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SCIENTIFIC AND TECHNICAL IMPROVEMENT OF FUNCTIONAL MODULES OF FORMATION OF STRUCTURAL ELEMENTS OF GROUP PACKAGE

M. Iakymchuk[1], O. Gavva[2], S. Tokarchuk[3]

Faculty of Mechanical Engineering and Packaging Equipment National University of Food Technologies, Ukraine, 01601, Kyiv, Volodymyrska str. 68, e-mail: MykolaIakymchuk@mail.ua

Abstract. *Creation of a new packaging equipment that has a flexible structure and is versatile for different types of food, packaging materials and containers are a major challenge today. In this work the operation of putting of packing units by the new machine construction for group packing by the drive roller track has been researched, the duration of layer putting has been defined, the methodology of definition of rational geometric, kinematic and force parameters of the mechanism of putting has been presented.*

Key Words: drive roller track, packing unit, packing equipment, roller track, mechanism of collision.

I. Introduction

Group packing is one of the most important logistic operations that transforms packing units into cargo. Depending on the type of packing unit, productivity of technological lines, three ways of forming of group package are used such as horizontal, vertical and combined ones [1]. For packing units of parallelepiped shape a horizontal way with layered horizontal structural elements of group package is used. On the basis of analysis and timeline of machines for group packing of packing units of parallelepiped shape it was found out that for the realisation of high productivity it is necessary to differentiate operations of forming of structural elements and to form group package by means of accumulation of layers of packing units on lifting and lowering platform.

II. Materials and Methods

To implement this technology a new machine construction for group packing of packing units of parallelepiped shape was offered (Fig.1).

The machine consists of accumulating and feeding conveyer, mechanism of putting, lifting and lowering mechanism, mechanism of collision of group package and device of positioning and retaining of transport container. Accumulating and feeding conveyer is represented in the form of roller conveyer 4. Machine construction provides displacement on the accumulating conveyer, previously formed layer of packing units. To position a layer of packing units on the feeding conveyer a retainer plane 13 was installed that makes a reciprocating motion. The mechanism of putting is constructively made in the form of two closed chain conveyers 6, between which roller tracks 1 were installed on two levels.

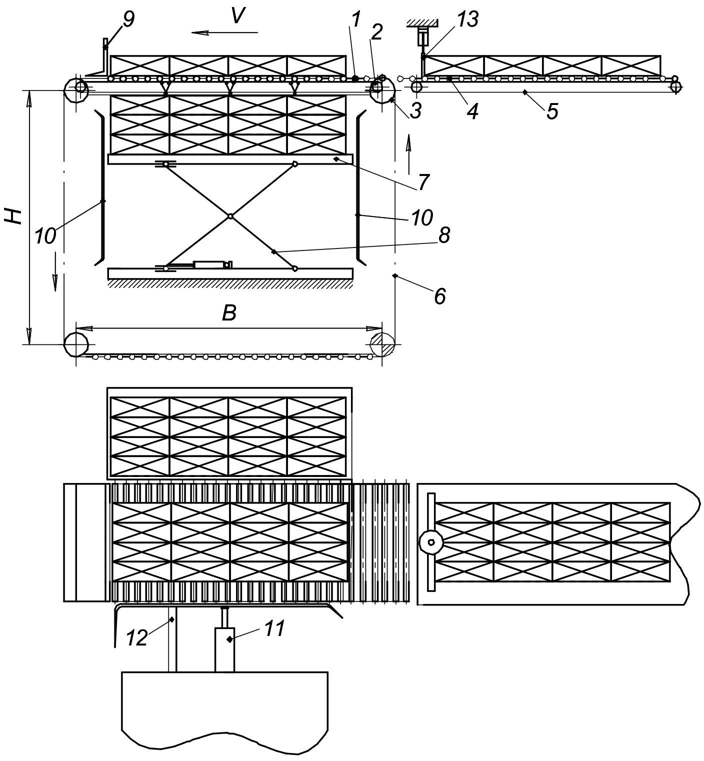

Figure 1. *Machine for group packing of packing units of parallelepiped shape.*

The length of roller tracks is defined by the length of packing units. Roller track that is located on the upper level is subjected to motion by the frictional and belt transmission of synchronous movement of rollers on the feeding conveyer.

