Influence of input parameters setting on the operating process of the weighing system

S Bulatov¹, V Nechaev¹,* and A Sergeev²

¹Engineering Institute, Nizhny Novgorod State Engineering and Economic University, 22a Oktyabrskaya Street, 606340, Knyaginino, Russian Federation
²Main Office, Doza-Agro LLC, 20 Zhirkombinata Highway, 603028, Nizhny Novgorod, Russian Federation

*E-mail: nechaev@ngieu.ru

Abstract. The problem of accuracy and speed of weight dosing of feed ingredients, as well as the material for the production of pellets, remains unresolved. The paper presents the results of experimental studies of the weight dosing system with a screw feeder DH-120. To improve the accuracy and speed of the dosing process, to eliminate subjective errors in the installation; an automatic Schneider control system is implemented. The dosed materials used are different in appearance, physical and mechanical properties, and feed value ingredients: salt, chalk, whole and ground barley grain, sawdust and shavings. Conditionally, at the first stage of the experiment, the input parameters are separated with fixed and variable values. Elements of the experiment planning theory were used to construct the experiment and process the results. The relative error of the weighting is used as the optimization criterion. For the DH-120 auger dispenser, the rational values of the rotational speed of the auger shaft when dosing sawdust and shavings are experimentally established to be 31.24, salts and grains – 28.4, and swept – 34.08 min⁻¹. Thus, based on the results of the analysis, the significance of the input parameters on the efficiency of the weight dosing system is determined.

1. Introduction
At the stage of production of food products, high-quality feed, pellets, as well as packaging of finished products, grain, premixes, sawdust, building mixes, the system of weight dosing has become widespread [1-3]. The main ingredients (more than 1% of the total weight) are dosed on a heavy-duty scale [4]. In this case, the permissible dosage error should be in the range of ±0.1-2% of the dose weight. When dosing micro-components and their mixtures, using small scales, the error must be maintained within ±3% of the productivity of the dispensers [5]. Due to the increasing requirements for dosing accuracy; this system must be continuously improved. Currently, well-known companies are engaged in the development and production of modern weight dosing systems: Ishida (Japan), Bühler AG (Switzerland), Van Aarsen International B V (the Netherlands), Tenzo-M (Russia), Technex (Russia) and others, which also strive to increase the speed and accuracy of the dosing process. However, the high level of technology in the production of the mentioned plants inevitably affects the cost and complexity of the design of the proposed equipment. It is often economically justified to look for the possibility of using simpler dosing systems, but no less reliable in operation. These include a system consisting of a screw feeder and a weight container with load cells. The feeder is necessary for uniform feeding of the material with the required accuracy into the container with the scales. These devices differ in
the level of automation, the number of dosed components, the type of weighing mechanism, etc. [6-8]. Of course, such a system cannot be universal, its accuracy (in our case, the error) will depend on the input parameters: structural and technological, physical and mechanical properties of the material, etc. [9-10]. Further, using the example of a screw dispenser, we will consider the main aspects of this problem. The purpose of the work is to determine the influence of control parameters on the accuracy of dispensing bulk materials.

2. Materials and methods

In the conditions of the experimental scientific and technical laboratory ‘Development experiment analysis Lab maker space’ of Nizhny Novgorod State Engineering and Economic University, an installation was made (figure 1), consisting of screw dispensers with a weight strain gauge system (figure 1a, 1b, table 1). The study of the significance of the input parameters inherent in such systems, as part of our work, will be considered on the example of the DH-120 dispenser (figure 1c). The possible theoretical throughput of this dispenser is from 0.06 to 0.8 kg/s, depending on the material being dosed and the operating mode.

![Figure 1](image-url)

Figure 1. General view of the laboratory installation: screw dispensers with a strain gauge system (a), a cabinet with touch control (b) and a general view of the DH-120 screw (c).

| Table 1. Technical characteristics of installation. |
|-----------------------------------------------|
| Characteristics | DH-60 | DH-100 | DH-120 |
| Screw speed, min⁻¹ | 0-92 | 0-141.5 | 0-142 |
| Electric motor power, kW | 0.37 | 0.75 | 2.2 |
| Screw outer diameter, mm | 53 | 100 | 120 |
| Turn pitch, mm | 24 | 90 | 110 |
| Spiral pen height, mm | 11 | 29 | 40 |
| Inner diameter of the casing, mm | 60 | 104 | 140 |
| Overall dimensions of the installation in the working position, mm: | | | |
| - length | 1800 | | |
| - width | 1300 | | |
| - height | 1750 | | |

Of course, with a sufficiently high throughput of the screw dispenser and low-weight attachments, it will be risky to hope for high accuracy of the process. However, due to the capabilities of the sensor terminal filling, as well as the applicable elements of the experiment planning methodology, the possibility of determining the optimal values of the control parameters under such conditions is not
excluded. A detailed description of the plant control system is presented in the early works [10]. It is necessary to explain the parameters that are assumed to be variable in terms of the factor experiment and are set via the interface. Setting the frequency of the dispenser is a value expressed in Hertz (Hz), at which the required maximum frequency (speed) of rotation of the screw is achieved over a certain period of time. Setting the filling of the dispenser (Hz) is related to the value of the screw speed in the filling mode. Pre-loading settings (kg) – the value at which the dispenser is switched off before reaching the weight of the hitch. In other words, it is the mass of the flying column. Setting the filling speed on (%) - the percentage of the weight of the suspension of one component, when it is reached, the filling mode is turned on at the dispenser.

