

Vibrocalibration of walnuts

G. Javakhishvili^{a,*}, A. Didebulidze^b

^aGeorgian Technical University; 77, Kostava Str., Tbilisi, 0160, Georgia

^bAgricultural University of Georgia; 240, David Aghmashenebeli Alley, Tbilisi, 0159, Georgia

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ABSTRACT

One of the directions for the development of agricultural product processing is the elaboration of small, energy-saving, high-productivity machinery and equipment. The article discusses a walnut calibration unit equipped with the direct current magnetic electromagnetic reciprocating vibration motor, with the ability to change the number of fractions and adjust the productivity; The trajectory of the walnut movement on the surface of the screen and the scheme of forces acting on it; Analysis of the optimal technological parameters obtained as a result of the study of the working modes of the walnut calibrator.

Keywords: Electromagnetic, Vibrating motor, Calibration, Walnut, Vibrating chute, Screen.

*Corresponding author: Gela Javakhishvili: E-mail address: gela_java@yahoo.com

Introduction

Walnut cultivation and processing is a highly profitable business. The world walnut market is characterized by high concentration of its production in a limited number of countries [1]. According to Food and Agriculture Organization (FAO), world's total volume of walnut production reached in 2010/2020 year 2,13 million metric tons; China

accounted for about 50% of the total walnut production, but consumes nearly all that it produces, the USA ranks second with above 30%. World exports, dominated by the USA, are expected to rise to 946,000 metric tons and European Union with 300,000 metric tons is the largest walnut import market in the world, representing almost half of all imports [2]. Fig. 1 shows the dynamics of walnut production worldwide in 2012-2020.

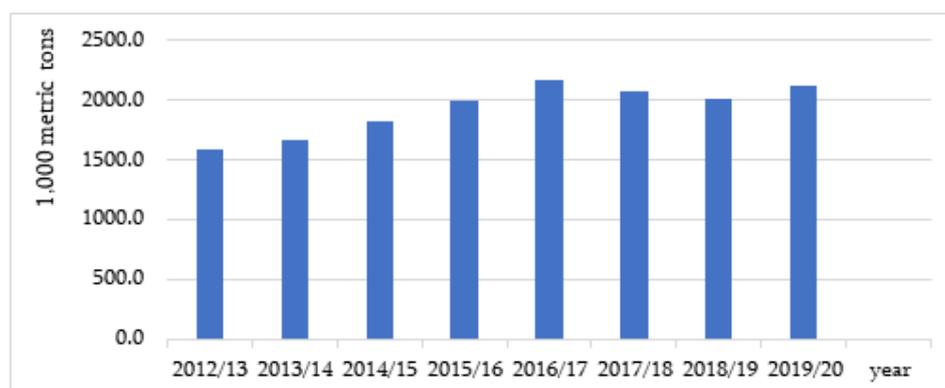


Fig. 1. Dynamics of walnut production worldwide, shelled, 1000 metric tons [3].

Walnut is considered to be the oldest culture in Georgia. The first information about its spread is found in Greek sources belongs to the VI-IV centuries BC. Walnuts have been present in the local traditional cuisine of Georgia (Satsivi, Churchkhela, Khartcho, Kuchmachi, Bazhe, Kaklis Muraba etc.). There are great prospects for its development – Georgia’s soil and climate is favorable for walnut cultivation and the plant is cultivated in every region of the country on the elevation of 500...900 m from sea level [4, 5] and the Autonomous Republic of Adjara is a leader in terms of production, followed by Regions of Shida Kartli, Kakheti, and Imereti [6]. Walnut production in Georgia in 2010-2019 is shown in Fig. 2 [7]. However, Georgia currently does not meet its own needs, demand on local market is more than 6 thousand metric tons of the in-shell walnut production, so walnuts are imported from other countries in high market prices [8]. Georgia needs to build the capacity of its producers to become more competitive in domestic and export markets and one way to become competitive is to improve walnut production quality, its storage and processing, that is, to go as soon as possible the path that Georgia has passed with the development of its hazelnut production, having become today the second after Turkey exporter to the world market - mainly to the EU countries.

