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Mathematical Modeling of the Process of Machine Splitting of Nut Shells

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ABSTRACT: The method of calculation of power-power parameters of nut shell splitting is given. Mathematically simulated operation of power mechanisms and impact of destruction of nut shell. Numerical experiments determined impact force of cluster destruction and kinematic parameters of machine hammer. The developed mathematical model will allow geometric and dynamic parameters of the combined nut of the fringing machine, and is also used in design for improving the design of this machine.

KEYWORDS: shell, nut, power mechanism, splitting, impact, destruction, kinematic parameter, hammer, machine.

I. INTRODUCTION

In the industrial processing of nuts by separating the shell from the kernel, there is a technological problem of preserving the kernel without damage and destruction. Existing devices for breaking the shell of nuts in one pass carry out destruction by 60–70%, and about 30% of the cleaned kernels come out after machine destruction of the shell damaged. The need to create such equipment is due to the fact that the nut is a valuable nut crop and an irreplaceable raw material for the confectionery industry. To study the process of cleaning hazelnuts in laboratory conditions, a special installation was designed and implemented (patent No. 2454897) [1]. A diagram of a device for cracking nutshells is shown in figure 1.

The principle of operation of this cleaning device [2] is as follows. Unpeeled nuts are poured into the hopper. Then the electric motor is turned on and rotation from the drive pulley mounted on the worm gear shaft is transmitted through the double belt to the driven pulley mounted on the shaft fixed in the bearing assembly. A flange is located on the shaft, on which the transporting drum is rigidly fixed. Rotating, the drum transports the nuts to the splitting area, while keeping them in their cells. The nuts are entrained into the gap between the outer pressure plate and the drum, where they are shattered. The nut, approaching the outer pressure plate, begins to squeeze, thereby pushing the plate away from itself. The stiff spring, applying pressure to the outer pressure plate, gradually breaks the nut shell. After breaking the nut shell, the kernel remains intact, thanks to the correctly set gap between the pressure plate and the drum. The shells and husks remaining in the cells are pushed out and cleaned with a stiff brush attached to the inner cheek. Chopped nuts are poured into a receiving hopper for further processing.

In ancient Asia, or rather, in the ancient city of Bukhara called the “Pearl of the East” has preserved the ancient recipe for traditional national salty apricot pits [3]. The essence of these apricot pits , is the preservation of rare vitamins B17, A and C, iron and potassium. They contribute to the enrichment of blood with hemoglobin, iodine, magnesium and phosphorus, which affect the activity of the thyroid gland, lower blood pressure and are necessary for hypertensive patients, as well as pectin. The method of preparation of such salty apricot pits involves mechanically splitting the shell (with a hammer of each apricot pits but separately) to form cracks. After that, they are moistened in a saline solution for 1–4 minutes, where the water temperature is 50–60 °C. Then the moistened apricot pits are heat treated, i.e. roasting in cauldrons.In this article, the author studied the methods of splitting apricot pits of different varieties for the formation of cracks in the shell, without damaging the kernel. Revealed the efforts needed to split. The effect of force on the splitting of apricot pits was investigated, and on the experimental installation GUNT WP 300.20 the installation power was 20 kN. The split was carried out on varieties of apricot pits, from the side of the junction of the apricot pits and from the side of the hollow part. The optimal conditions for splitting fruit pits, having approximately the same shape and structure, are

