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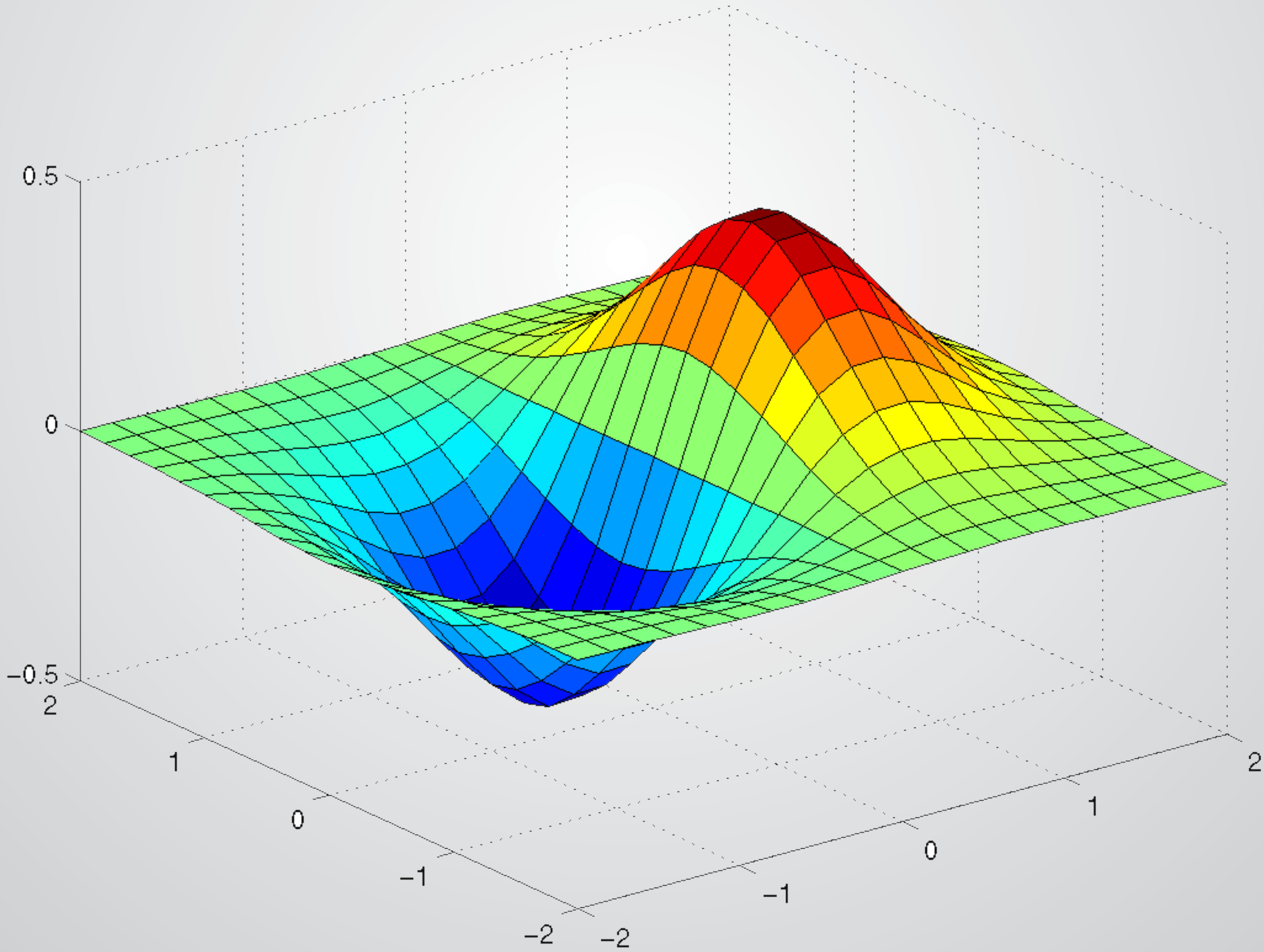