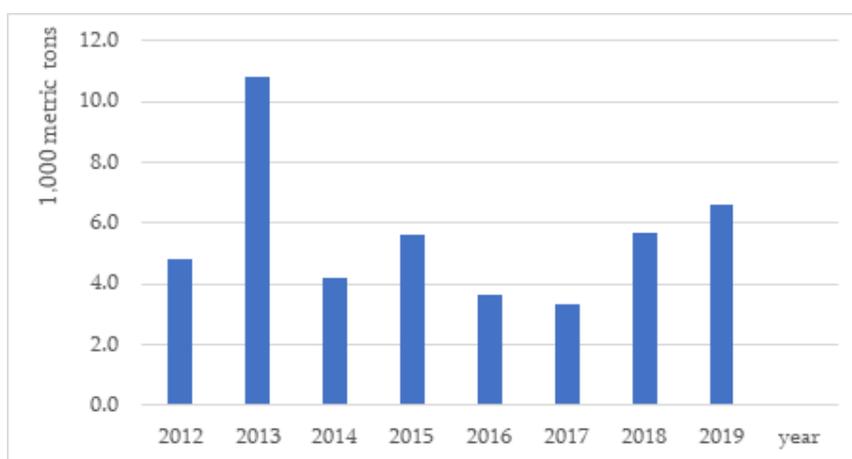


Fig. 2. Walnut production in Georgia in 2012-2019, 1000 metric tons

Recently, commercial development of walnut acreage is ramping, several hundred hectares of walnut orchards have been planted in Georgia and this process continues. Given the pace of orchard cultivation, we must assume that in a few years walnut imports will be reduced to a minimum and export opportunities will emerge, as result the country, which for a long time was a net importer of walnuts, began to dramatically increase the export of this product (Table 1).

Table 1. Walnuts (HS 080231/in-shell and 080232/shelled) External Trade of Georgia, 1000 US Dollars (8)

Year	2012	2013	2014	2015	2016	2017	2018	2019	2020
Export	57.9	80.0	50.2	42.6	2.0	224.4	361.6	1361.9	1129.5
Import	891.1	623.8	819.1	890.5	1830.9	4289.7	5525.2	5424.9	1877.2
Trade Balance	- 833.2	-543.8	-840.9	-847.9	1828.8	-4065.3	-5163.6	-4063.0	-747.7

To date, almost all varieties of walnuts grown in Georgia are rounded walnuts with thick shells, cultivated only in households and a significant part of the walnut processing is done by hand [4]. This is mainly due to the facts, that modern enterprises manufacture machines for processing walnuts with only thin shells, and when processing thick-shelled walnuts, part of the kernel remains in the shell, which reduces the yield. As a result, varieties with thick-shelled nuts are processed only by hand and not in the factory. Sorting is predominantly also done manually to ensure quality and consistency of the product batches. Accordingly, walnut production in Georgia is still mostly a labor-intensive business, with the majority of walnuts harvested by hand or rudimentary nut picking devices in family farms used by the previous generation of growers. And as is well known, small farms with mostly manual labor are characterized by unstable quality of their product, which pushes them into the low-level segment among buyers.

There are a number of constructions for walnut crushing machines, the technical data's of which must be taken into account when deciding to use them. First of all, the principle of walnut cracking used in the machine and during which it is necessary to calibrate the nut is important. Moreover, the more thoroughly such a calibration is performed (the greater is the number of fraction sizes), the better the crack will be and the greater the output of the partitions, which in turn will affect the quality and price of the shelled walnuts. Thus, calibration occupies an important place in the walnut processing chain.