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revealed. When the apricot pits are squeezed along the junction and from the side of the hollow part in the direction of the major axis of their ellipse shaped section, as a result, the core of the apricot pits remains undamaged. Graphs of F (kN) versus distance (mm) and duration (s) were obtained. The results of the experiments are shown in the table. Also, an increase in the effort exerted on the destruction of apricot pits on the shell wall thickness was revealed [4]. The thickness of the apricot pits depends on the thickness of the walls and the width of the junction of the apricot pits. The thinner the shell and the smaller the width of the shell interface, the less force is spent on splitting the apricot pits.
An attempt has been made to develop economically effective method and technology of obtaining the various profile and inexpensive carbon sorbents with improved quality index and for solving the problem of waste utilization (fruit stones). The grinded peach and apricot stones shells of 0.3-3.0 mm fraction were used for experiments. The carbonization was carried out at 500-950°C for 1-3 hours. The activation was carried out at 800-850°C for 1-5 hours using water vapor and vapor-gas mixture [5]. Optimal conditions of carbonization and activation of fruit stones shells have been developed.
In this article the solution of the problem of receiving the whole kernel of a nut is offered at its processing for a candy store and the dairy industry [6-8]. New development of the device for splitting of a shell of different types of nuts which will allow increasing quality of developed production is presented. By results of experiments parameters are optimized, the equations of dependences are received, analyses are carried out them and conclusions are drawn.
Under the conditions of Uzbekistan, more than 662123 tons per year of apricot are produced. Of this amount, the waste is 40%. At the moment, the processing and production of the finished product from this waste material is the most important task. The processing of apricots is carried out in the republic by canneries and private firms producing dried fruits. Apricot kernels contain a large amount of fatty acids, compounds of several minerals, organic acids and a number of both replaceable and essential amino acids [9-10].

II. RESEARCH METHODS

In the work, the equations of the describing kinematic, power, geometric parameters are used. Algebraic and differential equations are used to simulate the operation of the power mechanisms of the machine. Lagrange equations of the second kind are used in the dynamic analysis.

III. RESULTS AND DISCUSSION

The productivity [11] of the device for cracking the shell can be calculated if we imagine the cracking process as a certain number of nuts emerging from the crushing zone in the form of a tape with a width equal to the length L of the drum and a thickness equal to the width a of the exit slot. Then, in one drum revolution, the volume (m^2) of the tape passing through the exit slot is

$$V = \pi D L a, \qquad (1)$$

here D is the drum diameter, m; L - drum length, m; a is the distance of the outlet slit, m.
Hence, at ω (rpm), the productivity of the device for cracking the shell of nuts

$$Q = \pi D L a \omega, \qquad (2)$$

where ω is the number of drum revolutions, rpm.
It must be borne in mind that when cracking nuts, the spring that presses the pressure plate against the drum is somewhat compressed and diverges. In this case, the width of the exit slot can change significantly, which must be taken into account, especially when cracking the shell of nuts, because this can affect the quality (number of whole kernels), i.e. for *a* = 0. Hence, Q = 0.
In fact, the performance is not zero, because the pressure plate moves back a width c, depending on the actual crushing forces and the degree of spring stiffness. Then

$$Q_{\text{ф}} = \pi D L (a + b + c)\omega \qquad (3)$$

Based on practical data, b = 0.25 *ac*, i.e. in calculating the productivity, the width of the outlet slit, taking into account the deformation of the spring, is assumed to be equal to 1.25 *ac*.
It is also necessary to take into account the number of cells of the drum $n_{\text{яч}}$, the density of the processed nut ρ, the yield factor of the number of intact walnut kernels $k_{\text{вых}}$. Then the final performance of the device for cracking the shell of nuts will take the form

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$$Q = 1{,}25\pi DLan\rho k_{\text{вых}} n_{\text{яч}} , \quad (4)$$

where ρ is the density of the processed nut, kg/m^3; $k_{\text{вых}}$ – yield ratio of intact nuts, $k_{\text{вых}} = 0{,}8 \div 0{,}9$; $n_{\text{яч}}$ – number of cells in the drum, pcs.

The required installed power $N_{\text{дв}}$ of the electric motor of the device for cracking the shell of nuts can be determined by taking into account the power consumption for cracking nuts and friction in the bearings, i.e. to overcome all resistances during device operation

$$N_{\text{дв}} = \frac{(N_1 + N_2)}{\eta}, \quad (5)$$

where N_1 is the power consumed for cracking nuts; N_2- the power spent on overcoming the friction in the bearings; η - transmission efficiency, η = 0.95.