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CONTENTS

RATIONALE MODE OPERATING OF MECHANISM FOR COMPACTING BULK PRODUCTS IN CARTON BOX IN AUTOMATIC PACKAGING MACHINES

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Abstract: *In packaging machines, when bulk products were dosing into the carton box, negative phenomenon which was caused by the rheological properties of bulk food products is the formation of products hill. For hermetically closing carton box must be destructed hill of granular products by method of compacting.*

Keywords: bulk products, cardboard box, operating mode, operating, compacting, vibrations

I. Introduction

Technological efficiency of the packing of bulk products in a carton box defined by the design, parameters and operating modes of the dosing module of automatic packing machines and depends on many factors, which can be divided into three groups [1]:

- rheological properties of bulk food products,
- design and dimensions of the carton box,
- operating modes and parameters of dosing module.

Bulk products are dosed into the carton box and thereafter need to hermetically closing carton box.

As a consequence, there is a negative phenomenon, which was caused rheological properties of bulk food products- the formation of products hill. Depending on the rheological properties of products, dosing module design, environmental conditions (temperature and humidity) - the inclination angle of products hill within the box can be up to 60 ° ... 70 °. So, besides controlling the amount by weight of production, it is necessary to carry out control on a production level in the dosing modules [2, 3, 4].

II. Materials and methods

Compacting products in box appropriate conduct for all types of bulk products. Formed after dosing hill product (Fig. 1) hinders closing of the valve cap of the box. Product shatters, gets to the glue that has been applied to the valve box, prevents gluing and forming hermetic gluing root.

The strength of the powder structures P_m depends on the number of contacts n between the particles of the solid phase per unit volume and the average strength F_c of the elementary contact [5]:

$$P_m = a \cdot F_c \cdot n^{2/3}, \quad (1)$$

Cap of the box is deformed and its valves are inclined at different angles to the horizon and a horizontal surface does not create. Carrying out compacting operation enables evenly fill a box on the level of bulk product, reduce the height of the box and to increase the percentage of filling boxes of bulk products.

After this free volume packs must not be more than 7%.

For cereals, granulated sugar and similar products fairly short-compacting. For products that are saturated air (such as flour) in the normal state, compacting - long and repetitive operation.

Dosing problem of fine powder dispensing two-phase (solid phase particles in the gas phase) products is to reduce shear resistance and acquisition particles such production systems greater mobility.

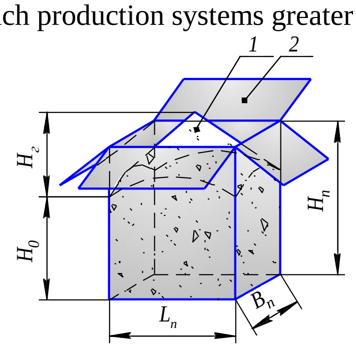


Figure 1. *Fill box of bulk product after dosing: 1- bulk product; 2- carton box; L_n, B_n, H_n, - respectively the length, width and height of the box; H_0 - the level of bulk products in a box; $H_г$ - height hill of bulk products*

where a - coefficient taking into account the homogeneity of the structure of bulk product.

From this expression shows that the strength of highly dispersed structure decreases with decreasing the number of particles per unit volume, can contribute applying vibration loads.

Vibration has a significant impact on the bulk products. This is because the vibration turns friction. At rest between particles act forces of dry friction. The vibration causes the particles products to move relative to each other, which leads to their contact. The particles start to oscillate with its own frequency and contacts between their surfaces are discrete. The forces of interaction between particles loose product converted to viscous forces and it becomes like fluidity [6].

The most effective course of action for bulk products to compacting their in a box - a way to create an inertial oscillations based on excess inertia forces, a change of direction, the friction forces.

Vibrational state of the bulk product is estimated intensity of vibration:

$$\lambda = A_{в} \cdot \omega_{в}^{2} / g, \qquad (2)$$

where $A_{в} \cdot \omega_{в}^{2}$ - vibration acceleration motion, $A_{в}$- the amplitude of vibrations of the operating of compacting mechanism, $\omega_{в}$ - the oscillation frequency of the operating of compacting mechanism.