Today, most walnut calibrators are rotary and have a sectional drum-shaped construction with

holes of different sizes in each section. The productivity of such a machine depends significantly on the number of fractions obtained. These types of calibrators are produced by the USA, France, Germany, Spain, China, Ukraine, Moldova and others. In these machines, the working frequency of the sorting drum is regulated by a frequency regulator, which increases the cost and complicates the operation process [9].

Purpose and methods

The aim of the work is to develop and research a vibrating walnut calibrator equipped with reciprocating electromagnetic vibrating motor; Analysis of the process of vibrational calibration of walnuts and determination of optimal technological parameters; Loose and solid matter sampling modes (methods) - oscillating with or without particle cutting from the working surface [10] - in the process of walnut calibration.

Research

An analysis of the calibration process and known constructions as a result of the study showed that the calibration of the nut can be achieved using vibration. Therefore, we have developed a nut calibration vibrating device (Fig. 3), which can be driven by our patented reciprocating electromagnetic vibrating motors 1 with direct current (DC) biasing [11-13], where it is possible to adjust the vibration of the working body by the use of bias current change.

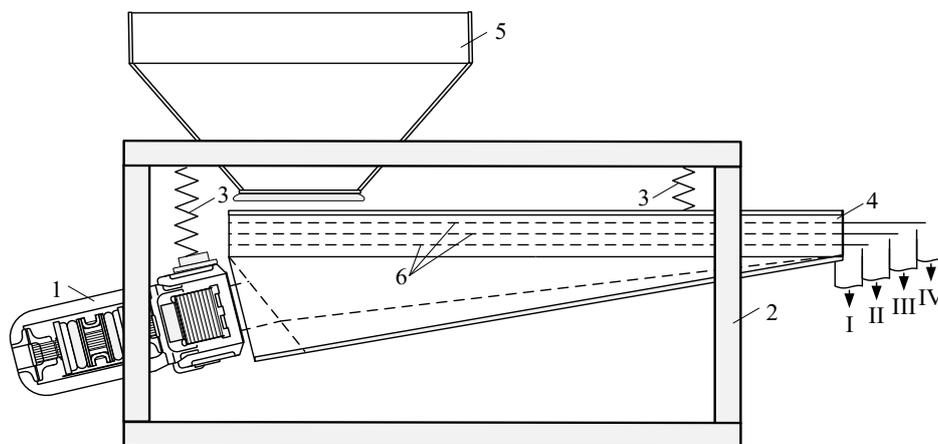


Fig. 3. Walnut calibrator with reciprocating electromagnetic vibrating motor.

1 - vibrating motor; 2 - frame; 3 - suspension elastic system; 4 - vibrating chute; 5 - hopper; 6 - screens with openings of different sizes

The machine works as follows. The walnut from the hopper 5 falls on the vibrating chute 4, in which three screens 6 are placed in parallel under each other, with openings of different sizes. The walnuts will be divided into four fractions, of which I will be small-sized walnuts and impurities, which are necessarily found in raw materials for the first time, II-larger than fraction II, and so on. The number of fractions can be changed if necessary. The machine can be used to sort hazelnuts, chestnuts and others.

During the calibration process, the walnuts move on the screen in the direction of the outlet and are divided into two fractions: a) which fit and pass through the holes of the screen; b) which cannot fit and move along the surface of the screen towards the exit. Under the influence of vibration there is a transport of walnuts along the screen in vibrating chute, which is necessary for the continuity of the process and is characterized by the average speed (velocity) of the center of the whole bulked walnut mass.

Consider one of the calibrators of a calibrator on the ABCD surface forming an α angle with respect to the horizon, a walnut whose mass in m , kg is the process of displacement (Fig. 4).

