OPTIMIZATION OF TRANSPORTATION OF BULK SOLIDS FOOD PRODUCTS IN THE LINEAR WEIGHTFEEDER OF PACKING MACHINE

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Abstract. *In this article considers Research results of work linear weightfeeder of packing machine subject to "rough" and "exact" dosing modes. For optimization of transportation of bulk solids food products in this weightfeeder was offered to use such assistive devices, as limiting guide. This guide provide the following conditions: vertical falling of product's solids into weigher capacity; falling of product's solids to a geometrical center of weigher capacity subject to "rough" and " exact" dosing modes. The mathematical analysis and graphical modeling position guide enabled to decide on its type and operation mode.*

Keywords: bulk solids food products, linear weightfeeder, packing machine, limiting guide, weigher capacity, vibratory feeder.

I. Introduction

At the present stage of development of the packaging industry, packaging machines for bulk solids food products is taking on employment use. This is due to increasing range of products and increase in the production of such products, its various structural and mechanical properties, the advent of new types of packaging materials and packaging [1].

Machines with using linear weightfeeder are dominating today in the domestic market of packaging mashines for bulk solids food product.

Dosage are performed in several stages in this devices:

- discharging of products from hopper through the discharging passage;
- transportation product with a given intensity in the direction of weigher capacity(subject to "rough" and " exact" dosing modes) in feeder's conveyor;
- falling products under the influence gravity from feeder's supporting surface into weigher capacity;
- accumulation and weighing products in the weight capacity ;
- unload the weigher capacity.

At each stage of dosing is essential to know the factors and their interaction, affecting the accuracy of dosing, which is the main criterion of effectiveness device as well as packing machine generally.

It is well known that for a weightfeeder between productivity dosing accuracy has definite relationship [4-8].

If you are using this steps to improve productivity of weightfeeder, then dosing accuracy is reducing:

- increasing the product's speed discharge through hopper's discharging passage;
- increasing layer thickness of products on feeder's conveyor;
- increasing the feeding conveyor speed;
- increasing the relative duration of "rough" dosing.

II. Materials and Methods

Also at increasing transportation velocity products by feeder (subject to "rough" and "exact" dosing modes) deviation of relative flight trajectory of product's solids is increasing the to the axis of symmetry of the position weigher capacity. This deviation of trajectory affects the accuracy of was offered to use such assistive devices, as limiting guideweighing system, so in order to ensure stable transportation of bulk solids products. This guide should provide the following conditions:

- vertical falling of product's solids into weigher capacity;
- falling of product's solids to a geometrical center of weigher capacity subject to "rough" and "exact" dosing modes.

Linear weightfeeder with vibratory feeder are the most common in the packing machines (Fig. 1). Consider transportation bulk solids food products to determine geometry of the limiting guide and her position subject to "rough" and "exact" dosing modes for such linear weightfeeder.

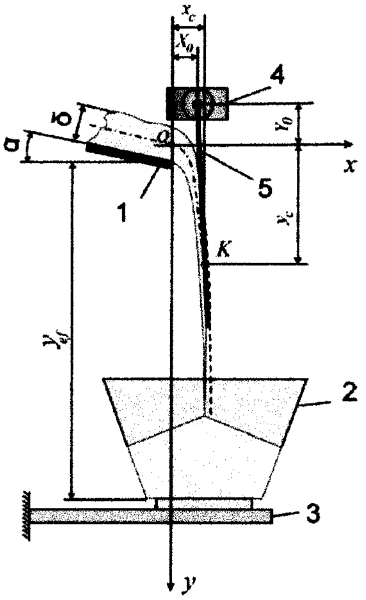

Figure 1. *Loading diagram of dosing bulk solids food products to the weigher capacity in the linear weightfeeder with vibratory feeder : 1 - vibratory feeder, 2 - weigher capacity, 3 - weighing system, 4 - pivot actuator, 5 - limiting guide*

Such following assumption was to make to simplify the mathematical model of the impact of product's solids to guide:

- the impact of product's solids to limiting guide can to describe as an elastic-plastic impact;
- bulk solids product is disconnecting, fine factional;
- solids size product neglect and consider its movement as a movement of material particle;
- material particle movement along the trajectory of the fall solids from average thickness of products on feeder's conveyor.