Under the influence of inertial forces bulk product particles move, so to take a position, that corresponds to the minimum value of the potential energy, and at the same time the trajectory of their movement affects the amount of kinetic energy applied externally.

For compacting the bulk product in a box is using vibrational compacting that occurs at low values of intensity vibrations λ ($\lambda \ll 1$). The particles gain certain mobility products, trying to take a position, that fits the minimum distance from the bottom of the box.

Change in the form of cross section doses of bulk product in a cardboard box after compacting.

For further description of densification bulk product in a carton box by vertical direction vibration, will make use of the results presented in the scientific papers [7, 8, 9, 10]. Fig. 2 shows as bulk product hill will look after compacting in box.

The research was conducted with the assumptions, that the particles in the product range of the gravitational forces, are trying to get a position, which will correspond to the possible minimum potential energy, with the rate of change of potential energy of the system is proportional to the difference in potential energy of the proposed and final state (minimum potential energy) in carton box, which is in sealing mechanism of the vertical vibrational direction:

$$if \quad W_p = f(t), \qquad (3)$$

$$then \quad \frac{df(t)}{dt} = K \cdot W_p. \qquad (4)$$

That is the first derivative of the function is directly proportional to the function itself.

Taking into account that the function $W_p = f(t)$ decreases with time, then:

$$y(t) = K \cdot e^{-\beta_n \sqrt{t}}, \qquad (5)$$

where K- factor of proportionality, β_n - damping coefficient, t - duration sealing.

For mathematical modeling of sealing bulk product in boxes advisable to change depending on the potential energy replace the dependence curve, that describes the surface hill products.

In longitudinal cross section this curve resembles a half Sinewave. It is suggested that the products remain in that hill after compacting is limited by this curve and the horizontal plane that passes through its base.

Sinewave equation is:

$$y(t) = A_c \cdot Sin\left(\frac{2\pi}{T} t\right). \qquad (6)$$

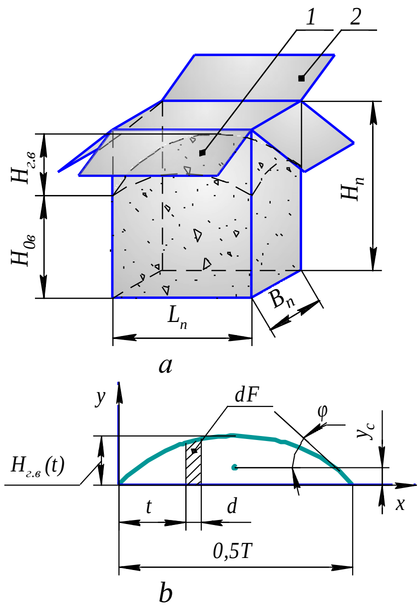


Figure 2. *Fill box of bulk product after compacting : a- surface hill product; b- curve, that describes the surface hill product; 1- bulk product; 2- carton box; L_n, B_n, H_n, - respectively the length, width and height of the box; H_0 - the level of bulk product in a box after compacting, $H_{г.в}$ - height hill of bulk product after compacting.*

To find the coordinates of the center of gravity hill bulk product define static moment area under the curve. Static point-sectional area hill bulk products axis O*x*, which lies in the same plane, called the entire area taken sum of product of elementary areas *dF* areas at a distance from the axis of:

$$S_t = \int y_c(t)\, dF \quad , \qquad (7)$$

then $y_c(t)$ - coordinates of the center of gravity elementary area.