To evaluate the weight dosing system, we used bulk materials that differ in their purpose and physical and mechanical properties: sawdust and shavings (LPC Poleco LLC, Russia), salt (grinding №1, Araltuz Co, Kazakhstan), whole and ground barley grain (Elf grade, Pokrovskaya Sloboda Co, Russia), chalk (fodder natural ground, Agrovit LLC, Russia). The material parameters that affect the weight dosing process are shown in table 2. As is known, internal friction also affects the angle of natural slope, the definition of which is shown in figure 2 for various bulk materials: sawdust (figure 2a), salt (figure 2b), chalk (figure 2c), shavings (figure 2d), crushed barley grain (figure 2e) and whole barley grain (figure 2f). In the laboratory during the research the temperature was maintained in the range from 20 to 22 °C and the relative humidity was 55-60%.

In the weighing system (figure 1a), three load cells T2 (of the company ‘Tenzo-M’ [11]) of the beam type with articulated supports and a maximum load of up to 50 kg are installed.

To determine the relative dosage error, well-known methods and dependencies were used. The control weight of the suspension was taken to be equal to 1 kg.
3. Results and discussion

At the first stage of the research, we will consider the influence of the control parameters of the system on the accuracy of dosing. To do this, the Box-Benkin plan is implemented \(3^4\): \(X_1\) - setting the frequency of the dispenser \(N_1\), Hz; \(X_2\) - installation of the pre-emptive filling \(U_1\), kg; \(X_3\) - setting the top-up speed on \(U_2\), %; and \(X_4\) - installation of the filling dispenser (frequency of the dispenser) \(N_2\), in % \(N_1\).

The first factor \(X_1(N_1)\) was set to 10 Hz (lower level), 30 Hz (main level) and 50 Hz (upper level). The second \(X_2(U_1)\) was introduced equal to 0.1, 0.3 and 0.5 kg. The third \(X_3(U_2)\) is 10, 50 and 90%. The fourth \(X_4(N_2)\) is 10, 55 and 100% of the frequency value of \(N_1\). In the course of the studies, the influence of the studied factors on the optimization criterion \(Y\) - the relative error of the weight dosage \(P\), % - was evaluated. The matrix of the plan and the results of the experiment are presented in table 3. After processing the results of the studies shown in table 3, regression models (1-5) of the workflow were obtained (insignificant factors were excluded):

\[
Y_1 = 25.969 + 55.642 \cdot X_1 - 19.208 \cdot X_2 + 21.867 \cdot X_3 + 18.983 \cdot X_4 + 8.457 \cdot X_1^2 + 20.575 \cdot X_1 \cdot X_3 + 11.4 \cdot X_1 \cdot X_4 - 18.425 \cdot X_3 \cdot X_4 + 9.545 \cdot X_4^2
\]

\[
Y_2 = 411.0 + 176.775 \cdot X_1 - 44.758 \cdot X_2 + 69.625 \cdot X_3 + 49.858 \cdot X_4 - 142.825 \cdot X_1^2 - 74.475 \cdot X_3 \cdot X_4
\]

\[
Y_3 = 127.76 + 86.992 \cdot X_1 - 24.367 \cdot X_2 + 34.8417 \cdot X_3 + 21.75 \cdot X_4 - 39.1017 \cdot X_1^2 - 39.45 \cdot X_3 \cdot X_4
\]

\[
Y_4 = 210.389 + 126.517 \cdot X_1 - 22.8083 \cdot X_2 + 48.3083 \cdot X_3 + 26.0667 \cdot X_4 - 55.0792 \cdot X_1^2 - 41.575 \cdot X_3 \cdot X_4 + 21.6708 \cdot X_4^2
\]

\[
Y_5 = -3.448 + 44.45 \cdot X_1 - 22.15 \cdot X_2 + 18.608 \cdot X_3 + 15.542 \cdot X_4 + 16.014 \cdot X_1^2 + 28.05 \cdot X_1 \cdot X_3 + 12.376 \cdot X_3^2 + 14.926 \cdot X_4^2
\]
Table 3. The matrix of the plan and the results of the experiment.

