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SIMULATION OF THE PROCESS OF OBTAINING HIGH-QUALITY MIXTURES USING A CONVEYING AND METERING MACHINE

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Abstract:

Using a mathematical analysis of the theory of random functions, a mathematical model is obtained for assessing the quality of operation of a conveying and metering machine for various schemes for the formation of a feed monolith in its bunker. The calculated and actual values of the indicator for assessing the quality of the working process of the proposed machine are given.

Keywords: *flow, feed, transformation, correlation function, probability, estimation, model.*

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INTRODUCTION:

Analysis of previous studies, as well as practice, showed that feed flows obtained using feed preparation and dosing machines have a high uneven distribution of mass along their length, which significantly affects the quality of mixing of components, as well as dosing accuracy [1, 2].

In this case, the quality assessment of these processes is carried out using the coefficient of variation – ν, characterized by dispersion - D or standard deviation - δ

$\nu = \frac{\delta}{\bar{q}} \cdot 100\%,$

where$\bar{q}$ – average value of mass, feed or energy value, protein, fat, vitamins, etc.

The lack of analytical models for assessing the quality of mixing and dosing processes during the transformation of the flow system makes it difficult to design highly efficient innovative methods and machines for the needs of animal husbandry.

The aim of the research is to obtain mathematical models that characterize the methods of transformation of the flow system, in terms of improving their quality indicators.

Research tasks:

- on the basis of the proposed scheme of transformation of the flow system, obtain an analytical model characterizing the degree of alignment of fluctuations in the qualitative composition of the product depending on the number of stacked layers in the prismatic tank of the transporting and metering machine;
- obtain an analytical model for estimating the leveling ability of a circuit with inclined stacking of layers;
- obtain an analytical model for assessing the leveling ability of the circuits that provide horizontal laying of layers by the translational and reciprocating formation of the monolith.

MATERIALS AND METHODS:

The analysis found that one of the ways to improve the quality indicators of the dosing processes and the production of mixtures can be the implementation of the filling process of the bins of the conveying and metering machine (CMM) by layering the product stream. In this case, it is assumed that in the process of layer-by-layer filling of the prismatic capacity of the CMM bunker, leveling (smoothing) of fluctuations in the qualitative and quantitative composition of the product stream to be transformed in time and space occurs.

If we denote by q (l) a specific implementation of the random function G (l) on the interval of the length of the flow Z, then the expectation M (q), the coefficient of variation νand correlation function $K_q(\Delta l)$, where$\Delta l = l_2 – l_1$, can be defined as

$M(q) = Z^{-1}\int_o^z q(l)dl\ ;$ (1)

$\nu = \left\{Z^{-1}\int_o^z [q(l) - M(q)]^2 dl\right\} \cdot q^{-1};$ (2)

$K_q(\Delta l) = (Z - \Delta l)^{-1}\int_o^{Z-\Delta l}[q(l) - M(q)][q(l + \Delta l) - M(q)] \cdot dl.$ (3)

Based on this approach, a working hypothesis was developed about the possibility of reducing the deviations of the control component and the mass of the feed mixture from the nominal values in the output stream from the CMM bunker due to the alignment of their oscillations in the input stream, by breaking it and layering in a prismatic CMM tank.

Considering the above, this scheme can be implemented in accordance with Figure 1.

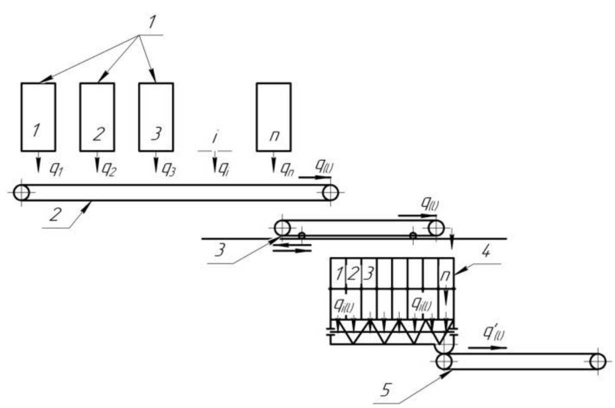

Figure 1: Flow pattern at the exit from the CMM

RESULTS AND DISCUSSION:

