Studiing of the viscous food producnts dosing accuracy by the piston batcher

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Abstract. *Were provided the research of plug-forming devices gaps size, technological mistakes, and mounting type of kinematic couples and parts of the actuator, influence on dosing systematic error.*

Key Words: batcher, dosing accuracy, systematic error, primary errors, viscous products.

Dosing accuracy – one of the main characteristics for any batcher, it's his ability to assure the error size lower then allowable, when the moving lows are specified and the input sections moves with errors.

There are several requirements for dosing accuracy, depending on product type and dose size. Also there are a lot of factors that can effect on the accuracy, such as hopper filling degree, uneven supply of the product to the dosing mechanism, the character of interaction of product and dosing mechanism, the changes of product characteristics in dosing process under the environment influence. Also it can be mounting incorrectness of the kinematic pars, deformation of the parts of the machine and speed difference of input section, speed and acceleration of output sections is different against ideal, it's also have influence on the dosing accuracy. The difference in kinematic parameters and the positioning of driven section are caused by technological inaccuracies of dimensions, forms of the relative positioning of kinematic pars elements and sections, that is, the primary errors, operation errors, dynamic errors and also structural errors.

Dosing error it's the difference between the real and the estimated (ideal) value of the product dose. Estimation of the accuracy is providing in percent ratio of nominal dose.

Calculation of absolute dosing error:

$$\Delta = \Delta_{cucm} + \Delta_{вип}, \quad (1)$$

де $\Delta_{сист}$ - systematic error;

$\Delta_{вип}$ - accidental error.

Systematic measurement error - error, that mostly lives unchanged or that changes in order of remeasure and depends from the technical parameters of dosing system. Accidental error – error that is permanently different (by the value and sign) in measurement process and depends on

subjective and objective factors of product interaction with technological dosing system and operator functioning.

Now days error calculation methods, their influence on the kinematics and dynamics of dosing mechanism, methods of their compensation and reduction and also the main tasks of accuracy analysis and synthesis of mechanisms, are based on mechanism accuracy theory, probability theory and mathematic statistics [2].

In some constructions of dosing equipment when performing the comparing calculations, it's needed to find out the mechanism section movement error, which is understand as the difference of driven section movement of real and ideal mechanism under the same movement of driving sections.

If the movement error is repeated in one of the position of driving section, but in different movement direction than the expression

$$\Delta\psi_{пр} = \Delta\psi_{к} - \Delta\psi_{п}, \quad (2)$$

were $\Delta\psi_{пр}$ - movement error of driven section,

$\Delta\psi_{п}$ - start movement error of driven section,

$\Delta\psi_{к}$ - end movement error of driven section,

determines the free (dead) stroke of the mechanism, which appears by reason of gaps presence in kinematic pars or spring strain of the sections.

For the determination of systematic error the analytical method of mechanism accuracy analysis can be used. The coordinate of driven section of ideal mechanism will be ψ_0, driving section – ψ and the matrix parameter of sections – q_j, where $j = 1,2\ldots$ - the index number of section. Coordinates ψ_0 and ψ can be linear and angular.

In ideal mechanism with the main ties, ψ_0 coordinate have the functional dependence of several variables (but not speeds):

$$\psi_0 = \psi_0(\varphi, q_1, q_2, \ldots q_n), \quad (3)$$

Where $q_1, q_2, \ldots q_n$ determine the size, form and interposition mechanism sections. Because of the presence of primary errors Δq_j the parameters of real mechanism is not the same with ideal mechanism parameters, and so the position of the real mechanism are determined by coordinate

$$\psi = \psi_0 + \Delta\psi_{вм} = \psi(\varphi + \Delta\varphi, q_1 + \Delta q_1, + \ldots +, q_n + \Delta q), \quad (4)$$

where $\Delta\psi_{ВМ}$ - the real mechanism driven section position error;

$\Delta\varphi$ - driving section position error.

Mostly the Δq_j error is not bigger then section sizes allowance, it means that it's much smaller then q_j parameter. Considering relatively small values of $\Delta\varphi$ i Δq_j, let's expand the function in to Teylor's line, limiting only it's zero and linear parts, receiving:

$$\psi = \psi_0 + \Delta\psi_{вм} = \psi_0(\varphi, q_1, \ldots, q_n) + \left(\frac{\partial\psi}{\partial\varphi}\right)_0 \Delta\varphi + \sum_{j=1}^{n}\left(\frac{\partial\psi}{\partial q_j}\right)_0 \Delta q_j, \quad (5)$$

Where from we will find approximate expression to define the real mechanism position error:

$$\Delta\psi_{ВМ} = \left(\frac{\partial\psi}{\partial\varphi}\right)_0 \Delta\varphi + \sum_{j=1}^{n}\left(\frac{\partial\psi}{\partial q_j}\right)_0 \Delta q_j. \quad (6)$$

