MATHEMATICAL DESIGN OF PROCESS OF DYNAMIC «SHAKING» OFF PEPPER SEEDS FROM CARPELS

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A mathematical model of process of the dynamic «shaking» off the pepper seeds from a carpel with the determination of the contact tension of destruction of the seeds-carpels connection has been developed.

1 Introduction

The creation of modern seed separating machines and production lines as difficult technical systems needs a deep theoretical study of the state of this question. The co-operation of the working organs of a machine and vegetables that are processed (carpels) with the purpose of high-quality separation of seeds from the carpels requires a clear design of the process which that allows to make a correct choice of the machine construction and its working organs at the stage of planning taking into account the desired results.

The machine offered by the authors for the receipt of the seeds of sweet and hot pepper is the machine of shock action [1, 11]. An object of treatment in it is the carpels, which has a shape of a semi-sphere, truncated pyramid or truncated cone with the seeds located perpendicularly to its surface. Every seed is fastened to the body of the carpels by a short neck (a stalk).

The plate of the whip strikes the carpels, that is located in the lower part of the perforated wall of a drum. The carpels is in the tensely-deformed state, and «shakes» off some part of the seeds from itself and then begins to move (to slide) on the internal surface of the drum. As the plate of the whip has a certain angle with the axis of the drum, the curve of the motion of the carpels is a spiral line with a small angle of ascent. At sliding on a cylinder surface it loses the certain amount of seeds as well. Obviously, the way passed by the carpels and the «loss of seed» are linked with the force of a blow (the speed of the whip plate). It is desirable that after the blow the carpels maks a complete turn on a circle and simultaneously moves up along the axis of the drum to interact with the next plate of the whip. Thus, on the average, the carpels perceives as many shots, as there are plates on the whip. The output of the seeds will be proportional to the force of the blow (linear rate of the plate movement) as well as to the number of shots. However, the force of the blow should be limited both cinematically and dynamically, although they are the associate factors. The kinematic limitations of the speed of the whip are determined by the length of the way of the carpels (one turn), and the dynamic ones by the possibility of destruction of the body of carpels and the seed. Thus, the contact pressure of the whip plate and that of the carpels should not exceed the limit of durability of the carpels material.

Thus, for theoretical grounding the process of segregation of the seeds of sweet and hot pepper it is necessary to create an adequate dynamic model of «shaking» off the seeds from the carpels.

2 Materials and methods

On the basis of the conducted analysis [2] the machines and equipment for vegetable plants, water-melon, melon and gourds it has been found out that while treating the pepper with the purpose of the separation of the seeds it is not obligatory to grind its body completely, but taking into account the biological features, after the separation of a small boll from the carpels (a core with the seed) it is advisable to separate the seeds by «shaking» them off [3, 4].

The theory of blow relates to the field of theoretical mechanics [5] and also mechanics of continuous environment [6, 7, 8, 9]. The character of interaction at a blow is determined by the force of the blow, time of the interaction and the material of the interactive bodies. But in the mentioned works the results obtained relate to the bodies of a regular geometrical shape, homogeneous material with the properties well studied.

The bodies of vegetable origin, such as pepper carpels, heterogeneous in their structure, of a wrong geometrical shape, considerably change these indexes depending on the variety. Therefore, the construction of the adequate mathematical models which describe the physical essence of the dynamic process of «shaking» off the seeds from the carpels will make it possible to optimize the choice of structural and technological parameters of the machine that is being developed.

3 Results and discussion

As far as the carpels moves chaotically inside the drum during the process of «shaking» off the seeds, it is next to impossible to foresee the appropriateness of the contact of the whip with the carpels. Therefore, mathematical description of the process of the separation of seeds from the carpels, it is advisable, with the purpose of adequacy to consider three models which in general will represent the reality very closely.

The first model represents the collision of a whip shoulder-blade of a working organ of the machine with a seed which is on the surface of the carpels. Let the carpels fall on a «flag» with the speed of falling V_0 (Fig. 1).