The formation of the output stream at the outlet of the prismatic tank is carried out by simultaneous or sequential feeding of feed components from feeders 1 to conveyor 2 and, further, to conveyor 3, reciprocating relative to the tank and feeding feed into it, presented as a random function q (l) At the same time, a monolith is formed in the tank with a vertical arrangement of the layers, with their number equal to n and the length$\Delta Z \cdot n$, moreover, after the end of the formation of the first monolith, on its surface is formed similarly to the second, and so on At the same time, vertically located layers of feed are continuously fed to the auger, which produces the transportation of feed to the animals for distribution (certificate of authorship No. 1565436). As a result of receipt of the feed product on the screw and further, on the conveyor-feeder - 5, the vibrations of the qualitative composition and mass of the feed mixture level off with the formation of a random process:

$q'(l) = \frac{1}{n}\sum_{i=1}^{n} q(l)$ (4)

For this process$q'(l)$ and two arbitrary sections of the flow l_1 and l_2, the correlation function is:

$K'q(l_1; l_2) = n^{-2}\left\{\sum_{i=1}^{n} K_{q_i}(l_1; l_2) + \sum_{\substack{i=1 \\ i \neq j}}^{n} \sum_{j=1}^{n} R_{q_i q_j}(l_1; l_2)\right\}$, (5)

where$K'_q(l_1; l_2)$ – process correlation function$q_i(l)$;

$R_{q_i q_j}(l_1; l_2)$ – cross correlation function of processes$q_i(l)$ and$q_j(l)$.

By definition, the mutual correlation function (3) we have

$R_{q_i q_j}(l_1; l_2) = M\left\{\left[q_i(l_1) - M \cdot \left[q_j(l_2) - M \cdot \left[q_j(l_2)\right]\right]\right]\right\}$(6)

For random processes $q_i(l)$, the following relation holds

$M[q_i(l_1)] = M\left[q_j(l_2)\right] = \bar{q}$, (7)

where$\bar{q}$ – average value.

Then expression (6) can be rewritten as follows

$R_{q_i q_j}(l_1; l_2) = M\{[q_i(l_1) - \bar{q}]\left[q_j(l_2) - \bar{q}\right]\}$ (8)

Consider the cross section $l_1$and$l_2$at a distance of not more than one interval$\Delta Z \cdot n$, those.

$l_2 - l_1 \leq \Delta Z \cdot n$ (9)

According to this condition$l_1$and$l_2$are within the horizontal monolith and within$\Delta Z \cdot n$.

Denote the probability$P\{[l_1; l_2] \not\subset \Delta Z \cdot n\}$finding sections and$l_2$ within adjacent feed monoliths through$P(l_1; l_2)$

$P\{[l_1; l_2] \not\subset \Delta Z \cdot n\} = P(l_1; l_2)$ (10)

Then the probability$P\{[l_1; l_2] \not\subset \Delta Z \cdot n\}$ finding sections$l_1$and$l_2$within a single feed monolith

$P\{[l_1; l_2] \not\subset \Delta Z \cdot n\} = 1 - P(l_1; l_2)$ (11)

For arbitrary sections$l_1$and$l_2$provided that

$l_2 - l_1 \leq \Delta Z \cdot n$

probability is equal

$P(l_1; l_2) = \frac{l_2 - l_1}{\Delta Z \cdot n} = \Delta l \cdot (\Delta Z \cdot n)^{-1}$(12)

whereΔl – correlation interval.

Then

$1 - P(l_1; l_2) = 1 - \Delta l \cdot (\Delta Z \cdot n)^{-1}$ (13)

Using equation (8), the cross-correlation function is presented as

$R_{q_i q_j}(l_1; l_2) = K_q\left[(j - i)\Delta Z + \frac{\Delta l}{n}\right]$ (14)

provided that$[l_1; l_2] \subset \Delta Z \cdot n$

$R_{q_i q_j}(l_1; l_2) = K_q\left[sign(\Delta l)(n - 1)\Delta Z + (j - i)\Delta Z + \frac{\Delta l}{n}\right]$ (15)

provided that$[l_1; l_2] \not\subset \Delta Z \cdot n$,

where$sign(\Delta l)\begin{cases} 1\ at\ \Delta l > 0 \\ 0\ at\ \Delta l = 0 \\ -1\ at\ \Delta l < 0 \end{cases}$ (16)