Real mechanism position error with ideal scheme:

$$\Delta\psi = \sum_{j=1}^{n}\left(\frac{\partial\psi}{\partial q_j}\right)_0 \Delta q_j, \quad (7)$$

position error, are caused only by primary error $\Delta q_К$ of $q_К$ parameter:

$$\Delta\psi_К = \sum_{j=1}^{n}\left(\frac{\partial\psi}{\partial q_К}\right)_0 \Delta q_К. \quad (8)$$

Proceeding from upper reflections the conclusion can be made that, partial derivative:

$$\left(\frac{\partial\psi}{\partial q_К}\right)_0 = \frac{\Delta\psi_К}{\Delta q_К}, \quad (9)$$

are gear ratio of the error $\Delta\psi_К$ from driven section to $q_К$ section, that contains error $\Delta q_К$.

Practical application of such error definition methodic we will consider on constructive scheme of piston batcher example. For viscous and plastic products (fig.1) and will define dosing systematic error value, having no primary errors.

For such scheme $q_i = f(a, b, \alpha, \beta)$

$$\Delta X_c = (\Delta X_c)_a + (\Delta X_c)_b + (\Delta X_c)_\alpha + (\Delta X_c)_\beta \quad (10)$$

For defining of mechanism driven section movement error we will wright an expression for defining X_C coordinate:

$$X_C = b \cdot ños\beta \pm a \cdot \sin\alpha, \quad (11)$$

where "+" – for first quarter of coordenats system;

"-" – for second quarter of coordenats system (fig.1).

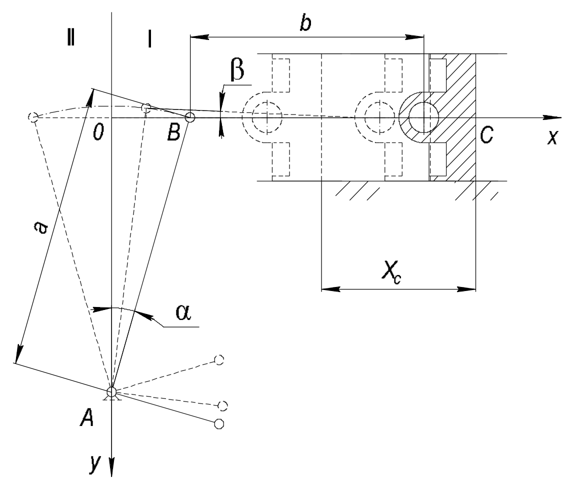

Fig.1. Construction scheme of piston batcher for viscous food products: d – piston diameter: a, b – section length; α, β – angels at sections; X_C – driven section movement.

For the further calculations we will use the following relation:

$$\beta = \arcsin\left(\frac{a \times \cos\alpha - h}{b}\right). \quad (12)$$

Movement error caused by rocker length a difference:

$$(\Delta X_C)_a = \frac{\partial X_C}{\partial a} \cdot \Delta a, \qquad (13)$$

where Δa - rocker length difference error (including size lines allowance and boundary deviation plantings of kinematic pars)

$$(\Delta X_C)_a = \pm \sin\alpha \cdot \Delta a. \qquad (14)$$

Bell crank length difference b:

$$(\Delta X_C)_b = \frac{\partial X_C}{\partial b} \cdot \Delta b, \qquad (15)$$

where Δb - crossbeam length difference error (including size lines allowance and boundary deviation plantings of kinematic pars).

$$(\Delta X_C)_b = \cos\beta \cdot \Delta b. \qquad (16)$$

Error from rocker position angel α:

$$(\Delta X_C)_\alpha = \frac{\partial X_C}{\partial \alpha} \cdot \Delta\alpha, \qquad (17)$$

$$(\Delta X_C)_\alpha = \pm a \cdot \cos\alpha \cdot \Delta\alpha. \qquad (18)$$

Error from crossbeam position angel β:

$$(\Delta X_C)_\beta = \frac{\partial X_C}{\partial \beta} \cdot \Delta\beta, \qquad (19)$$

$$(\Delta X_C)\beta = -b \cdot \sin\beta \cdot \Delta\beta. \qquad (20)$$

Then the total driven mechanism element position error will be defined by the expression:

$$\Delta X_c = (\Delta X_c)_a + (\Delta X_c)_b + (\Delta X_c)_\alpha + (\Delta X_c)_\beta = \\ = \pm \sin\alpha \cdot \Delta a + \cos\beta \cdot \Delta b \pm \\ \pm a \cdot \cos\alpha \cdot \Delta\alpha - b \cdot \sin\beta \cdot \Delta\beta. \qquad (21)$$

Error value defines by next terms: parts of the batcher (rocker, crossbeam) are made by workmanship 7-10; loose fit kinematic pars, 7-10 workmanship (fit H7/f7, H78/f8, H9/f9, H9/f9 for slide bearings) [1]; the error value for modern packing equipment is approximately ±1% (that means the systematic error is approximately ≈0,1%) from dose value [5]; Calculation results are displayed in graph (fig. 2). When the crankgear mechanism batcher is used the accuracy of his sections and kinematic pars must be at lest 7 – 8 workmanship with respective fits.