In the XOY coordinate system, a walnut that fails to pass through the screen opening will have the following equilibrium condition [14]:

$$\begin{cases} m\ddot{x} = F_f - mg \sin \alpha + F_i \cos \beta = 0 \\ m\ddot{y} = N - mg \cos \alpha + F_i \sin \beta = 0 \end{cases} \quad (1)$$

The force of gravity acts on the walnut is $P = mg$, N ; g - free fall acceleration, m/sec^{-2} ; N - normal reaction, N ; $F_f = Nf_s$ - frictional force, N ; f_s - sliding friction coefficient and $F_i = mx_m\omega^2 \sin \omega t$ inertia, N ; x_m -

amplitude of the screen oscillations, m ; ω - angular frequency of oscillation, sec^{-1} ; t - time, sec ; β - angle of oscillation direction towards the surface of the $ABCD$ screen, $^\circ$.

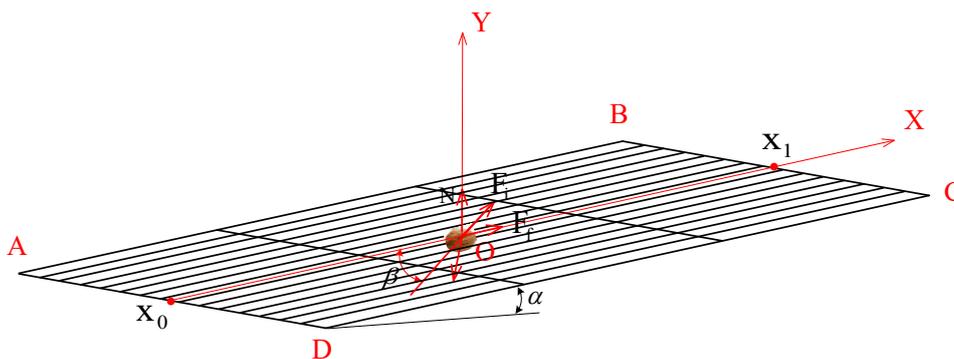


Fig. 4. Scheme of action of forces on a walnut moving on the surface of the screen tilted at an angle to the horizon

From (1) is a normal reaction

$$N = m(g \cos \alpha - x_m \omega^2 \sin \omega t \sin \beta) \quad (2)$$

In order for the walnut to move from x_0 to the point x_1 on the screen surface (Fig. 4) it is necessary to fulfill the condition $m\ddot{x} > 0$ or $F_i \cos \beta > mg \sin \alpha - F_f$, from which

$$x_m \omega^2 \sin \omega t \cos \beta > g \sin \alpha - \frac{N}{m} f_s \quad (3)$$

Depending on the operating modes, the walnut may travel with or without disconnection from the vibrating working surface:

a) the travel disconnect from the surface we have when $N < 0$. Accordingly, the reset parameter - dependence on the amplitude of the transverse component of the inertial force from the amplitude of the transverse component of the gravity

$$\text{force } w_0^* = \frac{x_m \omega^2 \sin \beta}{g \cos \alpha} > 1 \quad (4)$$

b) without tear off the walnut from the surface, $N > 0$, namely when $w_0^* < 1$.

When the body slides on the vibrating surface by inertia, there is a certain aspiration to get the orientation defined by it, the direction of its movement [10]. This phenomenon can be used in our case as well, especially to determine the shape of the opening.

1. Self-sorting - sinking of the walnuts with small size and high density into the bottom layer (near the surface of the screen) and pushing out of walnuts of large size and low density into the upper layer; During the separation with screens, the self-sorting intensity is measured by the speed v_{ss} at which

the nuts are sinking from the upper layer to the holes on the surface of the screen, overcoming a distance h_w in the time t_{ss} .

$$v_{ss} = \frac{h_w}{t_{ss}}$$

2. Screening - the movement of a walnut screen smaller than the size of the openings through the openings.

Screening as the last stage of calibration comes from the bottom layer, so when the bulk mass is thicker than the average size of the walnut, it is necessary to sink the walnuts into the bottom layer that are subject to screening. If such walnuts are coming to the surface, for example due to their low density compared to the surrounding ones, for effective calibration it is necessary to roll the bulk mass or reduce the thickness of the walnut layer.

