WAYS TO REDUCE DOSING ERROR OF GRANULAR PRODUCTS IN LINEAR WEIGHT DOSING MACHINES

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Abstract. *In this article there is the result of laboratory research of linear weight dosing machine, providing permanent product flow through outlet port of hopper and minimizing the dynamic part of granular product dosing error, by rational placing of weighing container.*

Key words. granular product; linear weight dosing machine; dosing accuracy; dynamic dosing error; weighing container.

I. Introduction

Granular products have the great part of all food products. They are different by structure and mechanical properties and packing of such kind of products are providing in different container types. These factors define the structure of packing machine.

Now days, linear weight dosing machines are dominating on the market. This is due to price, dosing accuracy and productivity ratio. It is totally understandable that more accurate and productive machine do exist, but there problem is the price. So the main priority is given to upgrades and development of linear weight dosing machines.

In general view the structure of linear weight dosing machines for granular products may be described as a complex of different elements, any of each performs it's function. (fig. 1). Granular products permanently or periodically are supplied to receiving hopper 1, from witch by the use of feeder 2 it goes to container 3 where the dose is forming. Weight of the product, in the container 3, are measured by weight sensor 4 and controlled by handling system 5. Handling system 5 of a modern packing equipment includes PLC and analog-digital transducer.

When the weight of the product in the container gets near to the dose value, handling system 6 turns transportation system 2 and regulated shutter 7, in hopper 1, to slow feeding control position and when the dose value are achieved, it stops the transportation system.

The modification of dosing machine provides research of it's characteristics based on integrated approach to designing. Metrological characteristics and ways to improve the accuracy, productivity for

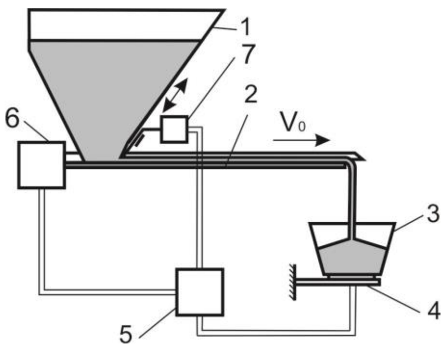


Figure 1. *Structure scheme of linear weight dosing machine for granular products.*

specified granular product are evaluated. Main criteria of the research are the dosing accuracy. It is important to know the factors and there interrelation which have influence on the dosing accuracy.

Dosing error depends from machine productivity, its structure, scheme, and design concept of machine parts. In the scientific work [1] there are three types of errors (three sources of dosing error):

drift – characterized by startup mode of machine. Minimal value are achieved by the delays interdiction between startup and beginning of dosing

static – characterized by performance inaccuracy of weighing system elements or else. This part of error is less than one percent.

dynamic – caused by transient in strain gauge transducer in time off the production flow to the container. Minimal value are achieved by time delays (installing of the filters witch define average weight value). It reduces the productivity of dosing machine.

Dynamic error consists from two parts: modeline and own. Modeline error depends from product feed intensity, cross-sections of the feeder feed channel area or else. Own error are defined by special characteristics of granulated product and it's interaction with machine elements. Reduce it by constructive changes is almost impossible. That is why the main regulated part of dosing error is modeline error.

Irregularity of granulated product feed in linear weight dosing machine – main source of modeline part of dynamic dosing error. It does not depend from the feeder type and product which are dosing. Modeline error depends from feeding speed, pressure of the product in hopper on working element of the feeder, cross-section of feeder channel area, using of special stabilizers of production height, time of product second feed, else.

To minimize one part of modeline error it is necessary to provide stable speed of product going through hopper outlet channel. For automatic regulation of hopper shutter position it's recommended to use a pneumatic positioning actuator (fig. 2) which consists of: controller, electropneumatic proportional pressure regulator, microcontroller of linear positioning actuator [2]. According to product level in the hopper, the position of the shutter is changing by the fact of inlet pressure value change in pneumatic actuator. Also, to minimize modeline part of dynamic dosing error, it is necessary to provide a correct placing of the weighing container against working element of the feeder.