Transportation of the product to the container are provided through output channel of piston batcher (fig. 3). Some parts of the products can go through the gaps between the body parts of batcher and stop elements.

Whereas the transverse gap size is small and the viscosity of the product is high, the leakage from the gap can be called crawling flat [4]. To make the calculations easier, we will take that product movement through the pap is permanent, so we can ignore the lag.

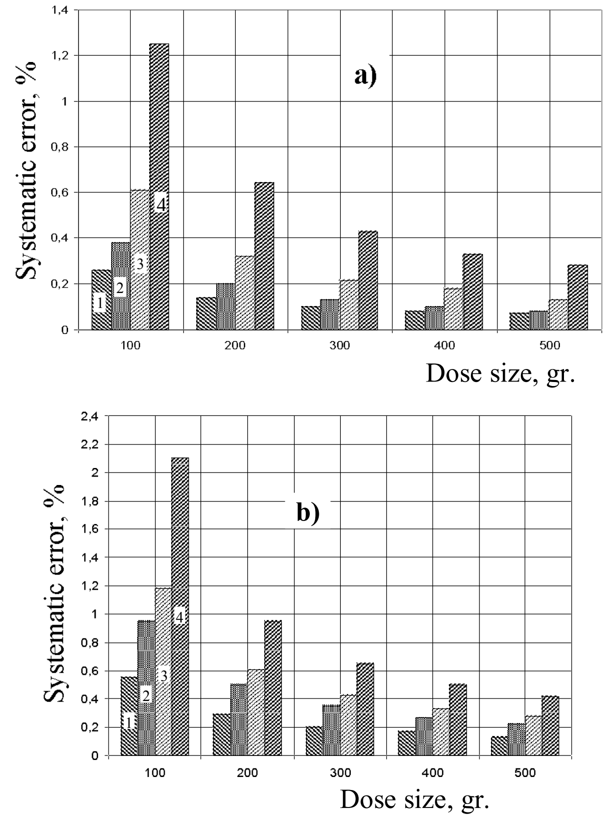

Fig.2. The dependence of dosing systematic error from batcher elements manufacturing accuracy with different dose value: a – minimum boundary deviation; b – maximum boundary deviation; 1 – 7 workmanship; 2 – 8 workmanship; 3 – 9 workmanship; 4 – 10 workmanship.

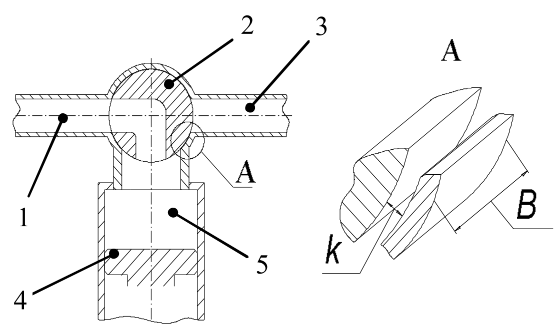

Fig. 3. Principle scheme of a batcher with stop ball valve: 1 – output channel; 2 – ball valve; 3 – input channel; 4 – piston; 5 – measure cylinder; k – gap height; B – gap width.

Velocity distribution in product layer is calculated by the next expression:

$$V_x = \frac{1}{2\cdot\mu}\cdot\frac{dp}{dx}y^2 + C_1\cdot y + C_2, \qquad (22)$$

where x i y – coordinates by height and width, μ - dynamic velocity value.

Boundary terms:

- $V_x = 0$, $V_y = 0$ when y = 0,
- $V_x = 0$, $V_y = 0$ when y = k,

where k – gap height, calculate the constants C_1, C_2 substituting the boundary terms in to expression(22): $C_1 = -\frac{k}{2\times\mu}\cdot\frac{dp}{dx}$, $C_2 = 0$.