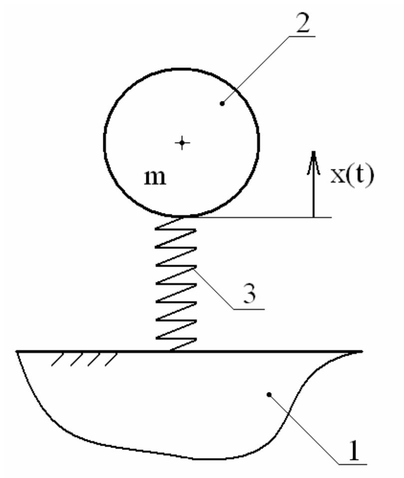

Figure 1 - Calculation chart for the first model of «shaking» off the seeds:
1 – body of carpels; 2 – seed; 3 – stalk of seed

At the moment of the carpels and flag collision the equation of motion of the seed on the neck is as follows [10]:

$$m\ddot{x} + kx = 0 \qquad (1)$$

where m – is mass of a seed;
k – is coefficient characterizing energy of deformation of neck.
In its turn,

$$k = \frac{S_ш \cdot E}{l}$$

where $S_ш$ – is area of transversal cut of neck;
l – is length of neck;
E – is module of resiliency of material of neck.
At the moment of blow $t = 0$ initial velocity of motion of seed neck is V_0.
For the sake of convenience (1) it is possible to rewrite the equation as follows:

$$\ddot{x} + \omega_0^2 \cdot x = 0 \qquad (2)$$

where ω_0 – is circular frequency of harmonic motion $x(t)$:

$$\omega_0^2 = \frac{k}{m}. \qquad (3)$$

Initial conditions look like:

$$x(0) = 0; \quad \dot{x}(0) = V_0. \qquad (4)$$

Then the solution of the equation (2) according to [10] looks like:

$$x(t) = \frac{V_0}{\omega_0} \sin \omega_0 t \qquad (5)$$

$$\dot{x}(t) = V_0 \sin \omega_0 t. \qquad (6)$$

Tension in a neck:

$$\sigma(t) = \frac{E \cdot x(t)}{l} = \frac{E \cdot V_0}{l \cdot \omega_0} \sin \omega_0 t. \qquad (7)$$

The maximum tension is achieved at the moment t_0 from a condition:

$$\sin \omega_0 t_0 = 1 \qquad (8)$$

$$\omega_0 t_0 = \frac{\pi}{2}. \qquad (9)$$

With (9) we will get:

$$t_0 = \frac{\pi}{2\omega_0}. \qquad (10)$$

Thus, we have:

$$_{\max}\sigma = \frac{E \cdot V_0}{l \cdot \omega_0}. \qquad (11)$$

Maximum tension is compared to the limit of durability of material of neck (by the limit of fluidity σ_T).

The second model of «shaking» off the seeds from the carpels is to the effect that a whip shoulder-blade contacts directly with the carpels, and through deformation of its body the point of fastening the neck (a stalk of seed) undergoes moving $y(t)$ (fig. 2).

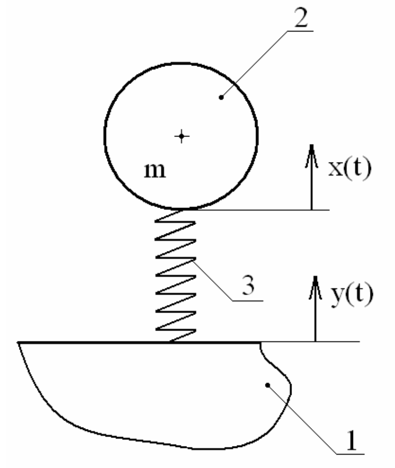

Fig. 2 - Calculation chart for the second model of «shaking» off seeds:
1 – body of carpels; 2 – seed; 3 – neck (stalk of seed)

In this case, the equations of motion of seed looks like:

$$m\ddot{x} = -k(x - y) \qquad (12)$$

where m – is mass of seed;
x – is law of motion of seed;

y – is law of motion of body surface of carpels.
Let $y = y(x)$ be the set (known) function of time.
Then equation (12) can be written down as follows:

$$\ddot{x} + \omega_0^2 \cdot x = \omega_0^2 y(t) \qquad (13)$$

where $\omega_0^2 = \dfrac{k}{m}$.

As there is a blow, then:

$$y(t) = y_0 \cdot H(t) \qquad (14)$$

where $H(t)$ – is the single function of Heavyside;
y_0 – is quantity.

Initial conditions:

$$t = 0; \quad x(0) = \dot{x}(0) = 0 \qquad (15)$$

Solution of equation (13) according to [10]:

$$x(t) = y_0(1 - \cos\omega_0 t) \qquad (16)$$

$$\dot{x}(t) = y_0\omega_0(1 - \cos\omega t) \qquad (17)$$

Then the size of tension in a neck will be determined as:

$$\sigma(t) = E\frac{(y(t) - x(t))}{l} = \frac{E}{l}y_0[1 - (1 - \cos\omega_0 t)] = \frac{Ey_0}{l}\cos\omega_0 t \qquad (18)$$

Maximum tension:

$$_{\max}\sigma = \frac{E \cdot y_0}{l} \qquad (19)$$

is achieved at in a moment $|\cos\omega_0 t| = 1$ or at $t_0 = \pi$.

