The model of dose formation in the drum batcher with the moving blades within the cells

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Abstract

The article considers a design and technological scheme of a drum batcher with a variable volume of cells. The mathematical model of the material dose formation in the drum batcher’s cell in the area of loading gate is considered. As a result of the analysis of the mathematical models the boundary conditions of operational integrity, as well as the factors affecting design parameters of the batcher and the material dosing process are determined.

Keywords: drum batcher, dose formation model, cam track, cell, moving blades

1. Introduction

A large number of different batchers in agriculture are used. Volumetric material dosing finds the greatest application because of the simpler design of the machine dosing element and more reliable operation. The drum batcher with installed blades in the cells produces the dosing material in batch and continuous modes with the ability to smoothly and efficient change the dose. The modelling process of the material dose formation is one of the important tasks in the development and design of machines for the preparation and delivery of feed. The design of the proposed batcher is shown in Figure 1. When the rotor of the drum batcher rotates with moving blades in the cells counterclockwise, the moving blades 15 make an alternate motion Figure 1. At the approach of cells to the loading gate, rollers 2 roll on the copiers 10 and turn the latches 17 relative to axis 4 in a clockwise direction; sector ratchets 5 are unfixed, rollers 2 with sector ratchets, approaching under copiers 6 and under their action direct to the axis of the drum rotation [4, 5, 7]. At the same time, the free ends of the moving blades 15 also move to the axis of the drum, resulting in a maximum volume of cells.

During the moving of the blades 15 to the drum axis, the cells are filled with material. With further movement of the cell in the area of the loading gate rollers 2 roll on the cam track 8, which are rotated together with the axis 7 when you rotate the frame 14 at a specified angle. As a result, the movable blade 15 moves to the loading gate of the drum, forming an established volume of the cell. Under the action of springs 18 latches 17 fix levers with sector ratchets 5, preventing the reverse movement of the blades 15 to the center of the drum and without preventing them from moving to the loading gate. This eliminates the replenishment of the material in the cell during the rollers descend from the cam track 8.

The material is unloaded from the cells by the blades 15 during they approach the unloading gate as a result of rolling the rollers11 onto the copier 10.

2. Theoretical research

During the continuous mode the dosing in the drum batcher is calculated by the formula [1]:

\[ Q = V_{bi} \cdot z \cdot n \cdot \rho \cdot \varphi_{fill} \]

where \( n \) - rate speed of the drum batcher, \( c^{-1} \); \( V_{bi} \) - the cell space during the dosing of \( i \)-dose, \( m^3 \); \( z \) - the number of cells; \( \rho \) - the bulk density of the material, \( kg/m^3 \); \( \varphi_{fill} \) - the fill factor of the cell.
The radius of the batcher drum is calculated on the basis of an established dosing or the maximum dose value in a cell [2, 3, 5, 6]:

\[ R = \frac{q_{\text{max}}}{\eta L} \]  \hspace{1cm} (2)

where \( q_{\text{max}} \) - the maximum amount of material in a cell, kg; \( \eta \) - the fill factor of the cell \( (\eta=0.85...0.95) \); \( L \) - the working length of the dosing cell, m.

To determine the limits of cell volume variation depending on the cam rotation angle, we’ll consider the scheme Figure 2. At the point of installation of the cam internal copier has a circle shape with a radius \( r_1 \). The cam is made of a plate with rounding radius \( r_2 \) \( r_3 \) Figure 3, the distance between the centers of rounding will be as follows \( O_1O_2=l \). The bending radius of the blade is equal to the radius of the batcher housing \( R \) Figure 2. The thickness of the blades in the calculation is neglected due to their small size. The most distant point of the cam from the center of rotation \( O \) when it is rotated by some angle is the point of intersection of the line passing through the center \( O \) and \( O_2 \) and the working surface of the copier. The center of rotation of the roller \( O_3 \) is at a distance \( k \) from the hinge.

