the direction of the vertical forces acting on a tuber during one full revolution of the crank is predominantly downward. The intermittent, jumping motion of the tuber along the sieve surface is caused by the portion of the force vector that lies below the horizontal axis. This upward repulsive force, which is responsible for lifting the tuber from the sieve, appears almost negligible in the graph due to its significantly smaller magnitude compared to the downward force that presses the tuber against the sieve surface.

This imbalance between the upward and downward force components explains the tendency of tubers to become lodged in the sieve openings. It also indicates that under the current operating parameters, the vertical excitation of the sieve is insufficient to generate the dynamic response required to ensure consistent particle displacement. Therefore, adjustments in angular velocity, rocker geometry, or sieve mass may be necessary to enhance the sorting performance and minimize product clogging and damage.

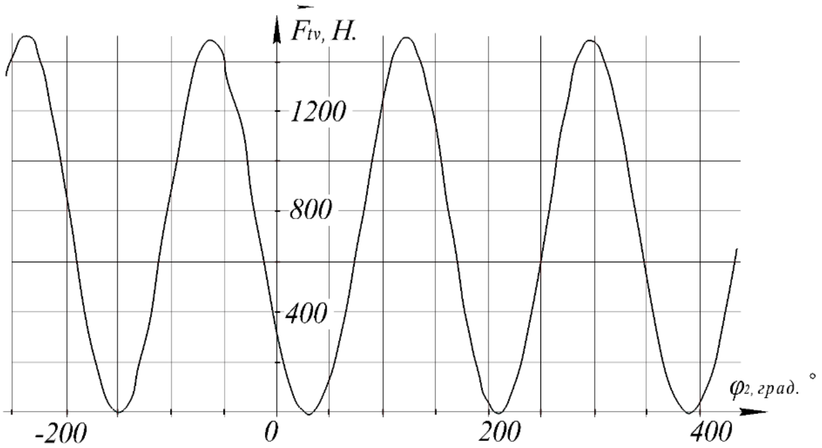

Fig.5. The change in the vertical force acting on the tubers, depending on the state of the crank, *while the mass of the tuber is conditionally obtained m = 0.1 kg*

One of the most significant drawbacks of this type of sorting machine is the tendency of tubers to become lodged in the working unit under the influence of inertial forces, which increases the risk of mechanical damage. Since the sieve openings are made of elastic materials and both potato and onion tubers also deform under external forces, the impact of vertical inertial loads causes the tubers to become "wedged" into the holes.

To address this issue, an additional mechanism has been installed on the machine; however, this modification does not completely eliminate the risk of tubers becoming stuck. Due to their oval geometric shape, tubers with a transverse diameter larger than the sieve hole can act as wedges when their longer axis is oriented perpendicularly to the sieve plane. This effect significantly reduces the efficiency of the sorting process, increasing the likelihood of product damage and decreasing the permeability of the sieve surface.

The problem is compounded by the inability of auxiliary technical solutions to fully prevent this phenomenon, especially under high-frequency oscillations or with large tuber sizes [6, 7]. Therefore, further design optimization or alternative sorting principles may be required to improve both productivity and product preservation.

Conclusions

As discussed above, the vibratory sorting machines developed by Tolsma offer several operational advantages. However, when it comes to potato harvesting, the primary indicator of machine performance is the level of tuber damage incurred during the sorting process [8–14].

Experimental observations and dynamic analysis show that sorting with vibratory machines tends to increase the incidence of mechanical damage to tubers. Based on these findings, we conclude that the main objective of future research should be to eliminate or minimize the factors that contribute to tuber injury during the sorting process, while preserving the other beneficial characteristics of the Tolsma machine design.

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