Velocity distribution in product layer low will be expressed as: [3]:

$$V_x = \frac{1}{2\times\mu}\cdot\frac{dp}{dx}\cdot y^2 - \frac{k}{2\times\mu}\cdot\frac{dp}{dx}\cdot y = \frac{1}{2\times\mu}\cdot\frac{dp}{dx}\cdot y\cdot(y-k) \qquad (23)$$

By using expression (23) we can calculate the required consumption of the product, considering the term that main movement direction is coaxial with environment movement, along the top of the gap:

$$q = -\int_0^k V_x dy = -\int_0^k \frac{1}{2\times\mu}\cdot\frac{dp}{dx}\cdot y\cdot(y-k)dy = -\frac{1}{2\times\mu}\cdot\frac{dp}{dx}\cdot\left(\int_0^k y^2dy - \int_0^k y\cdot hdy\right) = \frac{k^3}{12\cdot\mu}\cdot\frac{dp}{dx}. \qquad (24)$$

From this expression we can define product consumption from the gap, accepting, that consumption is defined as multiplication of required consumption and gap width:

$$dp = \frac{12\cdot Q_{\hat{a}\tilde{o}\grave{u}}\cdot\mu}{k^3\cdot d}dx, \qquad (25)$$

That means

$$Q_{\hat{a}\tilde{o}\grave{u}} = \frac{k^3{}_{\hat{a}\tilde{o}\grave{u}}\cdot d_{\hat{a}\tilde{o}\c{c}}}{12\cdot\mu\cdot\hat{A}_{\hat{a}\tilde{o}\grave{u}}}\cdot(Đ_{\hat{a}\tilde{o}\grave{u}} - Đ_{\hat{a}\hat{u}\tilde{o}\grave{u}}), \qquad (26)$$

where $Q_{вхщ}$ – product consumption through the gap;

$B_{вхщ}$ – gap length;
$k_{вх\ щ}$ – gap height;
$P_{вхщ}$ – pressure on the inlet to the gap;
$P_{вих\ щ}$ – pressure on the outlet to the gap.

Product quantity, which will move from cylinder through gap, will be defended as:

$$Q_{\hat{a}} = Q_{\hat{a}\tilde{o}\grave{u}}\cdot t_{\ddot{a}\hat{i}\c{c}}, \qquad (27)$$

where $t_{доз}$ – time to push out the product from measure cylinder

By the time of calculation we will accept that product width in the gap is equal to ball valve working part width. Pressure on the inlet of the gap will be:

$$P_{вхщ} = \Delta P_п - \Delta P_{1вих} - \Delta P_{мвих}, \qquad (28)$$

where $\Delta P_п$ – pressure, made by the piston;
$\Delta P_{1вих}$ – pressure drop on exhaust valve;
$\Delta P_{мвих}$ – pressure drop caused by constriction of exhaust channel.

Knowing the pressure value of the gap on the inlet and outlet, we can define product loss through the gap between the body and valve ball. Knowing the dosing time and product loss through the gap, we can define the product loss. By using the expression (27), will define batcher error for deferent kinds of viscous products (fig. 4).

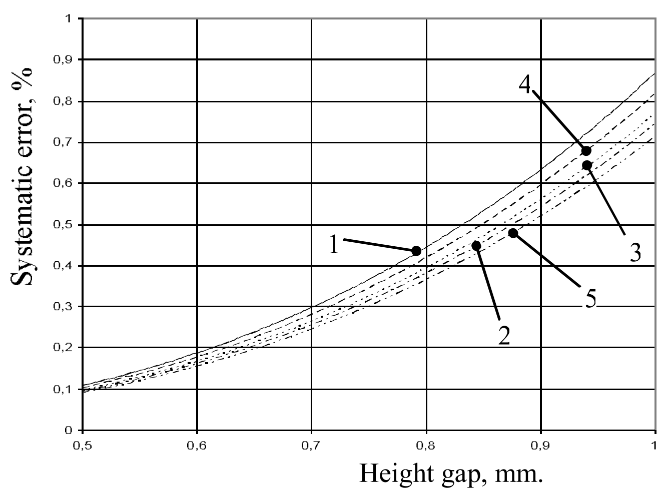

Fig. 4. Dependence character between the dosing systematic error and gap size (dose mass 250 gr.): 1 – evaporated milk; 2 – cream; 3 – melted cheese "Дружба"; 4 – melted cheese "Хрещатик"; 5 – mayonnaise "Оливковий".

Conclusions.

On the ground of studies been made, the character of dosing systematic error and manufacturing accuracy of working mechanism dependence, have been defined. When using the crankgear mechanism as the working mechanism of the batcher, manufacturing accuracy of the sections and kinematic pars must be 7 – 8 workmanship with respective fits. Dosing error value is equal to the product volume which went through exhaust valve. Considering this, the fewer will be the error or product volume which went through exhaust valve, which is the same, the greater will be the accuracy of the batcher. Knowing the properties of the product, which is packed and also a constructive parameters of batcher, we can define the value of product losses or dosing error at the product dosing time; also if we know the rheological properties of the product and dosing accuracy which is needed, on the ground of calculation been made, we can define the allowable value of the gap between valve ball surface and cylinder body, which will give the opportunity to avoid product loss to inlet valve.

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