MEASUREMENT OF NON-ELECTRIC QUANTITIES

DEVELOPMENT AND RESEARCH OF A DISCRETE-ACTING BATCHER WITH AN OVERTURNING BUCKET

Grygorii Cherepashchuk, PhD, Prof., Oleksii Potylchak, PhD, As.-Prof.
National Aerospace University "Kharkiv Aviation Institute", Ukraine,
e-mail: o.potylchak@khai.edu
Tetiana Bykova, PhD, As.-Prof.
V. N. Karazin Kharkiv National University, Ukraine

https://doi.org/10.23939/istcmtm2025.01.074

Abstract. The article deals with the issues of dosing bulk materials using weighing batchers. The existing types of batchers are described, the main disadvantages of the known discrete-acting batchers with an overturning bucket are given. A discrete-acting batcher with a tipping bucket developed by the authors is presented, its block diagram is given, according to which the principle of operation of the batcher is considered in detail. The batcher contains the following units: a feed hopper, a load receiver, upper and lower limiting supports, a counterweight, a weight measuring and display unit. The process of dosing bulk materials is reduced to the cyclical execution of four consecutive operations: feeding bulk material from the feed hopper into the load receiver below it; tilting and overturning the load receiver after reaching the set dose; abrupt stopping the tipped load receiver and unloading the dose; returning the emptied load receiver to its original position. All mechanical movements in these operations are carried out automatically and only at the expense of the potential energy of the dosed bulk material due to its weight. The second-order differential equation describing the movement of the load receiver during tipping is derived. The static equations of moments for different stages of the batcher's operating cycle are considered, from which recommendations for calculating the geometric and weight parameters of the batcher are obtained.

Keywords: Discrete-acting batcher, Bulk material, Load receiver, Counterweight, Feed hopper, Differential equation.

1. Introduction

Industrial enterprises in various industries perform a large number of operations with bulk materials. A significant portion of these materials is subject to dosing during the processing cycle, for which various batchers are used. Without the proper organization of the dosing process and the use of appropriate equipment, it is impossible to ensure the high quality of the final product.

Dosing is defined as weighing or measuring by volume with a given accuracy the amount of each component specified by the recipe to form a mixture of finished products, as well as forming a dose when packaging the finished product [1].

Incorrect dosing can lead to a decrease in the quality of the product, overconsumption of scarce and expensive components, and an increase in the cost of finished products. Thus, dosing is a very important technological operation at enterprises in many industries.

The general requirement for batchers is to provide accurate delivery of a certain amount of dosed material within specified time intervals to ensure specified technological processes with the ability to adjust the flow rate regardless of the pressure in the medium.

Bulk material batchers are divided into two large groups depending on the mechanism of operation [2]:

– continuous-acting batchers – designed to automatically supply products and materials to the appropriate process container or installation (e. g., a mixer). Such batchers are used in production processes with horizontal placement of machines and conveyor feeding of components;

– discrete-acting batchers – used when there is an intermittent supply of materials to the hopper. The batcher is switched on and off automatically when the technology provides for this operation. This type of batcher is focused on production processes with high-rise equipment placement. Discrete-acting batchers have become much more widely used, so further consideration will focus on this type.

2. Drawbacks

The discrete-acting batchers described in [3–9] are divided by design into:

– batchers with an overturning bucket;

– batchers with a bucket whose bottom opens.

The main disadvantages of the known batchers with an overturning bucket are additional energy consumption for overturning the bucket, dynamic effects on dosing accuracy, and a decrease in dosing accuracy due to sticking of bulk material residues on the bucket walls.

3. Goal

The goal of the current article is the development of an energy-saving discrete-acting batcher with an overturning bucket, which will have a simple design and increased dosing accuracy, as well as research of the mathematical model of the batcher.

4. Development of a discrete-acting batcher with an overturning bucket

To solve this problem, the authors developed a batcher [10], the block diagram of which is shown in Fig. 1.