Cracking of nuts is carried out by certain efforts, the average value of which is

$$\text{P}_{\text{ср}} = \sigma_{\text{сж}} L l \mu \quad (6)$$

where $\sigma_{\text{сж}}$ is the compressive strength of the nut, Pa; L - drum length, m; l- the length of the arc at the walnut cracking site, m; μ- coefficient taking into account shell crushing 0.3 ÷ 0.5.

The actual number of nuts splitting at any time is significantly less than the number of nuts in the crushing zone. Therefore, when determining the crushing force in the calculation formula, it is necessary to additionally enter the coefficient λ, taking into account the simultaneity of splitting, λ = 0.01-0.02.

Then the average crushing force

$$\text{P}_{\text{ср}} = \sigma_{\text{сж}} L l \mu \lambda \quad (7)$$

When a nut enters the splitting zone between the drum and the pressure plate, the average total crushing P_{cp} force causes a friction force equal to fP_{cp} (where f is the friction coefficient, f = 0.3 ÷ 0.45). The product of this force by the radius R of the drum is the moment of force, which requires the power of the engine to overcome.

The product of the frictional moment and the angular speed of the drum $\omega = 2\pi n$ (where n is the drum rotation speed, r/s) determines the power required for crushing,

$$N_1 = 2\pi n \text{P}_{\text{ср}} f R \quad (8)$$

Substituting the value P_{cp} , we get ,

$$N_1 = 2\pi n \sigma_{\text{сж}} f L l \mu \lambda R \quad (9)$$

The power required to overcome the frictional force in the drum bearings,

$$N_2 = 2\pi n z f_1 G, \quad (10)$$

where z is the diameter of the shaft neck, m; f_1 - coefficient of rolling friction, reduced to the shaft, f_1= 0.001; G - bearing load

$$G = \sqrt{Q^2 + P_{\text{ср}}^2} \quad (11)$$

In the existing methods for calculating power, in addition to the frictional force moment $P_{cp} f R$, the action of the force P_{cp} on the arc $l$is additionally taken into account. The forces that create a moment about the axis of the drum are preventing its rotation, and these forces are fully taken into account in the above expressions for determining $N_1$and N_2.

Then the final formula for determining the installed power of the electric motor of the device for cracking nutshells

$$N_{\text{дв}} = \frac{2\pi n (\sigma_{\text{сж}} f L l \mu \lambda R + z f_1 G)}{\eta} \quad (12)$$

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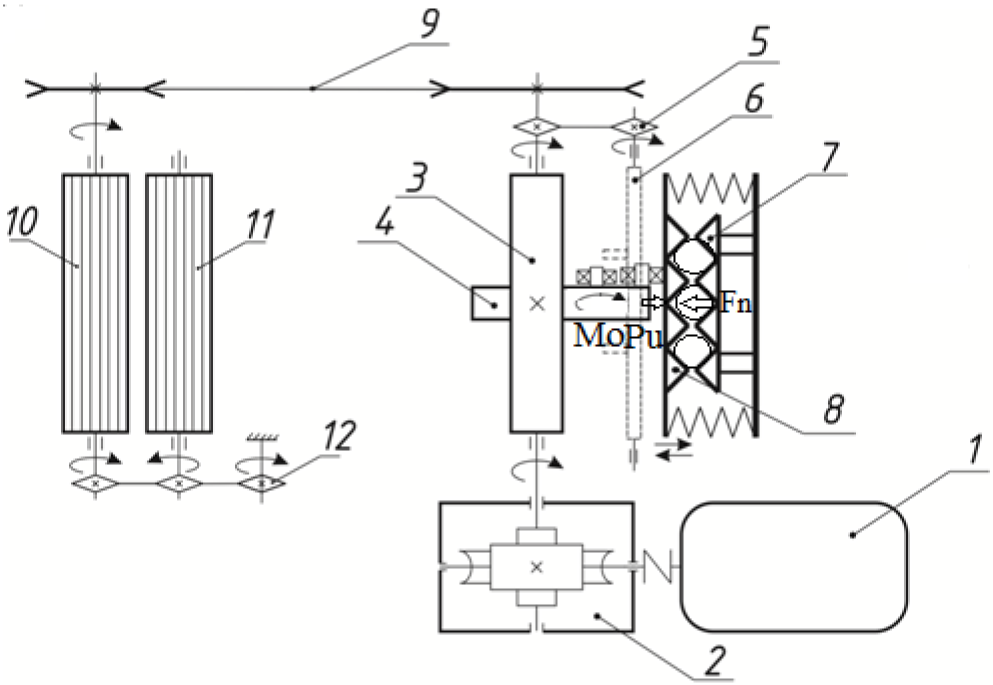