Limitation of movement of the layer of packing units on roller conveyer 1 is carried out by stopping 9. There is a lifting and lowering mechanism in the form of Nuremberg scissors 8 between chain outlines. The drive for this mechanism is a pneumatic drive. Carrying platform for Nuremberg scissors is a platform 7 on which layers of packing units are accumulated. The mechanism of collision of group package is represented in the form of vertical plane that moves in the horizontal direction with the help of pneumatic drive 11 and guide 12. Formed group package is moved into transport container 14 that is positioned and formed by the corresponding mechanism. Formed layer of packing units is fed on the feeding conveyer 4 before its contact with retainer plane 13.

At the time when the first roller of the roller track 1 moves to the upper horizontal level, frictional and belt transmissions of feeding and putting conveyer are made to move synchronously. Retainer guide 13 moves upwards and the layer of packing units is moved on the putting roller conveyer 1. When packing units reach retainer guide 9 they stop and the roller track continues to displace on outlines of the chain. Leading of roller track out from the layer of packing units results in their being put on the platform of lifting and lowering mechanism 8 or the layer of packing units put previously. The process of accumulation and putting of layers is carried out in uninterrupted mode that gives a possibility to increase a machine productivity greatly. Formed group package by the mechanism of collision 11 is displaced on previously formed and positioned corrugated carton box. The duration of the operation of collision and displacement on the upper layer depends on the duration of displacement of layer of packing units from the position of feeding conveyer into the position of putting conveyer.

To provide a qualitative accumulation of packing units layers and to define the duration of putting layers with possible selection of rational geometric, kinematic and force parameters of putting it is sensible to carry out research of putting operation of packing units by the diverter drive roller track.

III. Results and discussions

The peculiarity of operation of positioning of the packing units layer by the mechanism with diverter drive roller track is sliding of packing units on the cylindrical surface but not on the rib as it is pictured in the work [2].

During the mathematic modelling of positioning operation one can point out such characteristic stages of packing units (Fig.2):

displacement of packing unit with sliding on the working surface and retainer plane;

displacement of packing unit with sliding on the working surface of roller;

displacement of packing unit with sliding on the working surface of roller and surface of putting;

displacement of packing unit with sliding on the guide plane and surface of putting;

displacement of packing unit with sliding on the surface of putting.

At the first stage a complicated flat movement of the packing unit starts at the moment of equality of the length of the working surface of the diverter drive of the roller track is a value S_0.

The value S_0 can be defined from the static equilibrium of the packing unit in the horizontal state on the roller track:

$$S_0 = 0.5c(1 - f_1 f_2)\cos\gamma, \qquad (1)$$

where f_1, f_2 are coefficients of sliding friction of packing unit on the roller and guide plane: $c = \sqrt{a^2 + b^2}$; a, b - the length and the width of the packing unit; $\gamma = arctg\, b/a$.

There are normal reactions N_1, N_2 and force of sliding friction F_1, F_2 that act at the points of contact of the packing unit with guide plane and the last roller of the line.

Herewith packing unit does the sliding with friction on the working surface of the roller. During the next reduction of the working length of the line a disruption of the packing unit from the guide plane and contact with the surface of putting can be possible.

The conditions of ending of the first stage of the packing unit movement can be unequal:

$$N_2 \le 0, \qquad (2)$$

$$y \ge Y_c + H_c - 0.5 \cdot c \cdot \cos(\gamma + \varphi), \qquad (3)$$

or

$$H_c \le \cos\gamma \cdot \sin\varphi - (S_0 \cdot \upsilon_0 \cdot t + r_p \sin\varphi) \cdot tg\varphi, \qquad (4)$$

where H_c is a distance from the working surface of the roller track to the surface of putting; Y_c - distance from the axis of coordinates XOY to the surface of the roller track; φ - the angle of rotation of the packing unit; r_p - the radius of the roller.