The block diagram includes:

– a feed hopper 1, in which a vertical discharge opening 2 is equipped with a flap 3, which is made in the form of a rotary plate mounted on a support 4, having a pin 5 and supported by a platform 6 protruding from under the opening 2;

– a load receiver 7, in the upper part of which the pusher 8 of the flap 3 is fixed;

– upper limiting support 9 and lower limiting support 10, which are connected to a fixed base;

– counterweight 11;

– weight measuring and display unit 20.

A linear dose scale 12, graduated in units of weight of the dose of the material to be weighed, and an adjusting lever 13 are rigidly attached to the load receiver 7. A counterweight 11 can move along the lever 13 with the possibility of fixing its position in any known way and indicating this position on the scale 12 using, for example, an arrow pointer. On the front and rear walls of the load receiver 7 below its center of mass are rigidly attached two rotating axes 14, which are located on the same line perpendicular to the direction of the adjusting lever 13 and shifted horizontally in its direction relative to the center of mass of the load receiver 7. When the load receiver 7 is overturned, the semi-axes 14 can rotate freely in the holes of the sliding bushings 15, which are supported by weight measuring sensors, for example, strain load cells 16. Spiral springs 17, which are twisted when the load receiver 7 is overturned, form an elastic connection of the semi-axes 14 with the bushings 15. The outputs of the load cells 16, the upper limit switch 18 attached to the upper support 9, and the lower limit switch 19 attached to the lower support 10 are electrically connected to the inputs of the weight measurement and display unit 20.

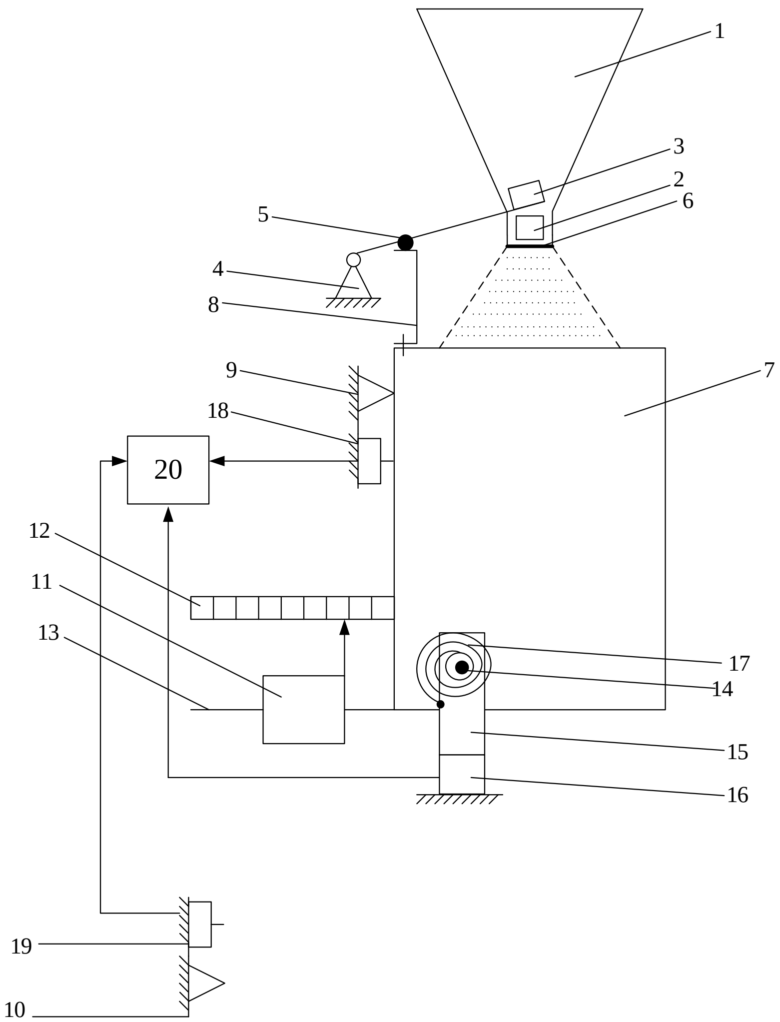

Fig. 1. Block diagram of a discrete-acting batcher with an overturning bucket

The process of dosing bulk materials is reduced to the cyclical execution of four consecutive operations:

• feeding of bulk material from the feed hopper 1 into the load receiver 7 under it;

• tilting and overturning of the load receiver 7 after the set dose is reached, which is accompanied by closing the gate of the feed hopper 1 and determining the total weight of the set dose and the load receiver 7 with all elements attached to it (gross weight)

• abrupt stopping of the overturned load receiver 7 and unloading of the collected dose;

• return of the emptied load receiver 7 to its original position, accompanied by determination of its weight (tare weight) and opening of the gate of the feed hopper 1.