Fig.1. Kinematic diagram of the combined machine: 1-electric motor, 2- crank gear, 3-working shaft with a knuckle, 4-plate (sektor), 5-chain transmission 6- portion shaft, 7- breaking part (stationary), 8 -breaking progressive-return striker, 9-belt transmission, 10,11- working shafts with rifled cells, 12- differential chain transmission

When multiplying the recommended values of all coefficients and constants included in the formula, as well as excluding the insignificant power consumption to overcome friction in the bearings, we obtain the formula for the installed power (W) of the electric motor of the device for cracking the shell of nuts:

$$N_{дв} = 1400\sigma_{сж} nLR^2. \tag{13}$$

From the analysis of the obtained expression, it follows that the installed power of the drive depends on the following parameters: radius and length of the drum; drum rotation frequency; from the strength properties of the split nut.
We have developed a combined splitting machine for nuts and small other dry fruits (fig.1) [12]. The power mechanisms of this machine will be mathematically modeled:

$$\begin{cases} J_{o1}\ddot{\varphi}_{o1} + k_{o1}(\dot{\varphi}_r - \dot{\varphi}_{o1}) + c_{o1}(\varphi_r - \varphi_{o1}) = M_{o1} \\ m_u \frac{dv_u}{dt} = \mathrm{M}_u - R_{pr} - R_o \\ (\sigma_{ij})\lambda_{ij} \le T(\tau) \\ \dot{T}(\tau, \lambda_{ij}) = m\dot{e}_p(\lambda_{ij}) \\ (\dot{e}^p_{ij}) = \int_{\Omega}^{\Omega_n} \dot{e}_p(\lambda^1{}_{ij})\lambda^1{}_{ij} d\Omega^1 \end{cases} \tag{14}$$

where σ_{ij} is the normal stress of the inelastic material, $T(\tau, \lambda_{ij})$ is the fracture factor of the material; e^P_{ij} is a random tensor of initial microstresses, λ_{ij} is a directional unit deviator that fixes a direction in deviatorial space, *d* is a differential form ("solid angle" in five-dimensional deviatorial space), (-) averaging sign.
The developed technique makes it possible to determine the number and energy of impacts required for the destruction of the sample. As applied to multistage centrifugal impact mills, where the destruction process is based on the free impact of particles on the baffle deck, in addition to the number of impacts, it is also necessary to calculate the equivalent velocity of particles escaping from the rotor blades of the mill.

$$E_{уд} = Mgh = \frac{mV^2_{экв}}{2}, \tag{15}$$

where M is the mass of the striker; *m* is the mass of the test sample; *h* is the height of the striker's fall; $V_{экв}$ is the equivalent velocity of the particle escaping from the blade of a centrifugal mill; $E_{уд}$ is the energy of one blow.
Let's write a formula for determining the equivalent speed