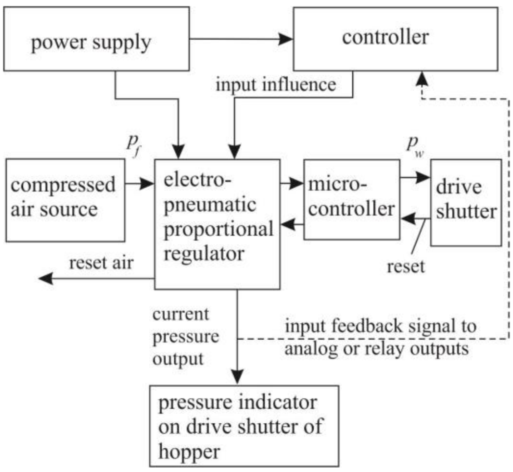


Figure 2. *Pneumatic positioning actuator of the hopper shutter control, structure scheme: p_f – feed pressure; p_w – working pressure*

Research methods: used methods of mathematical modeling.

II. Results and discussion

To define the rational working parameters of the feeder and to place weighing container the next assumptions will be adopted: granular products - disconnected; small fractions. It is possible to ignore the particles size and consider the granular product as a continuous medium. The movement of the product can be described by using laws of hydraulics.

To define rational cinematic and dynamic parameters of shutter movement by pneumatic positioning actuator, depending from product movement from the hopper intensity, the mathematic model are created. Total power load on the shutter are displayed on fig. 3.

Actuated shutter equation [3,4]**:**

$$M \cdot (d^2 x) / (dt^2) = p_1 \cdot F_1 - p_2 \cdot F_2 - F_{m1} - F_{m2} - \ldots$$
$$\ldots - F_{m3} - F_{m4}\,. \qquad (1)$$

Inlet chamber pressure change equation:

$$dp_1 / dt = \{k \cdot f_{L1} \cdot (R_g \cdot T_M \cdot (p_M^2 - p_1^2)^{0.5} / [F_1 \cdot (x + \ldots$$
$$\ldots + x_{01}) \cdot (\xi_1)^{0.5}]\} - \{k \cdot p_1 \cdot dx / [(x + x_{01})dt]\}. \qquad (2)$$

Rod chamber pressure change equation:

$$dp_2 / dt = \{k \cdot f_{L2} \cdot (R_g \cdot T_2 \cdot (p_2^2 - p_a^2)^{0.5} / [F_2 \cdot (S - x + \ldots$$
$$\ldots + x_{02}) \cdot (\xi_2)^{0.5}]\} - \{k \cdot p_2 \cdot dx / [(S - x + x_{02}) \cdot dt]\}, \qquad (3)$$

where: M – reduced mass of the shutter moving parts and positioning actuator; x – current value of the actuator rod movement; t – movement time of the rod; p_1, p_2 – pressure in rod and piston chambers; p_a – atmosphere pressure; F_1 – cross-section area of the piston, F_2 – useful area of the piston; k – granular product movement factor; f_{L1} – cross-section area of the inlet tube; f_{L2} – cross-section area of the outlet tube; T_2 – air temperature, that exhaust; T_M – system air temperature; $R_g = 287$ – specific gas constant, S – working stroke of the rod; x_{01}, x_{02}– *begin/end coordinate of the piston*; ξ_1, ξ_2 – inlet tube resistance coefficient.