All mechanical movements in these operations are carried out automatically and only at the expense of the potential energy of the dosed bulk material due to its weight.

In the initial position, the discharge opening 2 of the feed hopper 1 is blocked by the flap 3, which is supported by the platform 6. The empty load receiver 7 under the action of the torque generated by the weight of the counterweight 11, which is greater than the torque generated by the weight of the empty load receiver 7 and directed opposite to it, rotates counterclockwise on the semi-axes 14 until it touches the upper support 9. At the final stage of the rotation, the pusher 8 fixed in its upper part rests against the finger 5 of the flap 3 and raises it, and the left side wall of the load receiver 7 presses the upper limit switch 18, which leads to its closure and start of the unit 20 for measuring and displaying the weight. The unit 20, according to the signals of the weighing sensors 16, begins to periodically measure the weight of the load receiver 7 with the elements attached to it.

The design model of the discrete-acting batcher with a overturning bucket is shown in Fig. 2.

According to the model, the reaction force of the support 9 compensates for the total torque acting on the empty load receiver 7 and is calculated by the formula:

$$M_{sum} = P_{cw} \cdot l_{cw} - P_{elr} \cdot l_{elr} + W \cdot \alpha, \qquad (1)$$

where P_{cw} and P_{elr} – the weight of the counterweight 11 and the empty load receiver 7, respectively; l_{cw} and l_{elr} – horizontal displacement of the centers of mass of the counterweight 11 and the empty load receiver 7 relative to the axis of the rotary semi-axes 14 (shoulders of weight forces P_{cw} and P_{elr}); W – the specific counteracting moment of the spiral springs 17; α – the angle of deviation of the load receiver 7 from the vertical.

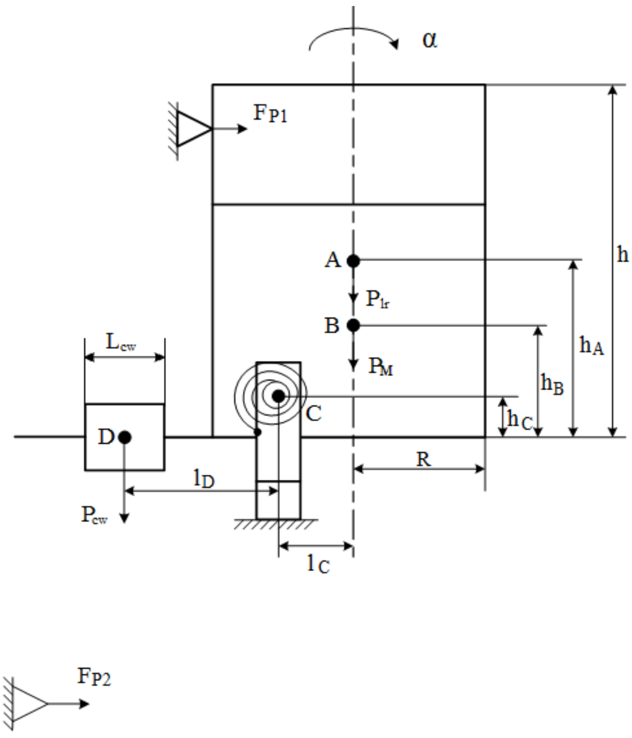

Fig. 2. Design model of the discrete-acting batcher with a overturning bucket

In the initial vertical position, the angle α = 0 and $l_{cw} = l_D$, $l_{elr} = l_C$. Through the open discharge opening 2 of the feed hopper 1, the bulk material begins to flow under its own weight into the load receiver 7 located below it. The overturning moment created by the weight of the bulk material poured into the load receiver 7 can be calculated by the formula:

$$M_{ov} = P_M \cdot l_M, \qquad (2)$$

where P_M – the weight of the bulk material filled into the load receiver 7; l_M – is the horizontal offset of the center of mass of the filled material relative to the axis of the rotary axes (shoulder of weight force P_M). With a symmetrical shape of the load receiver and α = 0: $l_M = l_{elr} = l_C$.