$$V_{экв} = \sqrt{\frac{2Mgh}{m}}, \quad (16)$$

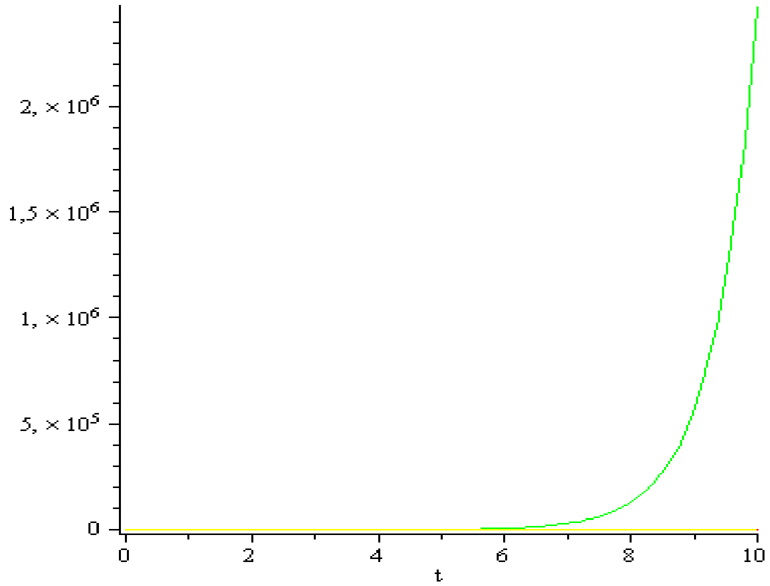

Fig.2. The actions of the striker when the walnut is heated

Let us compose the systems of the equation of the force of impact to the nut shell according to the equivalent scheme (fig.1)

$$\begin{cases} J_{o1}\ddot{\varphi}_{o1} + k_{o1}(\dot{\varphi}_r - \dot{\varphi}_{o1}) + c_{o1}(\varphi_r - \varphi_{o1}) = M_{o1} \\ J_r\ddot{\varphi}_r + c_r\varphi_r = M_r \\ m_u\frac{dv_u}{dt} = \mathrm{M}_u - R_{pr} - R_o \\ \frac{dA}{dt} = a\frac{dP_u}{dt}l \\ \frac{dP_u}{dt} = k\frac{dF_o}{dt} \\ \frac{dF_o}{dt} = 6(ad^2 - D^2) \end{cases} \quad (17)$$

Accepted initial data for numerical calculation: $J_{o1} = 80\,nm^2$, $J_r = 75\,nm^2$, $M_{o1} = 35\,nm$, $M_{r7} = 30\,nm$, $\mathrm{M}_u = 25\,nm$, $R_{pr}80 = 10\,n$, $R_o = 8$ n, $m_u = 2$, $k_{o1} = 3\,ms/rad$, $c_{o1} = 170\,m/rad$, $c_r = 160\,m/rad$, a=5, $l = 0{,}025\,m$, $k = 1{,}4$, $d = 0{,}02\,m$, $D = 0{,}023\,m$.
The work of crushing (destruction) of a body according to Steadler is equal to the product of the degree of crushing by the destructive force P_u and the path of action of this force l: $\frac{dA}{dt} = a\frac{dP_u}{dt}l$
where P - destructive force, proportional to the cross-sectional area of the conditional body, is equal to kF_o; k- coefficient of proportionality; F_o - sectional area of a conventional body.
From the calculation, we can say that periodically every 2.2 seconds the striker strikes the nut and destroys the shells (fig. 2). The system of equation (17) describes the force loading of the process of incandescence of the nut shell.
We have developed and manufactured a combined breaking machine of dry fruits on the land figure 1. Its tests were carried out according to the following initial data: -the number of rotation of the cam shaft 25-30 revolutions per minute;
- for the tests, Greek nut and hazelnuts with a humidity of 15-20%, nut sizes of 28-32 mm and hazelnuts of 18-21 mm were used;

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- produced Greek nut in the Central Asian region has a diameter of 25-32 mm, weight of 9-12 grams, shell thickness of 1.5-3.1 mm and humidity degree of 15-22% (in case of nut blindness).