Considering, that: $dF = y\ t\ \ dt$., (8)

and $y_c\ t\ = 0,5 \cdot y\ t$, (9)

the expression (7) for the static moment of the square cross-section hill bulk product, takes the following form:

$$S_t\ t\ = 0,5 \int_0^{0,5T} y\ t\ ^2 dt = 0,5 \int_0^{0,5T} \left[A_c \cdot Sin\left(\frac{2\pi}{T} t \right) \right]^2 dt \qquad (10)$$

and after integration:

$$S_t = \frac{A_c^2 \cdot T}{8} \quad . \qquad (11)$$

Area section hill products:

$$F(t) = \int_0^{0,5T} y\ t\ \ dt = \int_0^{0,5T} A_c \cdot Sin\left(\frac{2\pi}{T} t \right) dt \quad , \qquad (12)$$

similarly:

$$F = \frac{A_c \cdot T}{\pi} \quad . \qquad (13)$$

Ordinate sectional area of the center of gravity hill product:

$$y_c = \frac{S_t}{F} \text{, then } y_c = \frac{\pi \cdot A_c}{8} \quad . \qquad (14)$$

Assume the assumption that the angle of the surface hill products to the horizon at the edges of Sinewave is equal to the angle of shear bulk product. This means that when: $t_0 = 0$:

$$tg\ \ \varphi\ \ = y'\ \ t\ \ = \frac{2\pi \cdot A_o}{T_0}. \qquad (15)$$

where A_o , T_0 - the coordinates of the curve describing the surface of the hills.

Considering the formula (13) can be written:

$$T_0 = \frac{\pi \cdot F}{A_0}. \qquad (16)$$

Using formulas (13) and (16):

$$A_o = \sqrt{\frac{F \cdot tg\ \ \varphi}{2}}. \qquad (17)$$

The change of potential energy dependence of bulk product described (6). From the formula (14) shows, that the coordinate of the center of gravity hill bulk product, and therefore the potential energy depends on the amplitude of Sinewave. It concluded that the functional dependence of the amplitude of time has even same form as the dependence of the potential energy of the time. Therefore, we can write:

$$A(t) = A_0 \cdot e^{-\beta_n \sqrt{t}} . \qquad (18)$$

Taking into account equation (4) is obtained:

$$T(t) = \frac{\pi \cdot F}{A(t)}. \qquad (19)$$

Taking into account equation (18), the curve equation (6), which describes the hill product surface after compacting, can be written as:

$$y(t) = A_0 \cdot e^{-\beta_n \sqrt{t}} \cdot Sin\left(\frac{2\pi}{T} t \right). \qquad (20)$$

The formula (20) makes it possible to determine in advance how match hill height reduced bulk product in carton box for a certain period of time during compaction by vertically directed vibration:

$$K_y = \frac{H_г - H_{г.в}}{H_г} \cdot 100\% \quad , \qquad (21)$$

that is

$$K_y = \frac{H_г - y(t)_{\max}}{H_г} \cdot 100\% \qquad (22)$$

As it was established, a decisive influence on the compacting performance bulk products with identical parameters and operating modes of the compacting device, the compact and various properties bulk products, have its rheological properties.

In order to achieve technological effectiveness of compacting bulk products in box, necessary to determine the optimal operating mode of compacting mechanism is considered rheological properties of the granular product.

Basic kinematic parameters of compacting mechanism influencing the length of destruction hill of granular products in a carton box is amplitude, frequency, operating of compacting mechanism and the direction of the driving force of fluctuations.

The complex nature of the relationship factors that influence the duration of the compacting products in the box was identified the need for static methods research process. The duration of the densification process various types of granular products is the parameter, for which its value and its nature of the change can be determined mainly by experiment.

In accordance with this as an object of research was accepted compacting process of granular food products.

The purpose of experimental research is the scientific rationale and determination of optimal operating modes and parameters of the compacting mechanism of granular food products.