Using expressions (12-15) and the total probability formula (4), the cross-correlation function$R_{q_i q_j}(l_1; l_2)$can be represented through the correlation function$K_q(l)$ original random process$q(l)$

$R_{q_i q_j}(l_1; l_2) = (1 - \frac{\Delta l}{\Delta Z \cdot n})K_q[(j - i)\Delta Z + \frac{\Delta Z}{n} + \frac{\Delta l}{\Delta Z \cdot n} \times$

$\times K_q\left[sign(\Delta l)(n - 1)\Delta Z + (j - i)\Delta Z + \frac{\Delta l}{n}\right]$(17)

at $\Delta l \leq \Delta Z \cdot n$

For arbitrary l_1 and l_2 cross correlation function

$$R_{q_iq_j}(l_1;l_2) = \left(1 - \frac{\Delta l - k\cdot\Delta Z\cdot n}{\Delta Z\cdot n}\right)K_q[sign(\Delta l)\cdot k\cdot(n-1)\Delta Z +$$
$$+(j-i)\Delta Z + \Delta l/n] + \frac{\Delta l - k\cdot\Delta Z\cdot n}{\Delta Z\cdot n}K_q[sign(\Delta l)\times$$
$$\times(k+1)(n-1)\Delta Z + (j-i)\Delta Z + l/n], \qquad (18)$$

where $k\cdot\Delta Z\cdot n \le \Delta l \le (k+1)\Delta Z\cdot n$; $k = 1,2,3,\ldots$

Correlation function $K_q(l_1;l_2)$ at the outlet of the container of the dispenser we obtain from the expressions (5) and (18)

$$K'q(l_1;l_2) = K_q(\Delta l) = \frac{1}{n^2}\sum_{i=1}^{n}\sum_{j=1}^{n}\left\{\left[1 - F(\frac{\Delta l}{\Delta Z\cdot n})\right]\times K_q[sign(\Delta l)E(\frac{\Delta l}{\Delta Z\cdot n})\times\right.$$
$$\times(n-1)\Delta Z + (j-i)\Delta Z + \frac{\Delta l}{\Delta Z\cdot n}] + F\left(\frac{\Delta l}{\Delta Z\cdot n}\right)K_q[sign\,\Delta l\times E\left(\frac{\Delta l}{\Delta Z\cdot n}\right)+1]\times$$
$$\left.\times(n+1)\Delta Z + (j-i)\Delta Z + \frac{\Delta l}{n}]\right\}, \qquad (19)$$

where $F(q)$ and $E(q)$ – functions that represent the fractional and integer parts of q, respectively.

Analysis of expression (19) shows that the correlation function at the outlet of the capacitance depends on the correlation function of the original flow $K_q(\Delta l)$, length of the vertical layer ΔZ, number of vertical layers n of the feed product, as well as the interval of correlation. Expression (19) allows us to obtain a formula for determining the coefficient of variation of the qualitative and quantitative composition of the feed mixture. By taking the correlation interval to be $\Delta l = 0$, will get

$$\nu = \left\{n^{-2}\sum_{i=1}^{n}\sum_{j=1}^{n}\{K_q[j-i]\Delta Z\}\right\}^{0,5}q^{-1} \qquad (20)$$

By limiting fluctuations in the quality and quantity of the product $[\nu]$, it is possible to determine the minimum required number of layers of the feed product, at which the fluctuations will not exceed the allowable according to the zootechnical requirements

$$n_{min} = \left\{[\nu]^{-1}\sum_{i=1}^{n}\sum_{j=1}^{n}\{K_q[j-i]\Delta Z\}\right\}^{0,25}q^{-1} \qquad (21)$$

By approximating the correlation function by the expression

$$K_q(\Delta l) = D_{(q)}\cdot e^{-\alpha/\Delta l/}\cdot\cos\beta\cdot\Delta l \qquad (22)$$

and accepting $\Delta l = 0$, get an expression to determine the coefficient of variation of the quantitative and qualitative composition of the feed product at the outlet of the CMM, depending on the fluctuations in the input streams

$$\nu = n^{-2}\cdot\left\{\sum_{i=1}^{n}\sum_{j=1}^{n}D_{(q)}b_{xij}\right\}^{0,5}q^{-1} \qquad (23)$$

Taking this approach into account, a method has been developed for leveling fluctuations in the qualitative and quantitative composition of products according to the scheme presented in Figure 2.