To determine the required location, type and configuration guide needs to do: research the movement trajectory of material particle, mathematical modeling of elastic-plastic impact of material particle to limiting guide and choice of actuator.

For mathematical modeling of movement trajectory of material particle needs to specified coordinate system.

The origin of coordinates is at the point of falling bulk solids products from feeder. Axes Ox and Oy placed respectively horizontally and vertically. Then the coordinates (x (t), y (t)) and the projection of the velocity of falling (x '(t), y' (t)) of the material particle of vibratory feeder relative to axes Ox and Oy can be described by the following formula (Fig. 2):

$$\begin{cases} x(t) = V_0 \cdot t \cdot cos(\alpha); & (1) \\ y(t) = V_0 \cdot t \cdot sin(\alpha) + g \cdot t^2; & (2) \end{cases}$$

and

$$\begin{cases} x'(t) = V_0 \cdot \cos(\alpha); & (3) \\ y'(t) = V_0 \cdot \sin(\alpha) + 2 \cdot g \cdot t, & (4) \end{cases}$$

where $y(t) = 0 \ldots y_{max}$ – the current value of the height of the falling material particle;

$y_{max} = 0{,}5\ \delta / cos(\alpha) + y_{ef}$ – maximal height of the falling material particle [2]; δ – thickness of products on vibratory feeder; α – angle of inclination of vibrating feeder to the horizontal axis Ox; V_0 – velocity of transportation products by feeder; t – the current value of fall time of material particle.

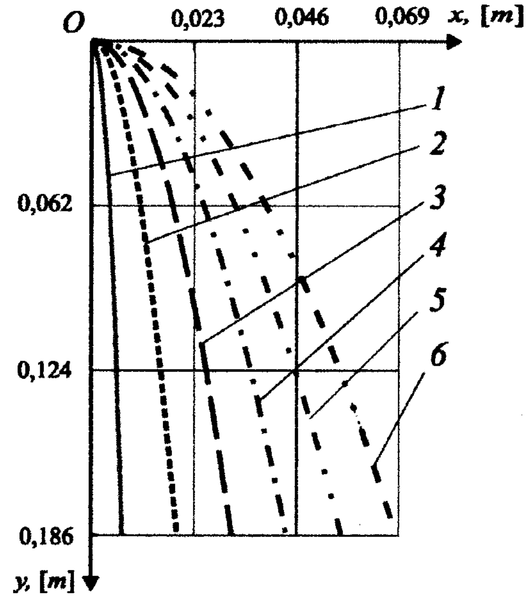

Figure 2. *Trajectory of falling material particle of vibratory feeder that operates at different velocities:*
1. $V_0 = 0{,}05$ [m/s]; 2. $V_0 = 0{,}14$ [m/s];
3. $V_0 = 0{,}23$ [m/s]; 4. $V_0 = 0{,}32$ [m/s];
5. $V_0 = 0{,}41$ [m/s]; 6. $V_0 = 0{,}50$ [m/s]

The current value of fall time of material particle into weigher capacity:

$$t = 0{,}5\ g \cdot \{[(V_0 \cdot sin(\alpha))^2 + 4 \cdot g \cdot y)]^{0,5} - \ldots \ldots - V_0 \cdot sin(\alpha)\}, \quad (5)$$

and the formula of the curve that describes the trajectory of the falling material particle can be derived from formula (1, 5):

$$x(t) = 0{,}5\ g \cdot V_0 \cdot cos(\alpha) \cdot \{[(V_0 \cdot sin(\alpha))^2 + \ldots \ldots + 4 \cdot g \cdot y)]^{0,5} - V_0 \cdot sin(\alpha)\}. \quad (6)$$

Velocity of falling material particle:

$$V_b(t) = \{[x'(t)]^2 + [y'(t)]^2\}^{0,5} = \{V_0^2 + \ldots \ldots + 4 \cdot g \cdot t \cdot (V_0 \cdot sin(\alpha) + g \cdot t)\}^{0,5}. \quad (7)$$

To determine the position of the guide need to do mathematical modeling of elastic-plastic impact of material particle to limiting guide under next initial conditions.