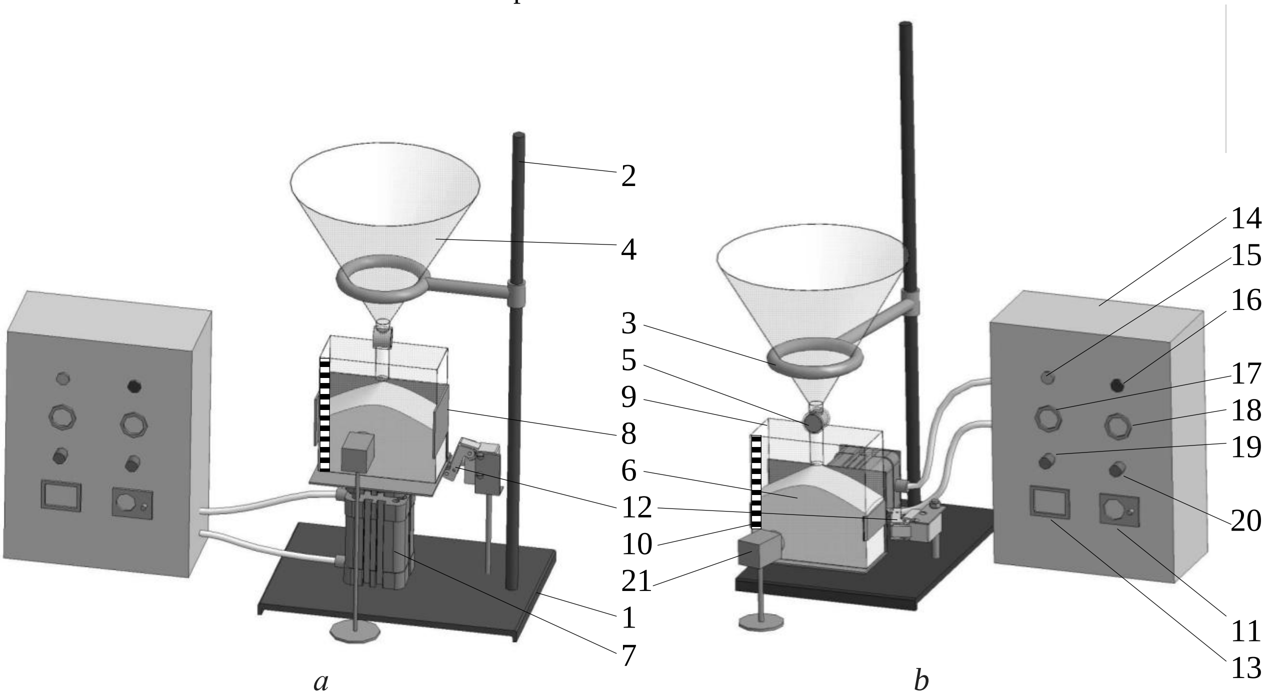


Figure 3. *Experimental device for research duration of the compacting process of bulk products, which performs: a- vertical vibrations; b- horizontal vibrations*

The program of experiments is considering three operating modes of the kinematic parameters variation of compacting mechanism in accordance with a direction of vibrations - vertical, horizontal along the length of the box, and horizontal along the width of the box.

Was designed and assembled two experimental devices, which perform horizontal and vertical vibrations (Fig. 3).

The experimental device has the based 1 with a rack 2. To the rack was fixed ring 3, hopper 4. In the hopper was filled granular bulk food product. Also hopper has a rotary valve 5. In addition to the based was placed compact pneumatic cylinder 7, respectively, in horizontal or vertical position.

On the rod of a compact pneumatic cylinder is fixed the pocket 8. In his pocket was placed transparent plastic pack 9 with calibration scale 10.

Frequency vibration rod pneumatic cylinder for a certain period of time, which was set on the timer 11 is fixed using the contact position sensor with mechanical roller operating 12 with the loop counter 13.

The basic elements of the electro-pneumatic control system of a pneumatic cylinder was contained in the control cabinet 14. Other designations are: 15, 16- button “on” and “off” for the compressor; 17, 18- pressure gauges to determine the pressure for the compressor and inlet in control system; 19, 20 - pressure regulators for compressor and inlet in control system, 21 - video camera.

Pressure gauges, pressure regulators, the loop counter, timer, contact position sensor with mechanical roller operating and louvre dampers elements and systems receivers that allow you to change the frequency of vibration and the vibration amplitude of the rod was included in electro-pneumatic control system of a pneumatic cylinder (Fig. 4).

Using an electro-pneumatic control system cylinder was set the required vibration frequency and amplitude of rod cylinders. The vibration amplitude was determined using the storyboarding video footage.