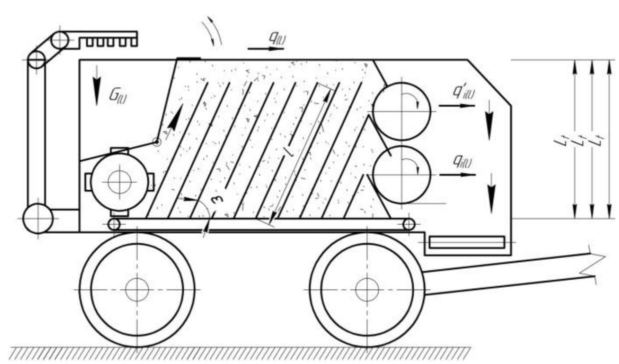

Figure 2: CMM filling scheme with sloping layers

It is realized by feeding the feed product into the bunker from the rear wall or the tines until a primary cone forms with a base angle equal to the angle of repose of the feed, and then moving it or the initial feed stream along the bunker. As a result of this movement, a monolith is formed with an inclined arrangement of layers placed parallel to the generator of the primary cone.

The alignment of the fluctuations of the quantitative composition of the feed product is carried out by shifting the layers by

$l' = H/\sin\varepsilon'$, (24)
where H - is the height of the formed feed monolith;
ε' - angle of repose feed in motion.
For this scheme, the correlation function at the output from the capacitance is determined by expression (5).

At the same time, the cross-correlation function $R_{q_iq_j}(l_1; l_2)$, part of expression (5), can be represented as

$R_{q_iq_j}(l_1; l_2) = K_q[\Delta l + (j-k)l']$ (25)

Substitute the expression (25) in the expression (5), we obtain the correlation function at the output from the capacitance CMM

$K'q(l_1; l_2) = K_q(\Delta l) = n^{-2}\cdot\{n\cdot K_q(\Delta l) + \sum_{i=1}^{n}\sum_{j=1}^{n} K_q[\Delta l + (j-k)l']\}$ (26)

Expression (26) can be converted to

$K_q(\Delta l) = n^{-2}\cdot\{n\cdot K_q(\Delta l) + \sum_{K=1}^{n-1}(n-K)[K_q(\Delta l + kl') + K_q(\Delta l + kl')]\}$ (27)

From this expression, you can determine the coefficient of variation at the outlet of the distributor's bunker

$$\nu = \left\{n^{-2}\cdot\left[n\cdot K_{q(0)} + \sum_{K=1}^{n-1}(n-K)\cdot K_q(kl')\right]\right\}^{0,5} q^{-1} =$$

$= \{n^{-2}\cdot[2\sum_{K=1}^{n-1}(n-K)\cdot K_q(kl') - n\cdot K_{q(0)}]\}^{0,5} q^{-1}$(28)

Analysis of the expression shows that the coefficient of variation at the exit from the distributor's bunker depends on the same factors as in the previous scheme.

From the expression (27) you can find the limit value of the correlation function (28)

$$K_q^o(\Delta l) = \lim_{n\to\infty} K'_q(\Delta l) = \frac{1}{\Delta Z\cdot n}\int_o^{\Delta Z\cdot n}(1 - \frac{l}{\Delta Z\cdot n})\times$$

$\times[K_q(\Delta l + l) + K_q(\Delta l - l)]\cdot dl$ (29)

At $n\to\infty$ variation coefficient of the random process is determined

$\nu = \left\{2(\Delta Z\cdot n)^{-1}\int_o^{\Delta Z\cdot n} K_q(\Delta l)\left(1 - \frac{l}{\Delta Z\cdot n}\right)dl\right\}^{0,5}\cdot q^{-1}$ (30)

When the CMM hopper is filled with horizontal layers in the forward mode of their formation, the flow transformation is provided by breaking the initial flow into segments of length ΔZ, equal to the length of the bunker, parallel to their laying in it on each other with a mixture of ends and began segments ΔZ (figure 3).