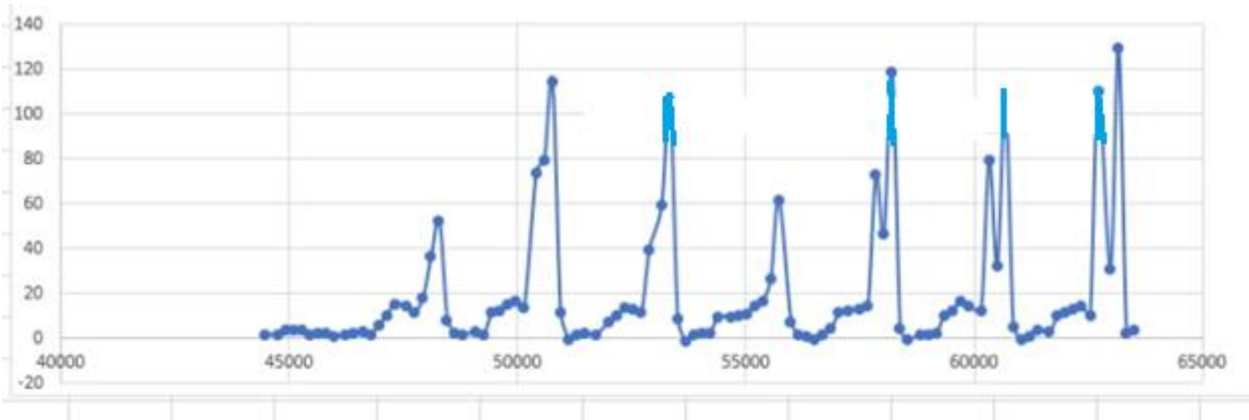

Fig.3. Strain measurement of impact force of knot (4) to striker (8) at nut breaking

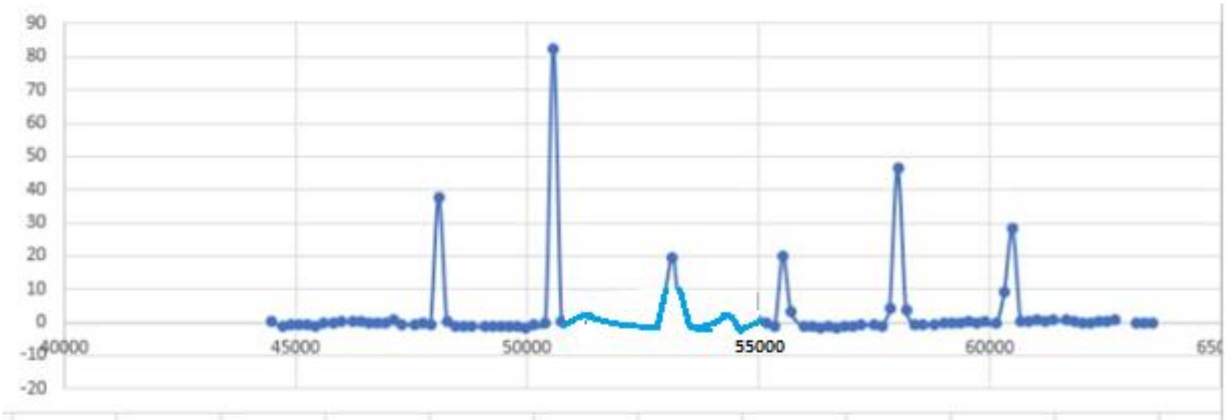

Fig.4. Strain measurement of force of the forward-return hammer of the unit (8) to the nut at its breaking

The breaking force of the nut depends on the thickness of the shell and the shape of the support of the inserted force, nuts and hazelnuts with a diameter of 25-35 mm break in part of the half-cone, nuts with a small thickness of the sorlup will be required by strain measurement 200-350 H, nuts with an average thickness of the sorlup will be required 351-550 N, and nuts with a thick thickness of the shell will be required 551-700 N (fig.3,4).

IV. CONCLUSION

Mathematical modeling of the process of machine cracking of the nut shell made it possible to describe the work of power mechanisms and the impact of the destruction of the nut shell. The impact force of destruction of the cluster and the kinematic parameters of the striker of the machine are determined numerically. The striker in every 2 second strikes the nut shell, the striking forces and the striker's linear velocity are periodically repeated. The developed mathematical model will allow the geometric and dynamic parameters of the combined nut of the heating machine, it is also used in the design to improve the design of this machine.

Strain metering determined nuts with a small shell thickness will require about 250 N, nuts with an average sorlup thickness will require about 450 N, and nuts with a thick shell thickness will require 650 N.

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