Variation of selected factors: the amplitude of rod pneumatic cylinder vibration A = 0,5 ... 4 [mm], the frequency of the rod actuators vibration n = 1 ... 10 [Hz], angle of repose for free flowing products φ = 29 ° ... 35,2 °, - are carried within the limits of caused by possible compacting’s technological parameters and rheological characteristics of the compacting products [11, 12, 13].

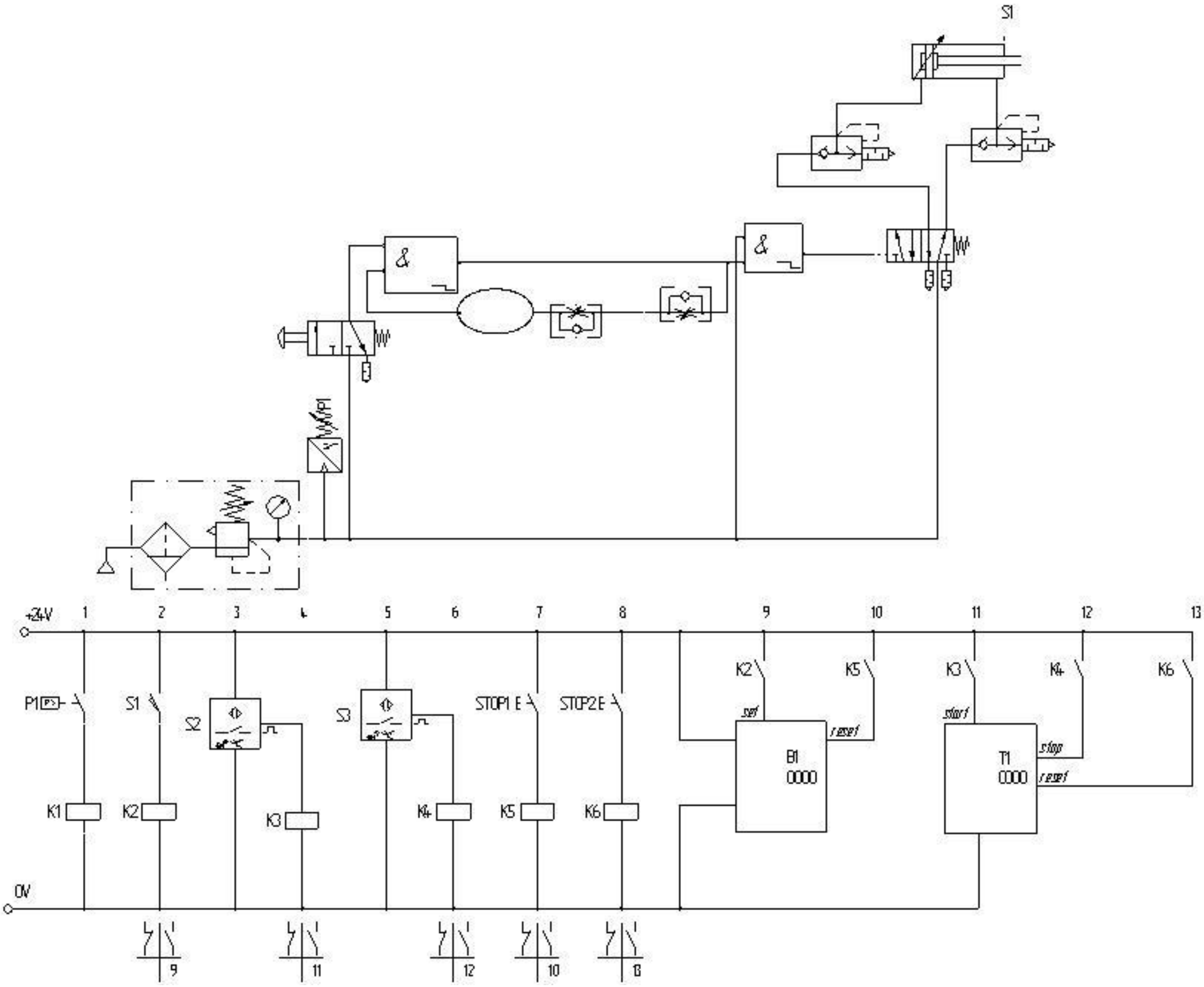
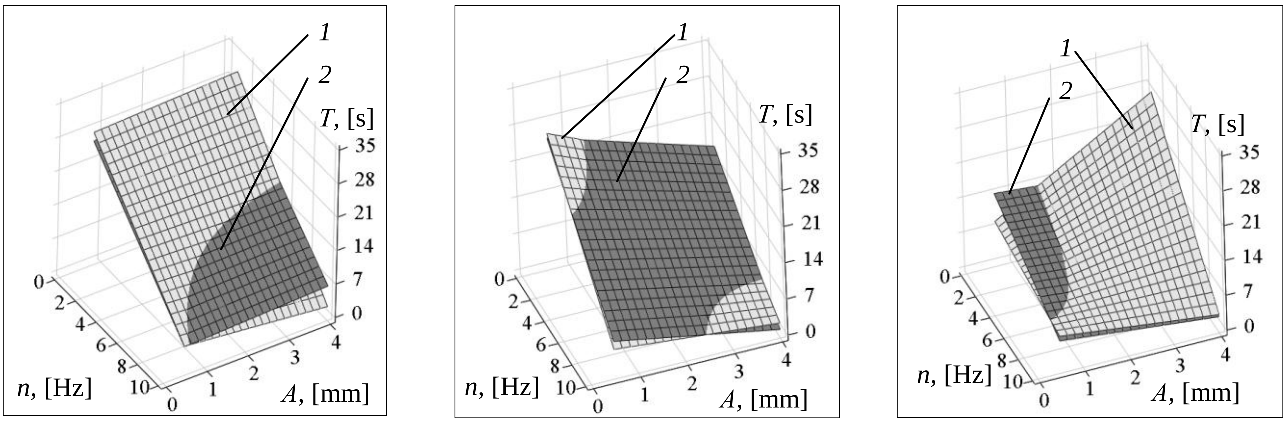