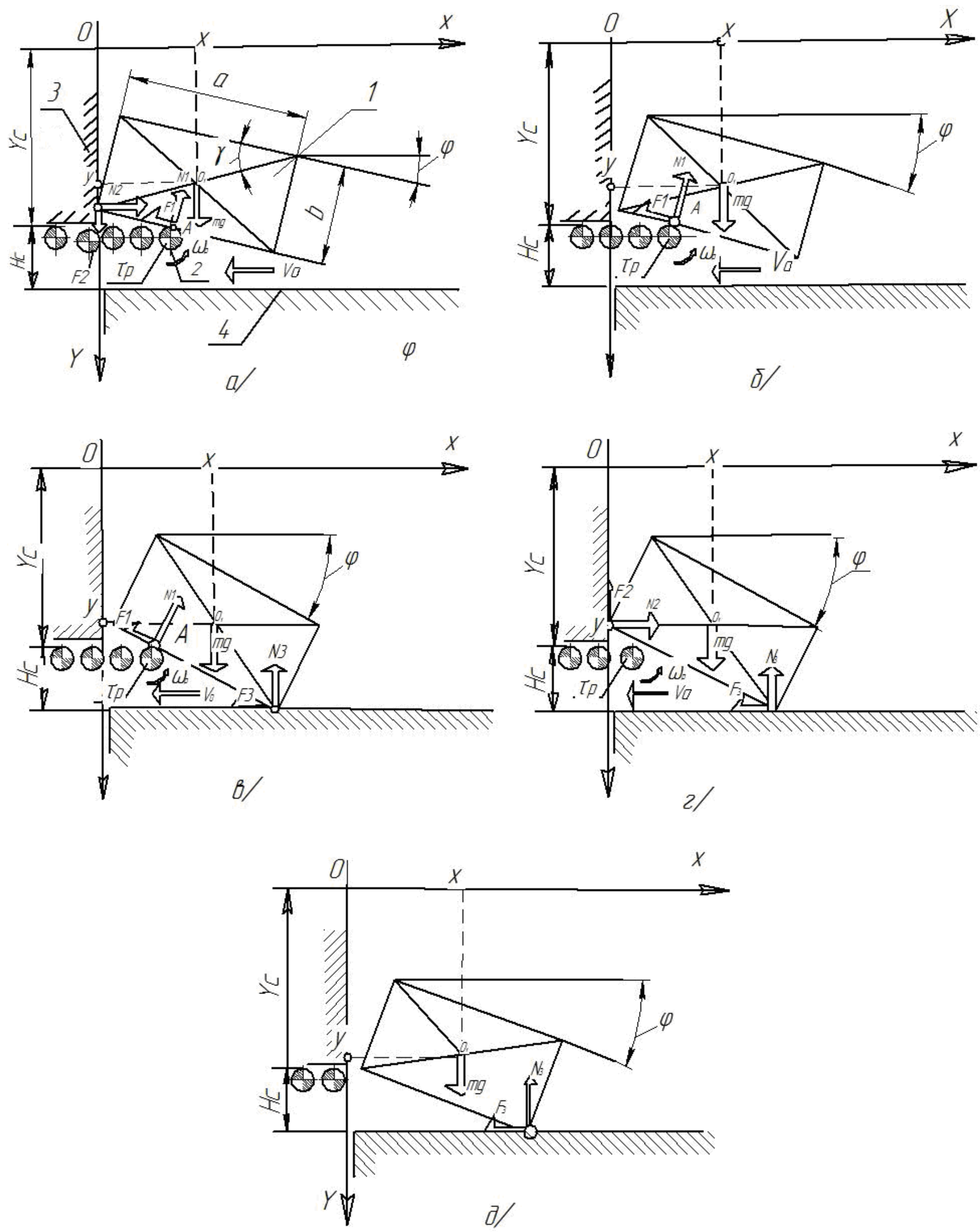

Figure 2. *Characteristic stages of the movement of the packing unit during its putting by diverter drive roller track*

The fulfillment of the condition (2) corresponds to the beginning of the second stage of the packing unit movement, the condition (4) - to the third one.