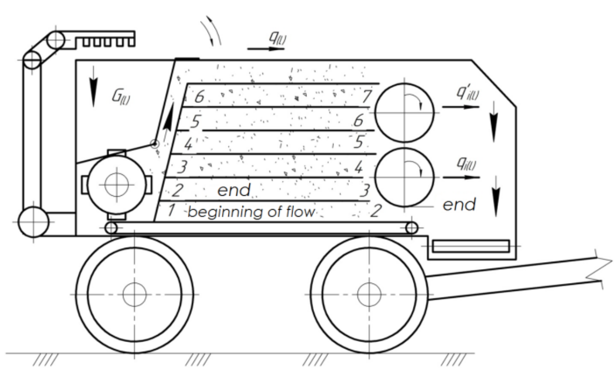

Figure 3: Layer-by-layer diagram of the CMM bunker with horizontal layers

The leveling ability of this filling method can be estimated using the mathematical model (19). By adopting a correlation interval $\Delta l = 0$, we obtain an expression for determining the coefficient at the exit from the CMM bunker (expression (20)).

Putting in it $|j-i| = K$ and using the honesty property of the correlation function $K_q(\Delta l)$, bring it to mind

$\nu = \left\{0,5\cdot\{2\cdot\sum_{K=1}^{n-1}(n-K)\cdot K_q[K\Delta Z - n\cdot K_{q(0)}]\}\right\}^{0,5} q^{-1}$ (31)

From the expression (31) it follows that the coefficient of variation at the exit from the CMM bunker when implementing this scheme with a horizontal arrangement of layers is determined by the correlation function of the source stream $K_q(\Delta l)$ and depends on the number of layers - n. This filling method ensures equalization of the quality of the feed product and mass deviations due to the shift of the initial flow segments by an amount equal to the length of the bunker. ΔZ. Analysis of dependence (31) also shows that the efficiency of alignment of vibrations is more influenced by the correlations between less distant cross sections of the feed flow. If a ΔZ exceeds the correlation interval of the original feed flow, then $K_q(K\Delta Z) = 0$ in this case, expression (31) is transformed into expression (23).

Assume that $\Delta Z \approx 0$, which corresponds to filling the bunker with short layers. Then at $\Delta Z = 0$ $K'_q(\Delta l) = K_q(\Delta l)\nu_{out} = \nu_{in}$That is, the scheme in this case does not provide for equalization of fluctuations in the qualitative composition and deviations of the mass of the feed product.

Using the mathematical model (19), an expression was obtained for the correlation function for a certain bunker length and an infinitely large number of layers

$$K_q^o(\Delta l) = \lim_{n\to\infty} K'_q(\Delta l) = \frac{1}{\Delta Z \cdot n}[1 - F(\frac{\Delta l}{\Delta Z \cdot n}) \cdot \int_o^{\Delta Z \cdot n} (1 - \frac{\Delta l}{\Delta Z \cdot n}) \times$$

$$\times \left\{K_q\left[sign(\Delta l)E\left(\frac{\Delta l}{\Delta Z \cdot n}\right) + l\right] + K_q \cdot \left[sign(\Delta l)E\left(\frac{\Delta l}{\Delta Z \cdot n}\right)\Delta Z \cdot n - l\right]\right\}dl +$$

$$+\frac{1}{\Delta Z \cdot n}F(\frac{\Delta l}{\Delta Z \cdot n})\int_o^{\Delta Z \cdot n}\left(1 - \frac{\Delta l}{\Delta Z \cdot n}\right) \times \{K_q[sign(\Delta l) \times [E\left(\frac{\Delta l}{\Delta Z \cdot n}\right) + 1 \times$$

$$\times \Delta Z \cdot n + l] + K_q \cdot \left[sign(\Delta l) \times [E\left(\frac{\Delta l}{\Delta Z \cdot n}\right) + 1\right]\Delta Z \cdot n - l]\} \cdot dl \quad (32)$$

Substituting in the expression (32) value$\Delta l = 0$, get the expression to determine the coefficient of variation

$$\nu = \left\{\lim_{n\to\infty} K'_q(o)\right\}^{0,5} q^{-1} = \left\{\frac{2}{\Delta Z \cdot n}\int_o^{\Delta Z \cdot n}(1 - \frac{l}{\Delta Z \cdot n})K_q(l)dl\right\}^{0,5} q^{-1} \quad (33)$$

Analysis of the expression (33) shows that with increasing number of layers$K'_q(\Delta l)$andνquickly strive for their limiting values.