Sliding friction forces:

- Product - shutter:

$$F_{m1} = f_1 \cdot F_n; \qquad (4)$$

- Shutter - guide:

$$F_{m2} = f_2 \cdot (F_n + m \cdot g), \qquad (5)$$

where m – shutter mass;

- Piston – positioning pneumatic actuator:

$F_{m3}=f_3 \cdot F_n$; (6)

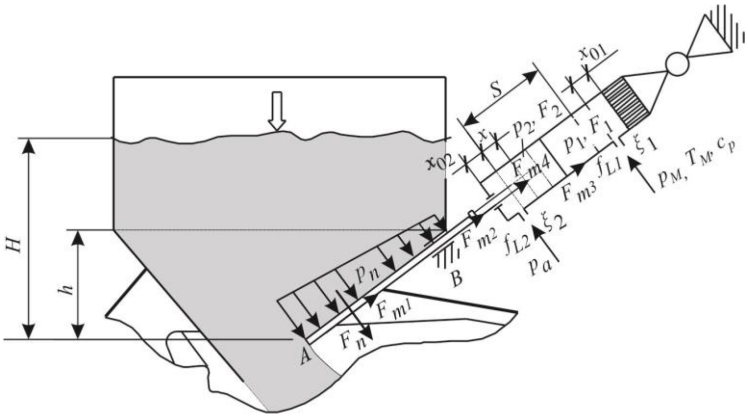


Figure 3. *Generalized shutter load force counting scheme depending on hopper production affect.*

- Positioning actuator rod:

$$F_{m4}=f_4 \cdot F_n \; ; \quad (7)$$

where: f_1, f_2, f_3, f_4 – sliding friction coefficient respectively to above values; F_n – the resultant force power of the product on the shutter, it's equal to:

$$F_n = 0{,}5 \cdot (\cos^2\alpha + k \cdot \sin^2 \alpha) \cdot \gamma \cdot S \times \ldots$$

$$\ldots \times l \cdot b \cdot (H + h), \quad (8)$$

where: k – granular product movement coefficient; α – hopper shutter slope angel; γ – specific product weight; l – shutter working part length; b – shutter width; H, h –product level height upper the shutter in A and B points.

Mathematics dependences counting results (1...8), which describes shutter movement in the hopper by the use of pneumatic actuator, are viewed in graphs on fig.4 considering such input values: *production – millet;* γ *=·800 kg/m*^{3}*; b =·0,1 m; S = 0,05 m; h = 0,380 m;H = 0,790 m; M =1 kg;* p_a *= 1 bar; ;* p_m *= 6 bar;* $F_1 = 2{,}011 \cdot 10^{-4}$ *m*^{2}*;* $F_2 = 1{,}728 \cdot 10^{-4}$ *m*^{2}*;* $f_{L1} = f_{L2} = 1{,}963 \cdot 10^{-5}$ *m*^{2}*;* $T_M = 290$ *K; S = 0,050 m;* $x_{01} = x_{02} = 0{,}05$ *m.*

To realize any constant shutter movement law it's necessary to change f_{L1} and f_{L2} respecting the functional dependence. This functional solution enables the intensity regulation of the product feeding from the hopper.

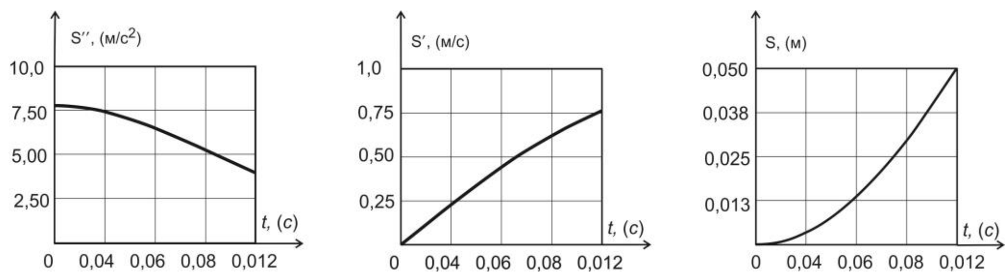
Definition of the weighing container rational placing are made with the condition, that the feeder is performed as a vibrator or belt conveyer (fig. 5).

In the dose forming process the weight sensor are forced by constant masses, and variable mass of the product, which is feeding to weighing container [5].