The cross-sectional area of the dosing cell is divided into two sections-segment AmB and sector ABC. Their area is denoted by \( S_1 \) and \( S_2 \). The full volume of the dosing cell [3]:

\[ V = (S_1 + S_2) \]  \hspace{1cm} (3)

Let’s consider the scheme (Figure 2) at the moment when the cam occupies the lowest position with the initial angles \( \alpha_0 \) and \( \beta_0 \). During the changing of the volume of the cell area \( S_1 \) remains constant, and since the triangle AOB is equilateral \( (AB=OB=OA \) from the construction of the batcher), then \( \angle AOB=\pi/3 \). Then:

\[ S_1 = \frac{\beta_0^2}{\sqrt{3}} \left( \frac{\pi}{3} - \sin \frac{\pi}{4} \right) \]  \hspace{1cm} (4)

The area:

\[ S_2 = \frac{\beta_0^2}{\sqrt{3}} \left( \frac{\pi}{2} - \varepsilon - \beta_0 \right) \]  \hspace{1cm} (5)
Figure 2. The design scheme of the batcher’s cam mechanism

Figure 3. Scheme for determination $l$

The angle $\epsilon$ we’ll find from a triangle $\Delta ADO_1$, so as $AD \cong DO_1$, the $\epsilon = \arcsin \frac{r_4}{r_1}$, and the angle $\beta_0$ we’ll find from a triangle $\Delta AO_3O$, using cosine theorem $\beta_0 = \arccos \frac{r_4^2 + r_1^2 - (r_1 + r_2)^2}{2r_4r_1}$, where $O_3O = r_4 + r_1$. Then

$$\beta_0 = \arccos \frac{r_4^2 + r_1^2 - (r_1 + r_2)^2}{2r_4r_1} \quad \ldots \quad (6)$$

Let’s substitute into the equation (5) the found values $\epsilon$ и $\beta_0$:

$$S_2 = \frac{\pi}{2} \left( \frac{r_4}{r_1} - \arcsin \frac{r_4}{r_1} - \arccos \frac{r_4^2 + r_1^2 - (r_1 + r_2)^2}{2r_4r_1} \right) \quad \ldots \quad (7)$$

Let’s substitute values from (4) и (7) into (3) and we’ll get the maximum cell volume:

$$V_{\text{max}} = \frac{\pi}{2} \left[ \left( \frac{r_4}{r_1} - \arcsin \frac{r_4}{r_1} - \arccos \frac{r_4^2 + r_1^2 - (r_1 + r_2)^2}{2r_4r_1} \right) \right] \quad \ldots \quad (8)$$

When you rotate the cam relative to the point $O_1$ (see Figure 2, dashed lines) at some angle $\alpha$, straight $O_1O_2$ will take a position $O_1' O_2'$, and the center of the roller $O$ will move to the chord $AB$ and take the position $A' B'$. The line of the blade will move to the chord $AB$ and take the position $A' B'$. As a result, the angle $\beta_0$ will be increased and equaled to $\beta$, the area of sector $S_2$ will also be changed.

Considering the trigonometric dependences, the angle $\beta$ can be expressed as follows:

$$\beta = \arccos \frac{r_4^2 + r_1^2 - (r_1 + r_2)^2}{2r_4r_1} \quad \ldots \quad (9)$$

At the moment when the cam occupies the top position, the volume of the cell will be minimal. Taking into account the dependence (5) expression (8) will be as follows:

$$V = \frac{\pi}{2} \left( \frac{r_4}{r_1} - \arcsin \frac{r_4}{r_1} - \arccos \frac{r_4^2 + r_1^2 - (r_1 + r_2)^2}{2r_4r_1} \right) \quad \ldots \quad (10)$$
The analytical equation relating the pressure angle and the main parameters of the swinging roller pusher and the cam will be as follows [2]:

$$\gamma = \frac{\sin\beta}{\sin\theta} \cdot \cot\beta \quad \ldots \ldots \quad (11)$$

where $\gamma$ - the pressure angle (the angle between the normal pressure $N$ and valuable component of its component $Q$, directed by the speed of the blade, that is, the part of the force $N$, which is used to perform effective power during the moving of the blade Figure 4; $k$ - distance from point $A_i$ to $O_3$, i.e. $k=A_iO_3$; $\beta$ - rotary acceleration of the blade movement; $R$ - the radius of the drum batcher ($R=A_iO$); $\theta$ - the current value of the blade angle to the center line ($\beta=\angle O_3A_iO$).