The operation of putting of the packing unit, depending on the correlation of the values of the geometric parameters of the packing unit and the mechanism of putting, can be viewed as a combination of stages of different quantity. Thus, during the fulfillment of the condition (4) at the moment of the ending of the first stage the second stage will not start. Let's consider the stages of the movement of the packing unit in succession taking into account fulfillment of the conditions (2) and (4). The second stage is characterized by the complicated flat movement of the packing unit 1 during the leading drive roller track 2 out. In this case the packing unit continues rolling on the surface of the roller with sliding on the contact line. During rolling with sliding at the point of contact there are reaction N_1, N_2 and force of sliding friction F_1, F_2 that acts on tangent to the surface of the roller and is directed to the side that is opposite to the additional direction X. The main feature of the ending of this stage of movement of the packing unit is a contact with the surface of putting. Mathematical description of the condition of ending of the second stage is represented in the form of inequality (4). The next stage characterises the movement of the packing unit during its simultaneous sliding on the surface of putting and the working surface of the roller. The duration of this stage depends on the correlation of geometric parameters of the packing unit and the mechanism of putting as well as the coefficient of the sliding friction f_2 between packing unit and the surface of putting. The conditions of the ending of the third stage can be described in the form of the following inequalities:

$$N_2 \le 0, \tag{5}$$

$$x \le 0.5 \cdot c \cdot \cos(\gamma - \varphi) \cdot \tag{6}$$

The fulfillment of the conditions (5) and (6) corresponds to the beginning of the fourth stage of the packing unit movement. At the fourth stage packing unit makes a flat movement with sliding on the surface of putting and guide plane.

The fulfillment of only one condition that is defined by the formula (6) can be possible. In this case the fifth stage of packing unit movement begins. The fifth stage characterises flat movement of the packing unit during sliding of its lower rib on the surface of putting. Final formulas and equations that describe stage-by-stage movement of the packing unit while its being put by the diverter drive roller track as well as boundary conditions for each stage are presented in the table 1. Received dependences are mostly non-linear differential equations that are solved by the numerical methods. The duration of the operation of putting of the layer of the packing units by the corresponding drive roller track can be defined by the formula:

$$T_y = n \sum_{i=1}^{i=5} t_i \,, \tag{7}$$

where *n* - is a number of packing units in the layer row of group packing; t_i - duration of the first stage of the operation of putting of the packing units on the lifting and lowering platform.

Table 1. *Calculation formulas for the definition of the main parameters of the operation of putting of packing units by the diverter drive roller track*