1. The impact of material particle to limiting guide can to describe as an elastic-plastic impact. From [3] coefficient of restitution for elastic-plastic impacts is given as:

$$k_i = tg(\varphi_b(t)) / tg(\varphi_a(t)). \quad (8)$$

$\varphi_b(t)$ – angle of reflection before impact;

$\varphi_a(t)$ – angle of reflection after impact.

2. A geometrical center of weigher capacity located at the point of falling product's solids, which was transported by vibratory feeder subject to "exact" dosing modes:

$$x_c = 0{,}5g \cdot V_{0min} \cdot \cos(\alpha) \cdot \{[(V_{0min} \cdot \sin(\alpha))^2 + \ldots$$
$$\ldots + 4 \cdot g \cdot y)]^{0{,}5} - V_{0min} \cdot \sin(\alpha)\}; \quad (9)$$

where V_{0min} - minimal transportation velocity of product's solids by vibratory feeder subject to "exact" dosing modes.

3. After impact, the material particle should fall vertically into the geometric center of the weigher capacity subject to "rough" and "exact" dosing modes:

$$\begin{cases} x_a = x_c, & (10) \\ y_a = \mathrm{tg}(\alpha) \cdot x_a + g \cdot (x_a)^2 / (V_0 \cdot \cos(\alpha)), & (11) \end{cases}$$

Research of geometry impact of material particle to limiting guide was maked, provided the origin of coordinates of the new coordinate system (Fig. 3) coincide with the point of impact of bulk solids products to limiting guide. Axes *Ox'* and *Oy'* placed respectively horizontally and vertically.

Since the geometry of the guide is unknown, we can provide its only additional coordinate axes *On* and *Oτ*. They coincide with the normal and tangent to the guide at the point of impact of bulk solids products to limiting guide.

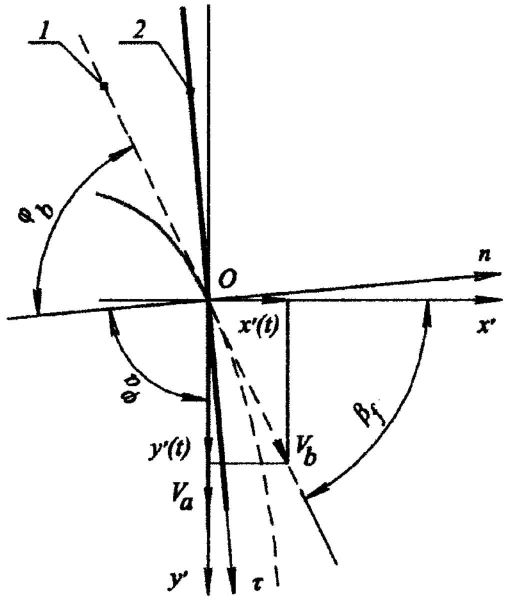

Figure 3. *Loading diagram of elastic-plastic impact of material particle to limiting guide*

According to loading diagram (Fig. 3), falling angle of material particle to the axes *Ox'*:

$$\beta_f(t) = \arccos\{x'(t) / V_f(t)\}.$$

Then taking into account (3,7) the formula for determining falling angle of material particle is:

$$\beta_f(t) = \arccos\{V_0 \cdot cos(\alpha) / [(V_0^2 + \ldots$$
$$\ldots + 4 \cdot g \cdot t \cdot (V_0 \cdot sin(\alpha) + g \cdot t)]^{0{,}5}\}. \quad (12)$$