To ensure continuous flow of walnuts, the thickness of the layer of nuts at a distance x from the opening of the screen

$$h_x = \frac{Q_w - Q_{ws}}{bv_x \rho_w}$$

where b is the width of the vibrating chute, m; v_x - average speed across the walnut layer, m/sec; ρ_w - density of walnuts, kg/m³; Q_w - mass production of walnuts (initial material), kg/sec; Q_{ws} - number of nuts, passed the openings from x_0 to x , kg/sec.

The screening of each walnut during its movement on the screen opening is a random event, the probability of which is subject to normal law when moving is without interruption

$$p_0 = 1 - \frac{1}{\sigma\sqrt{2\pi}} \int_0^v e^{-\frac{1}{2}\left(\frac{v-v_k}{\sigma}\right)^2} dv$$

where v is the speed of the center of mass of the nut relative to the grate, m/sec, $\sigma = tg\alpha / f_s$ - the inclination parameter of the screen surface, v_k - the value of the critical speed, m/sec, when $p_0 = 1/2$.

If the movement of the nuts comes off with interruption from the surface of the screen, the probability of screening is significantly reduced due to the reduced contact time of the nut with the screen. This happens not only by increasing the normal setting of the screen acceleration and violating the condition of movement without a smash, but also by "jumping up" after hitting the edge of the nut opening. The latter is observed when moving a thin layer. Increasing the layer

thickness to the optimum h^* magnitude increases the likelihood of screening, since the upper layers do not experience direct shocks and are resistant to cutting the lower layers from the screen. When $h > h^*$ jumps do not exist for this reason, but the pressure of the upper layers increases the friction between the nuts of the lower layer, which complicates the screening process.

The specific throughput of the screen q_w , kg/m²sec is proportional to the number of walnuts n_w that pass through the openings in 1 sec and the probability of their screening p_w

$$q_w = c_0 n_w p_w$$

where c_0 is the coefficient of proportionality, which depends on the "live" area of the screen, the concentration of the outgoing nut in the lower layer, density and other properties.

Experimental research has shown that, given the physical and mechanical properties of the walnut, calibration with the reciprocating motion vibrating motor is relatively effective in moving the walnut take place without detachment from the surface. To do this, it is necessary to fulfill condition (4), respectively, to justify the following parameters and modes of the vibrator: the angle of inclination of the screen with respect to the horizon α , oscillation frequency ω and direction angle β , also relevant are the amplitude of the oscillations x_m , the shape and size of the screen opening. At this time $Y = 0$, and the friction force

$$F_f = \begin{cases} -f_s N, & \dot{x} < 0 \\ f_s N, & \dot{x} > 0 \end{cases} \quad (5)$$

and when the walnut, that cannot pass through the screen surface is in a stationary position ($X = 0, Y = 0$), then the force of dry friction is calculated from (1) $F_{df} = -mg \sin \alpha + F_i \cos \beta$, however, this state is maintained until the inequality $-f_{fs} N < F_{df} < f_{fs} N$ is completed, where f_{fs} is the coefficient of friction of immobility, usually $f_{fs} \geq f_s$. The equation for the acceleration \ddot{x} , the speed \dot{x} and displacement x of the walnut on the screen surface is taken from (1), (2) and (5)

$$\ddot{x} = -g \frac{\sin(\alpha \pm \theta)}{\cos \theta} + x_m \omega^2 \frac{\cos(\beta \mp \theta)}{\cos \theta} \sin \omega t \quad (6)$$

$$\dot{x} = -gt \frac{\sin(\alpha \pm \theta)}{\cos \theta} \mp x_m \omega \frac{\cos(\beta \mp \theta)}{\cos \theta} \cos \omega t \quad (7)$$

$$x = -\frac{gt^2}{2} \frac{\sin(\alpha \pm \theta)}{\cos \theta} \mp x_m \frac{\cos(\beta \mp \theta)}{\cos \theta} \sin \omega t \quad (8)$$

where $\theta = \arctg f_s$ is the sliding friction angle; In the formulas (6) - (8), the upper mathematical signs (+ or -) correspond to sliding forward ($\dot{x} > 0$), and the lower ones - to sliding back ($\dot{x} < 0$).