Stages	**Calculation formulas and equations**	**Introduced markers**
1	2	3
First stage	Initial conditions: $t = 0, \varphi_{n1} = 0, x_{n1} = 0,5a, y_{n1} = Y_c - 0.5h$ $\ddot{x} = 0.5c(\ddot{\varphi}\sin(\gamma-\varphi) - \dot{\varphi}^2 \cdot \cos(\gamma-\varphi));$ $\ddot{y} = \ddot{\varphi}E_\varphi + \dot{\varphi}^2 F_\varphi + 2\dot{\varphi} \cdot \upsilon_0 \cdot \sec^2\varphi;$ $\ddot{\varphi} = (\dot{\varphi}^2(0.5 \cdot c \cdot \cos(\gamma-\varphi)(A_\varphi \cdot N_\varphi - f_2 \cdot L_\varphi) + F_\varphi \cdot L_\varphi) +$ $+L_\varphi(g - 2\upsilon_0 \cdot \sec^2\varphi))(\frac{A_\varphi \cdot c^2}{12} + E_\varphi \cdot L_\varphi - 0.5c \times$ $\times \sin(\gamma-\varphi)(f_2 \cdot L_\varphi - A_\varphi N_\varphi))^{-1};$ $N_1 = \frac{m}{A_\varphi}(g + f_2\ddot{x} - \ddot{y}); N_2 = \frac{m}{A_\varphi}(B_\varphi(\ddot{y} - g) + \ddot{x} \times$ $\times(A_\varphi - f_2 B_\varphi))$ Conditions of the stage ending $y = Y_c + H_c - 0.5c \cdot \cos(\varphi+\gamma), N_2 = 0$	$S_0 = 0.5c(1 - f_1 \cdot f_2) \cdot \cos\gamma; A_\varphi = (f_1 + f_2)\sin\varphi + (1-$ $- f_1 \cdot f_2)\cos\varphi; B_\varphi = \sin\varphi - f_1 \cdot \cos\varphi; E_\varphi =$ $= se^2\varphi(\upsilon_0 \cdot t - 0.5c(1 - f_1 \cdot f_2)\cos\gamma - r_p \cdot \sin\varphi -$ $-0.5c \cdot \cos^2\varphi \cdot \cos(\gamma-\varphi); F_\varphi = \sec^3\varphi(2 \cdot \upsilon_0 \cdot t \times$ $\times \sin\varphi - r_p(1 + \sin^2\varphi) - c(1 - f_1 \cdot f_2) \cdot \sin\varphi \times$ $\cos\gamma + 0.5c \cdot \sin(\gamma-\varphi) \cdot \cos^3\varphi;$ $K_\varphi = \sec\varphi(\upsilon_0 \cdot t - r_p \cdot \sin\varphi - 0.5c \cdot \cos\gamma(1-$ $- f_1 \cdot f_2 - \cos\varphi)) + 0.5c \cdot f_1 \cdot \sin\gamma;$ $L_\varphi = K_\varphi + (\sin\varphi - f_1\cos\varphi)(\sin(\gamma-\varphi) + f_2 \times$ $\times \cos(\gamma-\varphi) \cdot 0.5c;$ $N_\varphi = 0.5c(\sin(\gamma-\varphi) + f_2 \cdot \cos(\gamma-\varphi)).$
Second stage		$A_\varphi = (\upsilon_0 \cdot T - S_0 + x)\cos\varphi - (Y_c + r_p - y) \cdot \sin\varphi;$ $B_\varphi = (S_0 - \upsilon_0 \cdot T - x) \cdot \sin\varphi - (Y_c + r_p - y)\cos\varphi;$ $Д_\varphi = (\upsilon_0 + \dot{x}) \cdot \cos\varphi + \dot{y} \cdot \sin\varphi;$ $E_\varphi = (x - S_0 + \upsilon_0 \cdot T)\cos\varphi - (Y_c + r_p - y) \times$ $\times \sin\varphi + 0.5c \cdot f_1 \cdot \sin\gamma.$