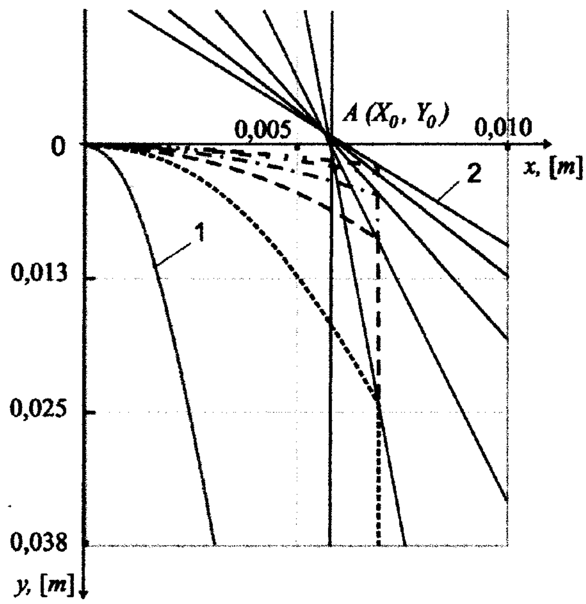

Figure 4. *Graphs tangent to the guide at different velocities of transportation bulk solids products in vibratory feeders:*
1 - trajectory of material particle;
2 - the tangent to limiting guide at the point of impact;

———————— $V_0 = 0{,}05$ [m/s];
- - - - - - - - - - $V_0 = 0{,}14$ [m/s];
— · — · — · $V_0 = 0{,}23$ [m/s];
· · — — · $V_0 = 0{,}32$ [m/s];
— — — — · $V_0 = 0{,}41$ [m/s];
— — — · · $V_0 = 0{,}50$ [m/s].

Falling angle of material particle to the axes *On*:

$$\varphi_b(t) = \beta_f(t) + \pi/2 - \varphi_a(t), \quad (13)$$

III. Results and discussion

The graph (Fig. 4) is visible: the tangent to the guide at the impact point also is its traces; deviations between the points of intersection of tangents are insignificant.

Therefore, can assume that the tangents intersect at some point *A* (X_0, Y_0). And the guide can be represented as a swivel shutter.

Location swivel of guide determined from formula (16, 17), which describe the desired position of the guide subject to such condition of transportation material particles in vibratory feeder as: minimal velocity V_{0min} ("exact" dosing modes) and maximal velocity V_{0max} ("rough" dosing modes):

$$\begin{cases} Y_0 = y_{c(min)} + tg(\varphi_{a(min)}) \cdot (X_0 - x_c); & (16) \\ Y_0 = y_{c(max)} + tg(\varphi_{a(max)}) \cdot (X_0 - x_c), & (17) \end{cases}$$

where $y_{c(min)}$; $y_{c(max)}$ – coordinates of impact point of material particle to limiting guide subject to minimal and maximal velocity of transportation material particles in vibratory feeder; $\varphi_{b(min)}$; $\varphi_{b(max)}$ – angle of reflection before impact subject to minimal V_{0min} and maximal V_{0max} velocity of transportation material particles in vibratory feeder.

By solving the system of equations (16, 17) can get swivel coordinates:

$$\begin{cases} X_0 = x_c + [\,y_{c(min)} - y_{c(max)}\,] \,/\, [tg(\varphi_{a(max)}) - \ldots \\ \quad \ldots - tg(\varphi_{a(min)})]\,; & (18) \\ Y_0 = [\,y_{c(min)} \cdot tg(\varphi_{a(max)}) - y_{c(max)} \times \ldots \\ \quad \ldots \times tg(\varphi_{a(min)})] \,/\, [tg(\varphi_{a(max)}) - tg(\varphi_{a(min)})]\,. & (19) \end{cases}$$

IV. Conclusion

The mathematical analysis and graphical modeling position guide enabled to decide on its type and operation mode: guide made as a swivel shutter; guide execute oscillatory motion, To drive the guide recommended rotary actuators.

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