When the distributor bin is filled with horizontal layers during a reciprocating mode of their formation, a feed monolith is formed without breaking the initial feed stream (Figure 3). In an arbitrary cross section of the aft monolith consisting of n layers, the average value$\bar{G}$the content of the component and the mass of the product per unit length can be determined by the formula

$$\bar{G} = \frac{1}{n}\sum_{i=1}^{n} G(l_i) \text{ ,} \quad (34)$$

where l_i – oflow springs along the length corresponding to the cross section of the monolith.

Consider the section of the monolith, which correspond to the segments l_i, separated from each other at a distance$S \approx \Delta Z$. Then the expression (34) will be

$$\bar{G} = \frac{1}{S \cdot n} \cdot \sum_{i=1}^{n} G(i \cdot S)S \quad (35)$$

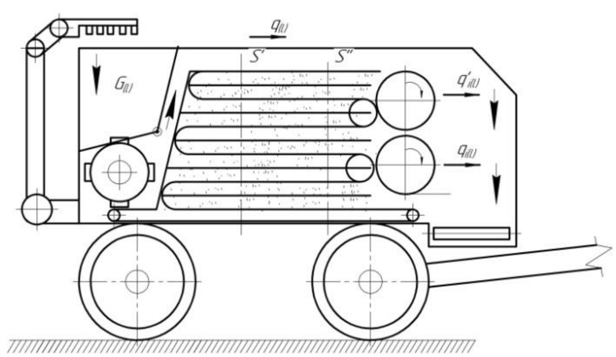

Figure 3: Filling the CMM bunker with horizontal layers in the reciprocating mode of their formation

The sum on the right side of this expression with increasing n tends to the value of a definite integral$\int_o^{\Delta Z \cdot n} G(l) \cdot dl$

Find the coefficient of variation for this scheme. It depends on the position of the sections to a great extent, since the flow is not broken.

In particular, the minimum number of effective$(n/2)$ layers will be in the extreme positions of the dispenser bunker, and the maximum - in the middle sections of the bunker.

Take as an overestimation of the coefficient of variation for the extreme sections. Then

$$\nu = \{\frac{1}{n^2}\left\{2 \cdot \sum_{K=0}^{n-1}(n-K)K_q(S) - n \cdot K_q(o)\right\} + \frac{2}{\Delta Z \cdot n}\int_o^{\Delta Z \cdot n}(1 - \frac{l}{\Delta Z \cdot n}) \times$$

$$\times K_q(l)dl - \frac{2}{\Delta Z \cdot n^2}\sum_{i=1}^{n}\int_o^{\Delta Z \cdot n} K_q(i \cdot S - l)dl\}^{0,5}q^{-1} \quad (36)$$

Analysis of expression (36) shows that the implementation of this scheme is the simplest, but it requires ensuring layer-by-layer filling with layers of lesser height in order to increase their number and, ultimately, reduce the value of oscillations.

CONCLUSION:

A theoretical analysis was obtained of a mathematical model characterizing the transformation of the flow system in space and time along the length of the flow using the properties of the correlation function and probability theory.

By the adopted approach, the methods of filling the CMM tank-bin with inclined and horizontal layers in the modes of translational and reciprocating formation of the feed monolith in the tank-CMM tank are justified.

By analyzing the models obtained for the layer-by-layer filling of the CMM tank-bin, it was found that in the limiting case, $n \to \infty$, they are identical, so the further solution of the problem is reduced to the determination of the optimal number of layers for the specific working conditions of the CMM.

By calculation and experiment it was confirmed that with the number of layers equal to n = 8-10, the mixture is highly homogeneous. $\nu_{mix} = \pm 5\%$, as well as dosing uniformity $\nu_d = \pm 10\%$, meets zootechnical requirements.

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