1	2	3
	Initial conditions: $t=0;\varphi_{n2}=\varphi_{k1};\dot{\varphi}_{n2}=\dot{\varphi}_{k1}$ $\ddot{x}=c^2(g\cdot\cos\varphi-\dot{\varphi}^2\cdot B_\varphi-2\dot{\varphi}Д\varphi)(\cos\varphi+...$ $+f_1\cdot\sin\varphi)(c^2+12\cdot A_\varphi\cdot E_\varphi)^{-1};$ $\ddot{y}=g-c^2(g\cdot\cos\varphi-\ddot{\varphi}^2B_\varphi-2\dot{\varphi}Д_\varphi)(\cos\varphi+...$ $+f_1\cdot\sin\varphi)(c^2+12\cdot A_\varphi\cdot E_\varphi)^{-1}$ $\ddot{\varphi}=12(g\cdot\cos\varphi-\dot{\varphi}^2B_\varphi-2\dot{\varphi}Д_\varphi)E_\varphi(c^2+12\times$ $\times A_\varphi\cdot E_\varphi)^{-1};$ $N_1=mc^2(g\cdot\cos\varphi-\dot{\varphi}^2B_\varphi-2\dot{\varphi}Д_\varphi)(c^2+12A_\varphi E_\varphi)^{-1}.$ Conditions of the stage ending $\ddot{\varphi}=0, y=Y_c+H_c-0.5c\cdot\cos(\gamma-\varphi)$	
Fourth stage	Initial conditions: $t=0;\varphi_{n4}=\varphi_{k3};\dot{\varphi}_{n4}=\dot{\varphi}_{k3}$ $\ddot{x}=-0.5c(\ddot{\varphi}\cdot\sin(\varphi-\gamma)+\ddot{\varphi}^2\cdot\cos(\varphi-\gamma))$ $\ddot{y}=-0.5c(\ddot{\varphi}\cdot\cos(\varphi+\gamma)-\varphi^2\cdot\sin(\varphi+\gamma))$ $N_2=m(\ddot{x}+f_3(g-f_2\cdot\ddot{x}-\ddot{y})(1+f_2\cdot f_3)^{-1})$ $N_3=m(g-f_2\ddot{x}-\ddot{y})(1+f_2\cdot f_3)^{-1}$ $\ddot{\varphi}=(\frac{2g}{c}-A_\varphi+\dot{\varphi}^2(A_\varphi(f_2\cdot\cos(\gamma-\varphi)-\sin(\gamma-$ $-\varphi))-B_\varphi\cdot\cos(\gamma-\varphi)))(\frac{1}{3}(1+f_2\cdot f_3)+A_\varphi(f_2\times$ $\times\sin(\gamma-\varphi)-\cos(\gamma-\varphi))-B_\varphi\cdot\sin(\gamma-\varphi))^{-1}$ Conditions of the stage ending N2=0, φ=0	$A_\varphi=f_3\cdot\sin(\varphi+\gamma)-(1-f_2\cdot f_3)\cos(\gamma-\varphi)-...$ $-\cos(\gamma+\varphi)-f_3\cdot\sin(\gamma-\varphi)$ $B_\varphi=f_2\cdot\cos(\gamma-\varphi)-(1+f_2\cdot f_3)\sin(\lambda-\varphi)$
Fifth stage	Initial conditions: $t=0;\varphi_{n5}=\varphi_{k4};\dot{\varphi}_{n5}=\dot{\varphi}_{k4}$ $\ddot{y}=0.5c\cdot(\dot{\varphi}^2\cdot\sin(\varphi+\gamma)-\ddot{\varphi}\cdot\cos(\varphi+\gamma))$ $\ddot{x}=f_3(\ddot{y}-g);\ddot{\varphi}=(-(2g/c)(\cos(\varphi+\gamma)-$ $-f_3\cdot\sin(\varphi+\gamma))+\dot{\varphi}^2(0.5\cdot\sin2(\varphi-\gamma)-f_3\sin^2(\varphi+$ $+\gamma)))(\frac{1}{3}+\cos^2(\varphi+\gamma)-0.5f_3\sin2(\varphi+\gamma))^{-1}$ Conditions of the stage ending $\varphi=0$	

IV. Conclusions

On the basis of analysis and synthesis of technological schemes and the structure of machines for group packing of the packing units of parallelepiped shape a new structure and construction of the machine were offered that provide uninterrupted mode of putting layers of packing units on the platform of the lifting and lowering mechanism that increases machine productivity greatly. To select rational kinematic and geometric parameters of the mechanism of accumulation of packing units layers a mathematic model of displacement of the layer of the packing units by the diverter drive roller track on the platform of lifting and lowering mechanism was developed.

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