Figure 4. Scheme for determination $l$ and $\gamma$

The expression (10) shows that the angle $\gamma$ will be increased with the increasing angle $\beta$ (at $k=$const. and $R=$const.). Therefore, the maximum value of the angle $\gamma$ will be observed in the position of the cell shown in the diagram (Figure 4) when the cam will be deflected by the maximum angle $\alpha_{max}$. In the synthesis of cam mechanisms on the allowable pressure angle, which depends on the material of the cam and roller, inequality $\gamma \leq \gamma_{max}$ must be observed. The scheme (Figure 4) shows that:

Using cosine theorem from triangle $\Delta A_iO_3O_2$ we can find the following:

$$A_iO_2 = \sqrt{k^2 + (n_i + r_2)^2 - 2k(n_i + r_2) \sin\gamma} \quad \ldots \ldots \quad (12)$$

To determine $O_0O_{\beta}$ we consider the new position of the cell in which its volume at the same angle $\alpha_{max}$, becomes the maximum Figure 3.

The diagram shows (fig. 5), that $O_0O_{\beta} = O_0O_{\beta} - O_0O_{\beta}$. The value $O_0O_{\beta}$ we can find from the triangle $\Delta A_iO_3O_2$:

$$O_0O_{\beta} = \sqrt{k^2 + R^2 - 2Rk \cos \beta_{max}}$$

so as, $\beta_{max} = \frac{\pi}{2} - \alpha$, $O_3O_i = n_i + r_i$ the

$$O_0O_{\beta} = \sqrt{k^2 + R^2 - 2Rk \cos \left(\frac{\pi}{2} - \alpha\right)} = \sqrt{k^2 + R^2 - 2Rk \sin \alpha} \quad \ldots \ldots \quad (13)$$

where $O_0O_{\beta}$ we can find from $\Delta A_iO_3O_2$ (see fig. 5) the following:

$$O_0O_{\beta} = \sqrt{k^2 + R^2 - 2Rk \cos \alpha_{\beta} A_iO} \quad \ldots \ldots \quad (14)$$

where $\omega_{\beta} A_iO = \omega_{\beta} A_iO_2 + \omega_{\beta} A_iO_3$
From the triangle $\triangle AO_1O_2$, we can define the angle according to sine theorem:
\[
\frac{AO_2}{\sin\angle A_1O_2O_1} = \frac{O_2O_1}{\sin\angle A_1O_2O_3},
\]
consequently:
\[
\angle A_1O_2O_3 = \arcsin\left(\frac{O_2O_1 \sin \angle A_1O_2O_3}{AO_2}\right). \quad (15)
\]
The angle $\angle O_2A_0O$ is calculated from $\triangle O_2A_0O$ (see Figure 5):
\[
\angle O_2A_0O = \arccos\frac{\Delta O_3A_0 + \Delta O_2A_0 - \Delta O_2O_3}{2\Delta O_2O_3}. \quad (16)
\]
So:
\[
\angle A_0O_2 = \arcsin\left(\frac{O_2O_3 \sin \angle A_1O_2O_3}{AO_2}\right) \quad (17)
\]
where $A_0O_2$ is calculated from the expression (12), $OO_2$ is calculated according to formula (13).
On the other hand, from $\triangle O_2O_3O_1$:
\[
OO_2 = \sqrt{(r_3 + r_2)^2 + 2r_3^2 - 2(r_3 + r_2) \cdot O_2O_1 \cdot \cos \angle O_2O_1O_2} \quad (18)
\]
The diagram Figure 5 indicates the following:
\[
\angle O_1O_2O_3 = \angle NO_2O_1 + \angle O_2O_3O_1 \quad (19)
\]
and $\angle O_1O_2O_3$ can be calculated from $\triangle O_2O_3O_1$:
\[
\angle O_2O_3O_1 = \arccos\frac{r_1^2 + r_2^2 - (r_3 + r_2)^2}{2r_1r_2}. \quad (20)
\]
where $r_1 = O_1O_2 - r_2$ - distance from the rotation axis of the drum point $O$ to the axis of attachment of the cam, points $O_1; O_2; O_3$.

