

RESEARCH RESULTS OF EXPERIMENTAL AUTOMATED SYSTEM FOR DOSING BULK MATERIALS

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Abstract. Automated systems for dosing bulk materials are widely used in agriculture, but the issue of measurement accuracy remains relevant. The studies were carried out on a developed laboratory setup. The results of the installation were investigated when dosing various bulk materials- softwood sawdust, wood flour, wood shavings. After processing the results of the conducted studies, regression models are constructed showing the influence of the parameters of the automated dosing system on its accuracy of weighing the materials under study. Work on the auger series DS-100 with size: step turns 90 mm, outer screw diameter 100 mm, height of the pen spiral 29 mm. The influence of the parameters of the dosing system on its weighing accuracy was studied. Experimental studies were conducted using the theory of experimental planning Box-Behnken design was implemented for four factors. When choosing the intervals of the studied parameters, we proceeded from the minimum and maximum values of the parameters set in the control program of the dosing system. The adequacy of the constructed models is shown. The parameters that have the greatest influence on the relative error of weighing the automated system are determined. The zones in which the system operation meets the requirements for metering devices are highlighted. Recommendations are given for choosing the optimal values of the parameters of the dosing system when weighing sawdust of coniferous species. With the help of the DS-100 series dispenser, it is possible to dose wood flour and sawdust with a mass of 1 kg with an error not exceeding 5%.

Keywords: dosing, weighing, materials, systems.

Introduction

Weighing systems for various materials and substances are widely used in all spheres of human life. Bulk materials are an integral part of a person's life. In a large number of cases, such materials are part of a large system and are introduced into it in certain quantities. Usually, for a given input of bulk materials, weighing and dosing systems are used. Such systems are widely used in all spheres of human life: in the food industry [1; 2]; in the construction sector [3]; in mining and oilfield processes [4; 5] and other areas [6; 7]. Perhaps the most widespread dispensers of bulk materials were in agriculture [8-9].

Currently, many companies in various countries are engaged in the development of weighing systems. Such companies include AEG (Germany), Bühler AG (Switzerland), Van Aarsen International BV (Netherlands), the Tenzo-M weighing company (Russia.), Techneks engineering company (Russia) and others [10-12]. Considerable attention is also paid to the issues of calculating weighing systems. The dosing process was modeled by Chadha G., Schulze D., Mills H., OI Imole O. Shimizu Y., D. Aufderheide, Miculec M. [13-18].

Currently, people tend to automate such systems in order to facilitate human labor. But due to the huge number of materials and substances with different physical and mechanical properties, it is necessary to conduct a preliminary calibration of the system for a specific material. To simplify this process, we need a database on the operation of such systems when weighing various materials. The purpose of the work is to study the operation of an automated system for dosing bulk materials.

Materials and methods

The bulk material dosing system includes: storage hopper, which is mounted on load cells; auger, which takes the material from the receiving bins and feeds it to the storage hopper; automated control system (Fig. 1). The automated system controls the operation of the screw motor, monitors the process of weighing materials. The accuracy of dosing is achieved by selecting the values of several parameters entered in the program.

The results of the installation were investigated when dosing various bulk materials – softwood sawdust, wood flour, wood shavings. After processing the results of the conducted studies, regression models are constructed showing the influence of the parameters of the automated dosing system on its accuracy of weighing the materials under study. Work on the auger series DS-100 with size: step turns 90 mm, outer screw diameter 100 mm, height of the pen spiral 29 mm.