The third model represents the process of «shaking» off the seeds at the direct contact of the carpels and seeds with the shoulder-blade of the whip.

We will consider the dynamic system of two masses: m_1 – body mass of the carpels and m_2 – mass of a seeds (or all seeds) (fig. 3). The masses are connected by an equivalent spring (a neck). Mass m_1 has undergone the influence of shock impulse $F(t)$.

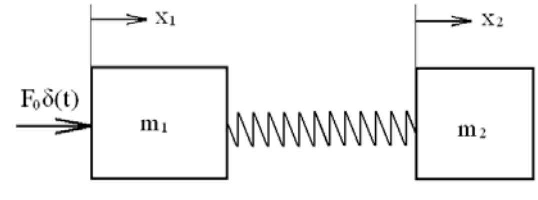

Fig. 3 - Calculation chart for the dynamic system of carpels-seed

Shock impulse $F(t) = F_0 \cdot \delta(t)$

where F_0 – is force of blow on the system;
$\delta(t)$ – it is Dirak's delta function, which looks like:

$$\delta(t) = \lim \frac{1}{t_0}[x(t) - x(t - t_0)] \qquad (20)$$

Delta function has the following properties:

$$\int_0^\infty \delta(t - a)dt = 1 \qquad (21)$$

$$\int_0^\infty f(t)\delta(t - a)dt = f(a) \qquad (22)$$

where $0 < a < \infty$.

Equation of motion of the system according to [10] looks like:

$$m_1\dot{x}_1 + k(x_1 - x_2) = F_0 \cdot \delta(t) \qquad (23)$$

$$m_2\dot{x}_2 - k(x_1 - x_2) = 0 \qquad (24)$$

We accept the initial conditions as zero ones.
Then, as it is shown in [10] the system of equations has the solution:

$$x_1(t) = \frac{F_0}{m_1 + m_2}\left(t + \frac{m_2}{\omega m_1}\sin\omega t\right) \qquad (25)$$

$$x_2(t) = \frac{F_0}{m_1 + m_2}\left(t + \frac{m_2}{\omega}\sin\omega t\right) \qquad (26)$$

where $\omega^2 = k\dfrac{m_1 m_2}{m_1 + m_2}$ (27)

$$k = \frac{S_{ш2} \cdot E}{l} \qquad (28)$$

where $S_{ш2}$ – is area of neck of a seed or seeds.
If $m_2 = n \cdot m$, them $S_{ш2} = n \cdot S_ш$, n – is a number of seeds.
The tension in necks will be as:

$$\sigma(t) = \frac{k(x_1(t) - x_2(t))}{S_{ш2}} = \frac{F_0}{S_{ш2}(m_1 + m_2)}\left(\frac{m_2}{\omega m_1} + \frac{1}{\omega}\right)\sin\omega t = \frac{F_0}{S_{ш2}\omega m_1}\sin\omega t \qquad (29)$$

At $t_0 = \pi / 2t_0$ we have

$$_{\max}\sigma(t) = \frac{F_0}{S_{ш2}\omega m_1} \qquad (30)$$

As a result of impulsive action the system has speeds

$$\dot{x}_1(t) = \frac{F_0}{m_1 + m_2}\frac{m_2\omega}{\omega m_1}\cos\omega t = \frac{F_0 \cdot m_2}{(m_1 + m_2) \cdot m_1}\cos\omega t \qquad (31)$$

$$\dot{x}_2(t) = -\frac{F_0}{m_1 + m_2}\cos\omega t \qquad (32)$$

If to designate $\dfrac{F_0 \cdot m_2}{(m_1 + m_2) \cdot m_1} = V_0$, then

$$\dot{x}_1(t) = V_0\cos\omega t \qquad (33)$$

$$\dot{x}_2(t) = -V_0\frac{m_1}{m_2}\cos\omega t. \qquad (34)$$

4 Conclusions

Three developed basic mathematical models of the dynamic «shaking» off the seeds from the carpels of pepper make it possible to describe adequately the process of destructing the carpels-seeds connection and determine the contact tension of destruction. Exactly such amount of models is rational for the description of physical reality of the process.

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