From the triangle $\triangle AO_1O_2$ (fig. 4) can be found $\rho O_3$ (Figure 4):
\[
\rho O_3 = \sqrt{R^2 + k^2 + 2Rk \cos \beta_{max} - (r_3 + r_2)}
\]
where $\beta_{max}$ - the smallest angle of deflection of the blade to the line $A_0O$. It is known that $\beta_{max} \leq \pi/3 - \epsilon$.
Substituting the last expression into equation (19), we'll obtain:
\[
\angle O_2O_3O_1 = \arccos\frac{\rho_{O_3}^2 + \rho_{O_3}^2 - (r_3 + r_2)^2}{2\rho_{O_3}^2}. \quad (21)
\]
Having equated expressions (17) and (21) we'll find:
\[
\cos \angle O_2O_3O_1 = \frac{(r_3 + r_2)^2 + 2(r_3 + r_2) \cdot O_2O_1 + (r_3 - r_2)^2}{2(r_3 + r_2) \cdot O_2O_1}
\]
Denoting the right side of the last equation as $B$, then:
\[
\angle O_2O_3O_1 = \arccos B.
\]
Taking account of expression (21):
\[
\arccos \frac{(r_3 + r_2)^2}{2\rho_{O_3}^2} + \arccos \frac{(r_3 - r_2)^2}{2\rho_{O_3}^2} = \arccos B.
\]
After the transformation and solution of this equation we'll obtain:
\[
\lambda = \frac{\pi}{2} + \text{arccot} - \lambda \quad (22)
\]
where \( N = 2n + B^2d^2 + d^2 - 2Bmd; M = 2Bmdn - n^2 - md^2; n = \frac{O_2 - (r_1 - r_2)^2}{2}; m = r_3 - r_2; d = 2OO_2. \)

3. Results and discussion

The analysis of the above mentioned theoretical dependences leads to the following conclusions:

- equation (10) is valid only when \( \alpha \geq \alpha_0 \) since \( \alpha < \alpha_0 \) the impact of cams on rollers is ceased and they roll on the inner copier with constant curvature, i.e. the angle \( \beta \) isn’t changed;
- so the movable blade should not be curved in the blade during material loading, the condition \( \beta \geq \pi/6 \) must be observed.
- the main parameters (see equation 10) that determine the volume of dosing cells are the radius of the body \( R \) and the inner copier \( r_1 \), the length of the cam \( l \), the distance from the center of the hinge to the center of rotation of the roller \( k \), the angle \( \alpha \) (the maximum volume of cells depends on the radius \( R \) and \( r_1 \), from \( l \) to \( k \)-the volume control limit).
- quickly adjust the dose at a discrete dosing material can be due to changes in the angle of rotation of the cam \( \alpha \).
- the radius of the rounding cam \( r_2 \) and \( r_3 \) (see Figure 3) are chosen for structural reasons with a check on the static condition of the cam profile safety or on the condition of its durability.
- the distance between the centers of fillets \( O_1O_2 = L \), see Figure 3, are selected from the following conditions: the permissible pressure angle in the kinematic pair (roller-cam); as far as possible the formation of the minimum dose.

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