Total force on the weight sensor F_Σ defines by the sum of static and dynamic force (fig. 5):

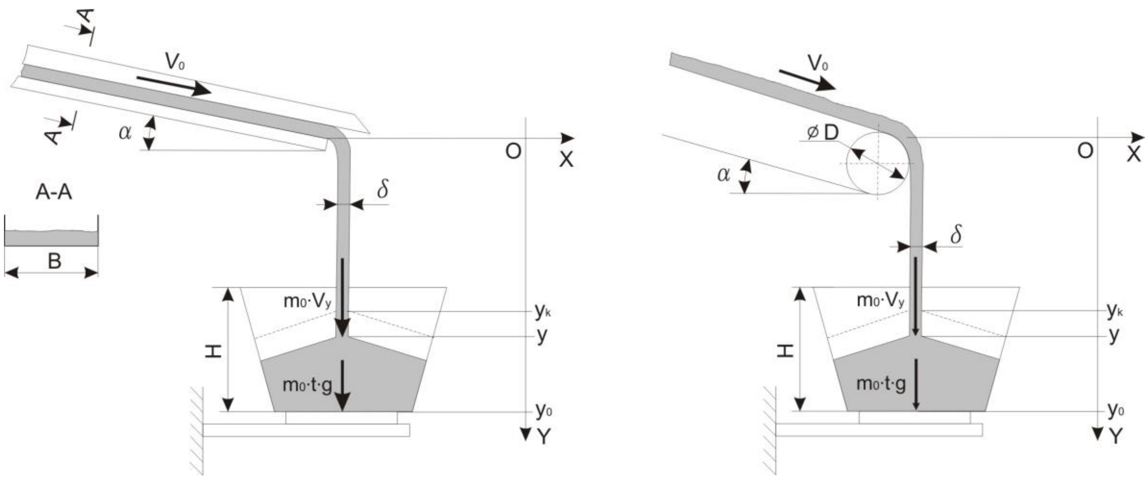
$$F_\Sigma = F_s + F_d, \quad (9)$$

where: F_s – static force on the weight sensor from weighing container mass; F_d – full dynamic force depending of product mass in the container.



a *b* *c*

Figure 4. *Changes graph: a – acceleration depend on time; b – speed depend on time; c – rod movement depend on time*



a *b*

Figure 5. *Weighing container weight sensor load scheme with production for dosing machine: a – with vibrator; b – with belt feeder*

Dose formation process control in weighing container are reduced to definition of total dynamic force F_d, which are define by the sum of instant weight of the product in the container and dynamic pressure of the product:

$$F_d = m_t \cdot g + F_t \,, \qquad (10)$$

where: m_t – current product in weighing container mass value ; g – acceleration of the gravity; F_t – dynamic product pressure on the weighing container.

Current value of the product mass in weighing container:

$$m_t = p \cdot t = B \cdot \delta \cdot \rho \cdot V_0 \cdot t, \,, \qquad (11)$$

where: t – dosing operation time, p – product feed intensity; B – product stream from the feeder width.

$m_t \cdot g$ value defines the product mass that we have in the container. So when the feeder will stop the sensor will take load:

$$F_\Sigma = F_d + M_d \cdot g \,, \qquad (12)$$

where: M_d – specified dose mass.

Forming and weighing of the dose are made in time, so the main part of total force on weight sensor, which will have influence on dosing accuracy, is the dynamic pressure of the product on the weighing container.

Dynamic pressure value depending on the product flow can be calculated as:

$$F_t = p \cdot V_y = B \cdot \delta \cdot \rho \cdot V_0 \cdot V_y, \qquad (13)$$

where: V_y – product flow speed in time when it contacts with the product in container, V_0 – feeder product speed.

F_t value views external force on the weight sensor, but it doesn't view real quantity of the product that will move to the container after the stop of the feeder. To ensure complaints of two loads it is needed to:

$$F_t = m_0 \cdot g, \qquad (14)$$

where: m_0 – product mass, which is moving after feeder stop.