Fig. 1. Laboratory installation for dosing of sawn materials

The influence of four factors included in the program and responsible for the operation of the unit on the dosing accuracy was investigated. One of the main factors is the main rotation speed n_1 (factor A) of the dispenser screw. At this frequency, the main feed of the material takes place. The speed of rotation of the screw is changed by the program through the frequency converter built into the control cabinet. To change n_1 in the program menu, we must set the value from 0 to 50 Hz, which corresponds to the minimum and maximum values of the screw speed. During the experiment, the widest possible range of values was taken. The minimum value of the parameter A was set to 10 Hz, and the maximum value was set to 50 Hz. By the end of the dosing process, the program switches the screw speed to a lower n_2 (factor D). This rotation frequency is called the filling speed. It is lower than the main one. Since the program does not allow n_2 to set more than n_1 , during the experiment, n_2 was set as a percentage of n_1 . The minimum value of the factor D was 10%, and the maximum value was 100% of the factor A. The switching time from n_1 to n_2 is also set in the program as a percentage of the bulk of the dosed material (factor C). This factor has changed from 10% to 90%. That is, when setting the minimum value (10%), switching from n_1 to n_2 occurred, when it was necessary to fill up 10% of the material to the specified mass. Load cells transmit readings of the material that is in the hopper. But they cannot account for the weight of the material that is in the fall. The action of the material that is in the fall takes into account the factor B. This factor is entered in the program with the dimension “kilogram”. The heavier the material, the higher the value of this factor should be. During the experiments, the boundary values of the factor B, equal to 0.1 and 0.5 kg, were taken.

The evaluation of the operation of the bulk material dosing system was carried out in terms of the relative weighing error δ , expressed as a percentage and determined by the formula 1:

$$\delta = \frac{(m - m_1)}{m} \cdot 100\% , \quad (1)$$

where m – mass of the hitch, kg;
 m_1 – mass of the hitch weighted by system, kg.

Studies of the dosing system were carried out on the following materials: wood chips, sawdust of coniferous trees, wood flour. The main characteristics of the materials are presented in Table 1. Sawdust passed through a sieve with holes of 0.5 mm was attributed to wood flour.

Table 1

Characteristics of the investigated materials

Material name	Material parameters			
	Density, kg·m ⁻³	Natural angle of the bevel, the degree	Weighted average size, mm	Humidity, %
Wood shavings	51	54	-	13
Sawdust	168	45	0.4	10
Wood flour	100	46	0.32	9

It is shown that the weighing error decreases with the increase in the weight of the hitch. Therefore, the experiments were carried out at the lowest possible weight of the suspension for the DS-100 screw under study, the value of which was 1 kg. The studies used standard and applied techniques for measuring and recording parameters, the results were processed in the program Statgraphics [19-21].

Results and discussion

The results of the experiments are presented in Table 2.

Table 2

Plan and results of the experiment when dosing wood flour, sawdust with a DS-100 auger

Factors			Optimization criterion (related error when dosing δ , %)		
A	B	C	D	Sawdust	Wood flour
30.0	0.3	50.0	55.0	-17.8	-16.6
10.0	0.1	50.0	55.0	-6.6	-6.6
50.0	0.1	50.0	55.0	17.0	21.7
10.0	0.5	50.0	55.0	-46.7	-46.8
50.0	0.5	50.0	55.0	-10.7	-2.3
30.0	0.3	10.0	10.0	-28.8	-28.6
30.0	0.3	90.0	10.0	-5.4	-0.9
30.0	0.3	10.0	100.0	-0.6	4.6
30.0	0.3	90.0	100.0	0.0	3.5
10.0	0.3	50.0	10.0	-23.8	-55.6
50.0	0.3	50.0	10.0	5.0	12.4
10.0	0.3	50.0	100.0	-23.8	-22.5
50.0	0.3	50.0	100.0	36.5	35.0
30.0	0.3	50.0	55.0	-17.8	-16.6
30.0	0.1	10.0	55.0	3.2	3.7
30.0	0.5	10.0	55.0	-36.4	-35.5
30.0	0.1	90.0	55.0	13.4	15.8
30.0	0.5	90.0	55.0	-22.2	-18.8
10.0	0.3	10.0	55.0	-26.9	-25.4
50.0	0.3	10.0	55.0	-4.1	1.2
10.0	0.3	90.0	55.0	-26.3	-26.1
50.0	0.3	90.0	55.0	32.3	37.5
30.0	0.1	50.0	10.0	-8.9	-8.4
30.0	0.5	50.0	10.0	-42.2	-37.3
30.0	0.1	50.0	100.0	20.9	24.2
30.0	0.5	50.0	100.0	-20.7	-14.7
30.0	0.3	50.0	55.0	-17.8	-16.6