Figure 4. *Diagram of electro- pneumatic control of pneumatic cylinders*



a *b* *c*

Figure 5. *Diagram of the duration of bulk products compacting for the three modes of the experimental device for: a - direction of vibrations is vertical; b - direction of vibrations is horizontal along the length of the box; c - direction of vibrations is horizontal along the width of the box; 1- φ = 29 °; 2- φ = 35,2°*

Experimental program also includes three modes of variation kinematic parameters of operating of compacting mechanism according with a direction of vibrations in bulk products in a box – vertical, horizontal along the length of the box, and horizontal along the width of the box.

III. Results and discussion

Based on the developed matrix, research plan, the calculations performed of the statistical analysis of the regression equation for the three modes of the experimental device has been determined regression equation, which describes duration compacting of bulk products in natural variables for:

1. direction of vibrations is vertical:

$$T = 39{,}847 + 4{,}183 \cdot A - 3{,}039 \cdot n - \ldots$$
$$\ldots - 0{,}252 \cdot \varphi - 0{,}127 \cdot A \cdot \varphi - 1{,}107 \cdot A \cdot n + \ldots \quad (23)$$
$$\ldots + 0{,}012 \cdot \varphi \cdot n + 0{,}333 \cdot A \cdot \varphi \cdot n ,$$

2. direction of vibrations is horizontal along the length of the box:

$$T = 41{,}364 - 10{,}907 \cdot A - 4{,}532 \cdot n - \ldots$$
$$\ldots - 0{,}31 \cdot \varphi + 0{,}229 \cdot A \cdot \varphi + 1{,}385 \cdot A \cdot n + \ldots \quad (24)$$
$$\ldots + 0{,}063 \cdot \varphi \cdot n - 0{,}036 \cdot A \cdot \varphi \cdot n,$$

3. direction of vibrations is horizontal along the width of the box:

$$T = -36{,}847 + 36{,}258 \cdot A + 4{,}866 \cdot n + \ldots$$
$$\ldots + 1{,}55 \cdot \varphi - 1{,}05 \cdot A \cdot \varphi - 3{,}801 \cdot A \cdot n - \ldots \quad (25)$$
$$\ldots - 0{,}172 \cdot \varphi \cdot n + 107{,}322 \cdot A \cdot \varphi \cdot n.$$

Diagram of the duration of compacting of bulk products for the three modes of compacting depending on the amplitude and frequency of vibrations rod cylinders for selected angles of repose are shown in Fig. 5.