As soon as the overturning moment created by the weight of the bulk material filled into the load receiver 7 equals the total moment M_{sum} created by the counterweight 11 and the empty load receiver 7, the load receiver 7 with all the elements attached to it begins to rotate clockwise (the friction force between the elements 14 and 15 can be ignored due to its smallness). At the same time, the flap 3 of the feed hopper 1, which is no longer held by the pusher 8, rotates on its axis under its own weight until it stops against the platform 6 and blocks the discharge opening 2, interrupting the flow of bulk material to the load receiver 7. Thus, the filling stops, which eliminates the dynamic impact of the material flow on the weighing sensors 16. At the same time, the side wall of the load receiver 7 moves away from the upper limit switch 18, which leads to its opening. According to the signal of the switch 18, the current measurement result is stored in the unit 20, not distorted by the dynamic effects of the material flow and the movement of the load receiver 7. This measurement result corresponds to the weight of the dosed portion of the bulk material and the load receiver 7 with all the elements attached to it, i.e., the "gross" weight P_G. Under the action of the overturning moment, and, after acceleration, the moment of inertia too, the load receiver 7 rotates clockwise on the semi-axes, and at the end of the overturning, its movement is inhibited by increasing the counteracting moment $W\alpha$ of the spiral springs 17. Stopping of the load receiver 7 in a vertical overturned position at α_{max} = 180° occurs due to the collision of its right side wall with the lower limiting support 10, which also additionally serves as a shock absorber and prevents the reverse movement of the load receiver 7. At the same time, the side wall of the load receiver 7 presses the lower limit switch 19, which causes it to close and restart the unit 20, which begins to periodically measure the weight with increased frequency. At the same time, the dosed portion of bulk material quickly spills out of the overturned load receptor 7 into the receiving container (not shown in the block diagram) due to the collision and under the influence of its own weight. Further, under the influence of the counteracting moment, if the condition

$$W \cdot \alpha_{\max} > \mathrm{P}_{cw} \cdot l_{cw} - \mathrm{P}_{elr} \cdot l_{elr} \quad (3)$$

is satisfied, that is ensured by selecting the required stiffness of the springs, the emptied load cell 7 on the semi-axes 14 begins to rotate counterclockwise, returning to its original position. At the same time, the side wall of the load receiver 7 moves away from the lower limit switch 19, it opens and, according to its signal, the current measurement result is stored in the unit 20, not distorted by the dynamic effects of the lower support 10 and the reverse movement of the load receiver 7. This measurement result corresponds to the weight of the empty load receiver 7 with all the elements attached to it and the remaining bulk material stuck to its walls, i.e. the "tare" weight P_T. After returning the load receiver 7 to its original vertical position, the process is automatically repeated without energy consumption for mechanical movement of the batcher elements.

Unit 20 calculates the precise value of the dose weight – the "net" weight – based on the two weighing results P_G and P_T obtained in one dosing cycle, which is calculated using the formula:

$$P_{\mathrm{M}} = P_G - P_T, \quad (4)$$

where P_T – the "tare" weight; P_G – the "gross" weight.

The calculated "net" weight is not distorted by dynamic influences and the weight of the bulk material residues adhering to the walls of the load receiver 7, and the summation of the obtained values allows determining the exact value of the total weight of the bulk material that has passed through the batcher.