During the experiment it was found that wood chips hang in the receiving hopper. Therefore, experiments with this material, when using the DS-100 auger, were not carried out. It is proposed to use augers with large dimensions for dosing wood chips. After processing the statistical data presented in

Table 2, an equation describing the change in the accuracy of dosing softwood sawdust with a 95% confidence probability is constructed:

$$\delta = 21.189 - 1.471 \cdot A - 107.424 \cdot B - 0.318 \cdot C - 0.145 \cdot D + 0.013 \cdot A^2 + 0.775 \cdot A \cdot B + 0.011 \cdot A \cdot C + 0.009 \cdot A \cdot D - 0.313 \cdot B^2 + 0.125 \cdot B \cdot C - 0.231 \cdot B \cdot D + 0.003 \cdot C^2 - 0.003 \cdot C \cdot D + 0.003 \cdot D^2. \quad (2)$$

The coefficient of determination of the equation $R = 94.5$ percent and Durbin-Watson statistic $DW = 2.33$ indicates this model's adequacy. When analyzing the results of the experiment, 4 combinations of factors were identified, for which the optimization criterion is 0 (Table 3).

Table 3

Optimal combination of factors when dosing softwood sawdust

Name	Factor combinations			
	1	2	3	4
Factor A	35.964	10.743	45.411	49.525
Factor B	0.201	0.104	0.491	0.107
Factor C	51.768	24.780	13.336	14.132
Factor D	62.959	76.157	97.402	25.906
Actual relative error, %	3.5	5	1.7	3

The lowest actual relative error is observed for the third combination of factors and is 1.7% (Table 3). In general, for any combination of factors, the sawdust dosing error does not exceed 5%.

The accuracy of dosing in this case is described by the regression model:

$$\delta = -8.08 - 0.373 \cdot A - 141.47 \cdot B - 0.403 \cdot C + 0.41 \cdot D + 0.014 \cdot A^2 + 1.013 \cdot A \cdot B + 0.012 \cdot A \cdot C - 0.0029 \cdot A \cdot D + 56.354 \cdot B^2 + 0.144 \cdot B \cdot C - 0.278 \cdot B \cdot D + 0.004 \cdot C^2 - 0.004 \cdot C \cdot D + 0.002 \cdot D^2. \quad (3)$$

The analysis of the equation indicates its adequacy: the coefficient of determination of the equation $R = 93.2$ percent, Durbin-Watson statistic $DW = 2.97$. The optimal combinations of the studied factors are determined, at which the zero value of the dosing error is achieved (Table 4).

Table 4

Optimal combination of factors when dosing wood flour

Name	Factor combinations			
	1	2	3	4
Factor A	35.268	13.089	39.410	47.093
Factor B	0.212	0.108	0.469	0.121
Factor C	51.838	38.571	70.156	12.393
Factor D	61.429	76.566	90.725	11.01
Actual relative error, %	0	3	1	8.6

When combining factors for combination 4 (Table 4), the dosing error exceeds 5%, so this combination should be excluded. In general, regression models (1) and (2) have high coefficients of determination, which indicates the possibility of accepting hypotheses, that is, these models are adequate.

Experiments have shown that it is possible to achieve the minimum dosage error by several combinations of factors. However, it is necessary to take into account the fact that the system should not only provide accurate weighing, but also carry out this process as quickly as possible, that is, have a high throughput. Based on the characteristics of the control system, in order to achieve maximum throughput, it is necessary for the factors A and B to strive for maximum values, and the factor C to the minimum. Based on this, the following recommended combinations were selected: for softwood sawdust – combination No. 4 (in accordance with Table 3), wood flour – combination No. 3 (in accordance with Table 4). Visualization of changes in the optimization criteria for optimal parameter values is shown in Fig. 2 and 3.

In general, the experimental results show that the DS-100 auger, which is controlled by an automated control program, can meter wood flour and sawdust of coiferous species weighing 1 kg with

an acceptable error (no more than 5%). And when dosing wood shavings, it is necessary to use large augers in order to prevent material from hanging in the storage hopper.