IV. Conclusions

Research of the duration of compacting of free flowing bulk products for the three modes of the experimental device allowed to determine that the horizontal direction of the driving vibration force of the operating of compacting mechanism directed along carton box has minimal time loss and maximum compacting of products. Moreover, allowed to determine reducing height bulk product in carton box in accordance with duration compacting of bulk products for vertical vibrations of operating compacting mechanism.

References

[1] Gavva O.M. Obladnannya dlya pakuvannya produkciї u spozhivchu taru / O.M. Gavva, A.P. Bespalko, A.I. Volchko. – K.: IAC «Upakovka», 2008. – 436 p.

[2] Padoxin V.A., Kokina N.R. Fiziko-mexanicheskie svojstva syrya i pishhevyx produktov. Ucheb. posobie / Ivan. gos. xim. -texnol. un-t., Institut ximii rastvorov RAN. - Ivanovo. 2007. - 128 p.

[3] Sokolovskij V.V. Statika sypuchej sredy. / V.V. Sokolovskij. – M.: Nauka, 1990. – 272 p.

[4] R. M. Nedderman. Statics and Kinematics of Granular Materials Hardcover – November 27, 1992.

[5] Rebinder P.A. Izbrannye trudy. Poverhnostnye javlenija v dispersnyh sistemah. Kolloidnaja himija. - M.: "Nauka" 1978. - 371 p.

[6] S.D. Rudnev. Fiziko-mehanicheskie svojstva syr'ja i produkcii. Uchebnoe posobie dlja studentov special'nostej 170600 «Mashiny i apparaty pishhevyh proizvodstv», 271300 «Pishhevaja inzhenerija malyh predprijatij», napravlenija 551800 «Tehnologicheskie mashiny i oborudovanie» Kemerovskij tehnologicheskij institut pishhevoj promyshlennosti. – Kemerovo. 2004. – 117 p.

[7] Pershina S.V. Vesovoe dozirovanie zernistyh materialov. Uchebnoe posobie / S. V. Pershina, A. V. Katalymov, V. G. Odnol'ko, V. F. Pershin. – M.: Mashinostroenie, 2009. – 260 p.

[8] Osipov, A.A. Razrabotka, issledovanie i raschet vibracionnoj ustanovki dlja prigotovlenija mnogokomponentnyh smesej: dis. kand. tehn. nauk/ A.A. Osipov. – Tambov, 2004. – 211 p.

[9] Pershin, V.F. Jenergeticheskij metod opisanija dvizhenija sypuchego materiala v poperechnom sechenii gladkogo vrashhajushhegosja cilindra/ V.F. Pershin// Teoreticheskie osnovy himicheskoj tehnologii. – 1988. – T. XXII. – №2. – pp. 255 – 260.

[10] Baryshnikova, S.V. Razrabotka novyh konstrukcij i metodov rascheta ustrojstv dlja nepreryvnogo dozirovanija sypuchih materialov: dis. ... kand. tehn. nauk/ S.V. Baryshnikova. – Tambov, 1999. – 171 p.

[11] Filipenko A.S. Osnovi naukovix doslidzhen: konspekt lekcij / A.S. Filipenko – K.: Akademvidav, 2004. – 208 p.

[12] Jeffrey H. Hooper. Confectionery Packaging Equipment (Chapman & Hall Food Science Book) Hardcover – September 30, 1998.

[13] John R Henry. Packaging Machinery Handbook: The complete guide to automated packaging machinery including packaging line design Paperback – November 17, 2012.