The weight of the dosed portions of bulk material is directly determined by the ratio of stable values of the geometric and weight parameters of the dosing elements, calculated by the formula:

$$P_{\mathrm{M}} = \frac{\mathrm{P}_{cw} \cdot l_D - \mathrm{P}_{elr} \cdot l_C}{l_C}. \quad (5)$$

The weight of the dosed portions of bulk material can be adjusted by selecting the weight P_{cw} of the counterweight 11 and moving it along the lever 13, which changes the value l_D, with the dose indication on the scale 12. The weight of the portion and the dosing process itself practically do not depend on the friction forces in the rotating bearings of the load receiver 7, due to their smallness, which is ensured by design (lubrication, protection against contamination, etc.). This increases the reliability and accuracy of batch weighing of bulk materials while almost eliminating energy consumption for dosing. Precise measurement of net weight by weighing sensors and a weight measuring and display unit increases the accuracy of accounting for the weight of portions and the total weight of the bulk material to be dosed. This allows for remote weight control of the weight of the dispensed portions of bulk components in the process flows.

5. Mathematical model of the batcher

The process of overturning the batcher's bucket is described by the following differential equation:

$$J\frac{d^2\alpha}{dt^2} + P_{fr}\frac{d\alpha}{dt} + M_{lr} + M_M - M_{cw} - M_{el} = 0, \quad (6)$$

where J – the moment of inertia of the system; P_{fr} – the coefficient of friction in the bearings; M_{lr} – the moment produced by the weight of the load receiver; M_M – the moment produced by the weight of the bulk material; M_{cw} – the moment produced by the counterweight; M_{el} – elastic moment produced by the springs.

The moments included in equation (6) can be expressed through the constructive parameters of the batcher, which are indicated in the design model (Fig. 2).

Moment produced by the weight of the load receiver:

$$M_{lr} = P_{lr} \cdot \sqrt{(h_A - h_C)^2 + {l_C}^2} \cdot sin(\gamma + \alpha), \quad (7)$$

where P_{lr} – is the weight of the load receiver; h_A – the height of the center of gravity of the load receiver; h_C – the height of the rotating axis; l_C – the distance between the line of action of the load receiver weight and the rotation axis;

$$\gamma = arcsin\left(\frac{l_C}{\sqrt{(h_A - h_C)^2 + l_C^2}}\right);$$

α – the angle of inclination of the load receiver.

Moment produced by the weight of the bulk material:

$$M_M = P_M \cdot \sqrt{(h_B - h_C)^2 + {l_C}^2} \cdot sin(\beta + \alpha), \quad (8)$$

where P_M – the weight of the bulk material; h_B – the height of the center of gravity of the bulk material; β – the angle of initial spring tension.

Moment produced by the counterweight:

$$M_{cw} = P_{cw} \cdot \sqrt{h_C^2 + l_D^2} \cdot sin(\eta - \alpha), \quad (9)$$

where P_{cw} – the weight of the counterweight; l_D – the distance between the center of gravity of the counterweight and the axis of rotation;

$$\eta = arcsin\left(\frac{l_D}{\sqrt{h_C^2 + l_D^2}}\right).$$

The elastic moment produced by springs:

$$M_{el} = K_{el} \cdot \alpha, \quad (10)$$

where K_{el} – the specific elasticity of the springs.

Taking into account expressions (7)–(10), the differential equation (6) will take the form:

$$J\frac{d^2\alpha}{dt^2} + P_{fr}\frac{d\alpha}{dt} + P_{lr} \cdot \sqrt{(h_A - h_C)^2 + {l_C}^2} \cdot sin(\gamma + \alpha) +$$
$$+ P_M \cdot \sqrt{(h_B - h_C)^2 + {l_C}^2} \cdot sin(\beta + \alpha) -$$
$$- P_{cw} \cdot \sqrt{h_C^2 + l_D^2} \cdot sin(\eta - \alpha) - K_{el} \cdot \alpha = 0. \quad (11)$$

The second-order differential equation (11) is nonlinear and can be solved only by numerical methods. Therefore, to determine the geometric and weight parameters of the batcher in the first approximation, it is necessary to consider the static equations of moments for different stages of its operating cycle.