Established modes of motion of a substance without detachment from the oscillating sur-

face are discussed in [5]. For effective calibration of the walnut, taking into account the shape of the screen openings we have chosen, it is advisable to use the mode when the walnut slides in one direction from point x_0 to point x_1 (Fig. 4).

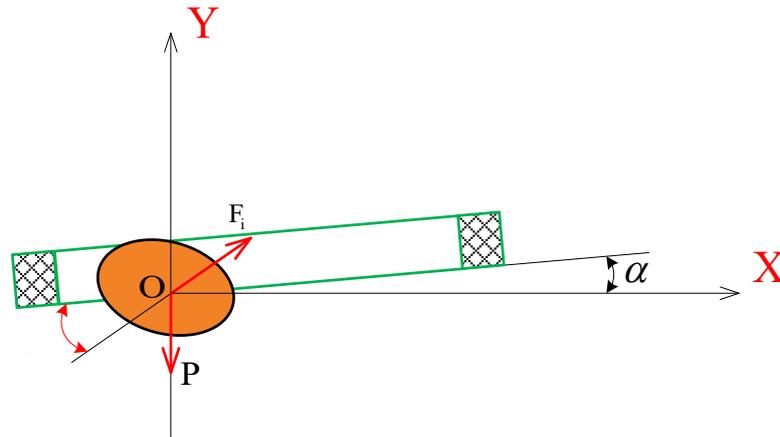


Fig. 5. Scheme of the action of forces on a walnut moving in the opening of the screen tilted at an angle α to the horizon

In the XOY coordinate system, a walnut moving through an opening (Fig. 5) will have the following equation of motion:

$$\begin{cases} m\ddot{x} = -F_i \cos \beta \\ m\ddot{y} = -mg + F_i \sin \beta \end{cases} \quad (9)$$

from which, after appropriate little manipulation we obtain

$$\begin{cases} \dot{x} = -x_m \omega^2 \sin \omega t \cos \beta \\ \dot{y} = -g + x_m \omega^2 \sin \omega t \sin \beta \end{cases} \quad (10)$$

$$\begin{cases} \dot{x} = x_m \cos \omega t \cos \beta \\ \dot{y} = -gt - x_m \omega \cos \omega t \sin \beta \end{cases} \quad (11)$$

$$\begin{cases} x = x_m \sin \omega t \cos \beta \\ y = -g \frac{t^2}{2} - x_m \cos \omega t \sin \beta \end{cases} \quad (12)$$

and from (11) - the movement speed of the walnut is

$$v_w = \sqrt{(x_m \cos \omega t \cos \beta)^2 + (-gt - x_m \omega \cos \omega t \sin \beta)^2} \quad (13)$$

which depends on the amplitude, frequency and angle of the oscillation direction. These values, as well as the distance to the next screen surface on which the walnut to be driven into the upper screen should fall, should be selected so that jumps are minimized.

The results of the obtained theoretical and experimental studies show, that if the width of vibrating chute of the calibrator is $b = 0.6$ m, height $h = 0.15$ m, length $l = 1.5$ m and amplitude of oscillations $X_m = 0 \dots 0,0015$ m with oscillation frequency $\omega = 314 \text{ sec}^{-1}$, the walnuts can be calibrated without disconnecting from the screen surface at the values of β and α , given in the Table 2.