For dosing machines scheme on fig.5:

$$m_0 = B \cdot \delta \cdot \rho \cdot y. \qquad (15)$$

Then, after expression simplification (13, 14, 15) equation to define the end value of the producte layer, which will move to the weighing container will take the next view:

$$y_k = V_0 \cdot V_y \; / g. \qquad (16)$$

Rational placing of the weighing container relative to working surface of the product movement, can be calculated:

$$y_0 = y_k \; + (2 \,/\, 3)\, H \,. \qquad (17)$$

The end value of the product layer, which moved to weighing container, relatively to working surface of the product movement with a respect to equation (16) can be calculated as:

- vibrator feeder:

$$y_k = \lambda \cdot V_0^2 \; \cdot \{\lambda + [\, (\, \lambda^2 + \sin^2(\, \alpha\,)\,]^{\,0,5}\} \,/\, g\,; \qquad (18)$$

- belt feeder:

$$y_k = (\lambda \cdot V_0)^2 / g + R - \pi \cdot (0,5\pi - \alpha) / (2\pi) \times ...$$
$$... \times (\delta + 2R) + \lambda \cdot V_0 \cdot [V_0^2 \cdot (1 + \lambda^2) - ... \qquad (19)$$
$$... - 2\pi \cdot g \cdot (0,5\pi - \alpha) / (2\pi) \cdot (\delta + 2R) + ...$$
$$... + 4g \cdot R \cdot \sin^2(0,5\alpha)\,]^{0,5} / g .$$

where: λ – product flow air resistance coefficient; V_0 – approximated product feeding speed by the working element of the feeder; α – feeder angel relative to the horizon; H – weighing container height; R – driven drum radius of belt feeder; δ – product layer height on the feeder; g – gravity acceleration.

By numerical calculation results of equations (18) and (19) it is defined that the key parameter that defines the rational placing of the weighing container (fig. 6) is the production flow speed when it converge with the carrier plane of the feeder.

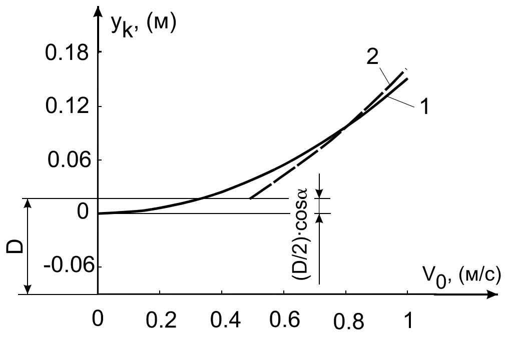


Figure 6. *Weighing container rational* placing *change depending on the product flow speed:*
1 – vibrator;
2 – belt (angel relative to the horizon α = 6°)

Weighing container rational placing deviation relatively to working surface of the product movement decreases dosing accuracy. Modeline part of the dynamic error:

- vibrator feeder:

$$\varepsilon = \gamma \cdot \delta \cdot B \,\big|\, y \cdot g - \lambda \cdot V_0 \cdot (V_0^2 \cdot \sin^2\alpha + ...$$
$$... + 2 \cdot y \cdot g)^{0.5} \,\big|\, / (M_{\text{д}} \cdot g) \cdot 100; \qquad (20)$$

- belt feeder:

$$\varepsilon = \gamma \cdot \delta \cdot B \cdot \big|\, \lambda \cdot V_0 \cdot [V_0^2 + 2 \cdot g \cdot (y - ...$$
$$... - R \cdot \cos\alpha)]^{0.5} - g \cdot (y - R + ... \qquad (21)$$
$$... + (0,5 \cdot \pi) / (2 \cdot \pi) \cdot (2 \cdot \pi \cdot R + ...$$
$$... + \pi \cdot \delta) \,\big|\, / (M_{\text{д}} \cdot g) \cdot 100,$$

b – feeder tray width; $M_{\text{д}}$ – product dose weight.

III. Conclusions

Created shutter movement mathematics model enables to realize rational working mode of leaner weight dosing machine. Also, as a result of rational placing of weighing container it's possible to minimize the influence of one of the dynamic dosing error parts. One of the technical decisions to regulate the weighing container position relative to feeder working element, can be the installation of weighing system on driven moving guides by which the control is realized.

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