At the beginning of filling the load receiver, the equation of moments has the following form:

$$M_{lr} - M_{cw} + M_{P1} = 0,$$

where M_{P1} – the moment of clamping force of the load receiver against the upper limit switch,

$$M_{P1} = M_{cw} - M_{lr} > 0,$$
$$M_{cw} > M_{lr}.$$

From this, we can derive the ratio to ensure a stable equilibrium:

$$l_D > \frac{P_{lr}}{P_{cw}} \cdot l_C. \quad (12)$$

At the end of filling the load receiver, the equation of moments is as follows:

$$M_{lr} + M_M - M_{cw} + M_{P1} = 0,$$
$$M_{P1} = M_{cw} - M_{lr} - M_M. \quad (13)$$

Putting the expressions for the corresponding moments in (13), we can obtain the static characteristic of the transformation:

$$P_{MF} = P_{lr} - \frac{P_{cw}}{l_C} \cdot l_D, \quad (14)$$

where P_{MF} – the value of the weight of the bulk material at the end of filling the load receiver.

We can also formulate constraints that are imposed on the l_D parameter. Geometric constraints are calculated by the formula:

$$l_{Dmin} = R - l_C + \frac{L_{cw}}{2}, \quad (15)$$

L_{cw} – the length of the counterweight.

Weight constraints give us value:

$$l_{D\min} = \frac{(P_{MF\min} + P_{lr}) \cdot l_C}{P_{cw}} = \frac{(K_M h_C + P_{lr}) \cdot l_C}{P_{cw}}. \quad (16)$$

6. Conclusions

The article considers batchers of bulk materials used in technological processes at enterprises of various industries. The design of a discrete-acting batcher with an overturning bucket is proposed, which consists of a feed hopper, a load receiver, a counterweight, limiting supports, weight measuring and display unit.

The proposed batcher has the following advantages in comparison with known ones:

- exclusion of additional energy consumption for dosing due to the design features of the batcher;
- reduction of dynamic influences on the dosing accuracy;
- elimination of the dosing error caused by sticking of bulk material on the walls of the load receiver.

The second and third advantages are provided by the chosen method of calculating the weight of a portion of bulk material.

The mathematical model of a discrete-action batcher with an overturning bucket is investigated, and recommendations for calculating the geometric and weight parameters of the batcher are given. It should be noted that the values of the batcher's parameters obtained from the consideration of the static equations of moments should be verified and clarified by using the results of the numerical solution of the second-order differential equation describing the process of overturning the batcher's bucket.

Conflict of Interest

The authors state that there are no financial orother potential conflicts regarding this work.

References

[1] DSTU OIML R 61-1:2019 Dozatory dyskretnoi dii vahovi avtomatychni. Chastyna 1. Metrolohichni ta tekhnichni vymohy (OIML R 61-1:2017, IDT).

[2] S. Petrichenko, V. Oleksienko, A. Lomeiko, "Analysis of batchers of packing machines for dispersed materials", Proceedings of Tavria State Agrotechnological University, No. 20, Vol. 1, pp. 35–42, 2020.

[3] I. Kovalenko, V. Malynovskyi, *Osnovni protsesy, mashyny ta aparaty khimichnykh vyrobnytstv*, Volia, 2006.

[4] O. Havva, A. Bespalko, A. Volchko, O. Kokhan, *Pakuvalne obladnannia*. IATs "Upakovka", 2010.

[5] Stasevych & others. Tekhnolohichne obladnannia biotekhnolohichnoi i farmatsevtychnoi promyslovosti. Novyi Svit-2000, 2018.

[6] "Equipment system for changing bulk material into container canning", B65G 65/32, Pat. CN221499860U, 09.08.2024.

[7] K. Holmes, S. Will, "Bulk material receiving, conveying, storing, and dispensing", B65D90/205, Pat. EP4222077A2, 09.08.2023.

[8] "Bulk grain container movement-free rapid overturning accurate loading system and method", B65G 47/248, Pat. CN112061984B, 07.04.2023.

[9] "Intelligent weighing and boxing machine", B65B 1/32, Pat. CN210618520U, 26.05.2020.

[10] O. Potylchak, G. Cherepashchuk, Yu. Alistratova, "Prystrii portsiinoho zvazhuvannia sypuchykh materialiv", G01G13/00, Pat. 150979 UA, bul. 20, 18.05.2022.