Table 2. Value limits of vibration angle β and chute angle α in vibrating calibrator for calibration of walnuts without disconnecting from the screen surface for specific values of X_m and ω

#	$X_m, \text{ m}$	$\omega, \text{ sec}^{-1}$	β^0	α^0	w_0^*
1	0,0005	314	$0^\circ \leq \beta \leq 11^\circ$	$0^\circ \leq \alpha \leq 15^\circ$	$0 \leq w_0^* \leq 0,992$
2	0,0010	314	$0^\circ \leq \beta \leq 5^\circ$	$0^\circ \leq \alpha \leq 28^\circ$	$0 \leq w_0^* \leq 0,991$
3	0.0015	314	$0^\circ \leq \beta \leq 3^\circ$	$0^\circ \leq \alpha \leq 37^\circ$	$0 \leq w_0^* \leq 0,987$

Conclusion

It is advisable to use a vibrating device for calibration of walnuts due to its design simplicity and high reliability of operation.

Analysis of the movement of the walnut on the surface of the vibrating screen and through the openings allowed us to determine the influence of the main factors on the design-kinetic parameters that ensure the calibration of the nuts.

For effective calibration of the walnuts, the mode should be used when the walnut slides in one direction from point x_0 to point x_1 (Fig. 4).

The productivity and quality of the vibrating calibrator depends on the speed of movement of the walnut on the screen surface, which in turn depends on the coefficient of friction, the angle of inclination of the screen towards the horizon, the frequency, amplitude and direction of vibration.

References

- [1] Nuts and Dried Fruits Statistical Yearbook 2019/2020. The International Nut and Dried Fruit Council Foundation (INC), 2021.
- [2] Tree Nuts: World Markets and Trade, United States Department of Agriculture - Foreign Agricultural Service, October 2020.
- [3] Shahbandeh M., Nut industry worldwide - Statistics & Facts. Statista, 2020.
- [4] Shengelia N. and Kvaliashvili V., Prospects of Walnut Production in Georgia. V International Walnut Symposium. Acta Horticulture. 705, 2005, pp. 35-39.
- [5] Bobokashvili Z., Maghlakelidze E., Shengelia N., Maghradze D, Evaluation of some introduced walnut (*Juglans regia L.*) cultivars in Shida Kartli Region of Georgia. International J. of Minor Fruits, Medicinal and Aromatic Plants, Vol. 3 (2) (2017) 16-20.
- [6] Walnut Value Chain Analysis in Ajara Region of Georgia. ENPARD, Tbilisi, 2016.
- [7] National Statistics Office of Georgia <https://www.geostat.ge/en/modules/categories/196/agriculture>.
- [8] National Statistics Office of Georgia. <https://www.geostat.ge/en/modules/categories/35/ex-ternal-trade>.
- [9] Negovsky A.N., Pakhno V.G., Equipment for Processing of Walnuts. http://www.sdtb.kiev.ua/sdtb_food_en.htm
- [10] Bottega W.J., Engineering Vibrations. 2nd Edition. CRC Press, 2014.
- [11] Didebulidze A., Ksovreli R., Javakhishvili G., Machavariani K., Two-stroke electromagnetic vibrator. Patent of Georgia # 114, Sakpatenti Official Bulletins of Industrial Property, # 2, 1994. pp. 46-47 (in Georgian).
- [12] Javakhishvili G., Three-phase electromagnetic vibrator. Patent of Georgia # P2866, Sakpatenti Official Bulletins of Industrial Property # 24, 2002 (in Georgian).
- [13] Ksovreli R., Javakhishvili G., Midelashvili E., Ksovreli N., Electromagnetic vibrator. Patent of Georgia # P3108, Sakpatenti Official Bulletins of Industrial Property # 20, 2002 (in Georgian).
- [14] Javakhishvili G., Analysis of the grain delivery process by weigher equipped with electromagnetic reciprocating vibration exciter. Georgian Academy of Agricultural Sciences: International Conference Proceedings, Tbilisi, 2020. pp.132-137 (in Georgian).
- [15] Eglays V.O., On the orientation of parts on a vibrating chute, Automation of production processes in mechanical engineering and instrument making. Riga: Latv. publishing house, 3, 1964, pp. 113-122 (in Russian).
- [16] Blekhman I. Selected Topics in Vibrational Mechanics. Series on Stability, Vibration and Control of Systems. Volume 11). World Scientific Publishing Co., 2004.