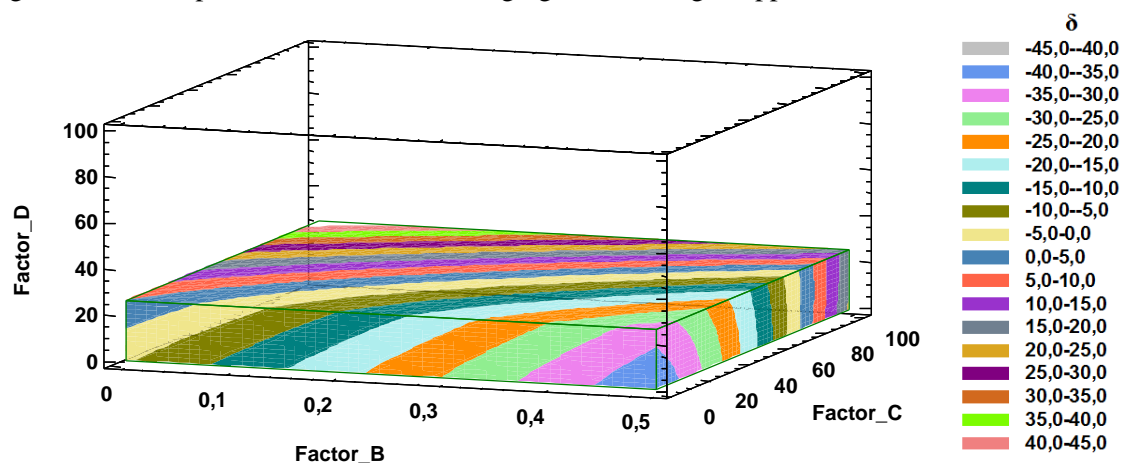


Fig. 2. Change in the dosing error of wood flour with a combination of factors No. 4 (in accordance with Table 3)

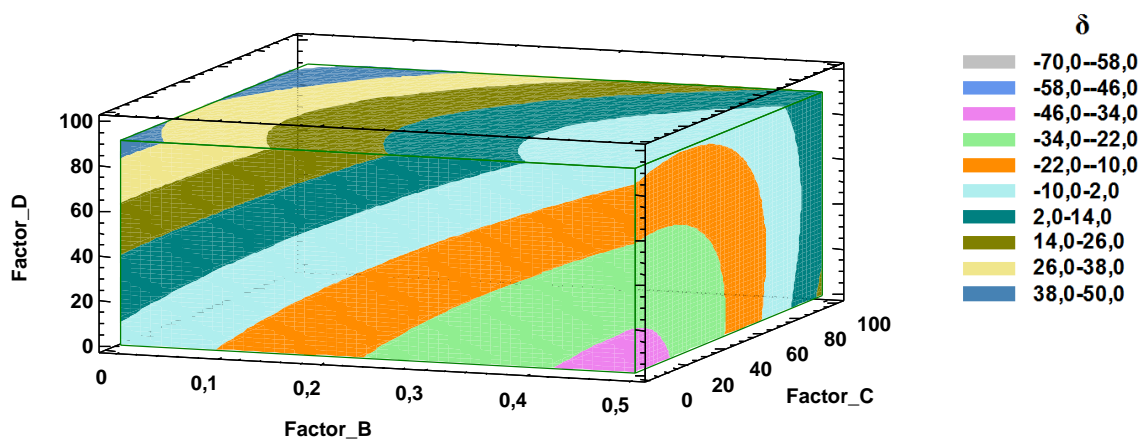


Fig. 3. Change in the dosing error of wood flour with a combination of factors No. 3 (in accordance with Table 4)

Conclusions

With the help of the DS-100 series dispenser it is possible to dose wood flour and sawdust with a mass of 1 kg with an error not exceeding 5%. The optimal combinations of the studied factors are determined, at which the zero value of the dosing error is achieved. Due to hanging of wood chips in the receiving hopper, its dosing with the DS-100 auger is impossible. When dosing carpentry chips, it is necessary to use large augers in order to prevent the material from hanging in the storage hopper.

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