| p/p No | Setting the frequency of the dispenser \( N_1 \), Hz | Installation of the pre-emptive filling \( U_1 \), kg | Setting the top-up speed on \( U_2 \), % | Installation of the filling dispenser (frequency of the dispenser) \( N_2 \), in % \( N_1 \) | \( X_1 \) | \( X_2 \) | \( X_3 \) | \( X_4 \) | \( Y_1 \) | \( Y_2 \) | \( Y_3 \) | \( Y_4 \) | \( Y_5 \) |
|--------|-----------------------------|-----------------------------|-----------------------------|---------------------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| 1.     | 0.0 | 0.0 | 0.0 | 0.0 | 22.3 | 448.1 | 154.3 | 206.4 | -9.8 |
| 2.     | -1.0 | -1.0 | 0.0 | 0.0 | 0.3 | 128.2 | 20.2 | 50.4 | -3.3 |
| 3.     | 1.0 | -1.0 | 0.0 | 0.0 | 111.4 | 482.6 | 209.9 | 303.5 | 69.4 |
| 4.     | -1.0 | 1.0 | 0.0 | 0.0 | -41.0 | 72.7 | -12.6 | 19.3 | -42.7 |
| 5.     | 1.0 | 1.0 | 0.0 | 0.0 | 51.5 | 399.6 | 132.0 | 233.8 | 14.3 |
| 6.     | 0.0 | 0.0 | -1.0 | -1.0 | -22.1 | 179.9 | 28.0 | 114.7 | -26.4 |
| 7.     | 0.0 | 0.0 | 1.0 | -1.0 | 51.6 | 485.8 | 180.9 | 285.8 | 25.3 |
| 8.     | 0.0 | 0.0 | -1.0 | 1.0 | 53.9 | 493.5 | 155.2 | 259.9 | 30.6 |
| 9.     | 0.0 | 0.0 | 1.0 | 1.0 | 75.9 | 389.0 | 143.6 | 249.2 | 55.8 |
| 10.    | -1.0 | 0.0 | 0.0 | -1.0 | -26.1 | 87.6 | -15.9 | 29.2 | -29.0 |
| 11.    | 1.0 | 0.0 | 0.0 | -1.0 | 75.9 | 389.0 | 143.6 | 249.2 | 55.8 |
| 12.    | -1.0 | 0.0 | 0.0 | 1.0 | 10.1 | 123.4 | 14.7 | 50.7 | -19.0 |
| 13.    | 1.0 | 0.0 | 0.0 | 1.0 | 137.5 | 484.6 | 219.3 | 345.4 | 102.5 |
| 14.    | 0.0 | 0.0 | 0.0 | 0.0 | 22.3 | 448.1 | 154.3 | 206.4 | -9.8 |
| 15.    | 0.0 | 0.0 | -1.0 | -1.0 | 23.7 | 254.8 | 77.9 | 142.6 | 19.5 |
| 16.    | 0.0 | 1.0 | -1.0 | 0.0 | -12.1 | 213.8 | 44.9 | 115.3 | -22.4 |
| 17.    | 0.0 | 0.0 | 1.0 | 1.0 | 71.1 | 515.4 | 199.3 | 301.2 | 54.0 |
| 18.    | 0.0 | 1.0 | 1.0 | 0.0 | 33.5 | 429.2 | 134.5 | 261.0 | 4.0 |
| 19.    | -1.0 | 0.0 | 0.0 | -1.0 | -19.0 | 65.2 | -6.8 | 16.6 | -21.9 |
| 20.    | 1.0 | 0.0 | 0.0 | -1.0 | -19.0 | 65.2 | -6.8 | 16.6 | -21.9 |
| 21.    | -1.0 | 0.0 | 0.0 | 1.0 | 47.1 | 437.2 | 153.6 | 268.1 | 20.7 |
| 22.    | 1.0 | 0.0 | 1.0 | 1.0 | 136.1 | 476.7 | 195.5 | 334.3 | 134.0 |
| 23.    | 0.0 | 0.0 | 0.0 | 1.0 | 25.3 | 481.2 | 124.3 | 247.9 | 15.5 |
| 24.    | 0.0 | 0.0 | -1.0 | -1.0 | -12.1 | 213.8 | 44.9 | 115.3 | -22.4 |
| 25.    | 0.0 | 0.0 | 1.0 | 0.0 | 75.4 | 535.9 | 154.0 | 292.0 | 62.8 |
| 26.    | 0.0 | 0.0 | 0.0 | 1.0 | 33.3 | 422.3 | 106.5 | 235.5 | 17.7 |
| 27.    | 0.0 | 0.0 | 0.0 | 0.0 | 22.3 | 448.1 | 154.3 | 206.4 | -9.8 |

The research results were processed on a personal computer using the Portable Statgraphics Centurion 15 software application for Windows. The degrees of confidence in the approximation of the obtained regression models (1)-(5) \( R^2 \) were 97, 89, 92, 95 and 88%, respectively.

From the analysis of the obtained regression equations it can be noted that the general tendency to reduce the relative dosing error for all cases is a decrease in the speed of the electric dispenser drive (sufficient coefficient before \( X_1, X_1^2, X_4, X_4^2 \)), the weight of the material suspension at which the filling mode is activated (coefficient before \( X_3 \)) as well as an increase in the mass at which the dispenser is
switched off not reaching the value of the control hitch (coefficient before $X_2$). There is an equally significant relationship between different combinations of factors on the optimization criterion.

For a visual representation of the obtained equations (1-5) the response surfaces are constructed (figures 3-7) with factors fixed at zero $X_2$ and $X_4$. It can be seen that the chosen optimization criterion tends to the lowest values for $X_1$ and $X_3$ from 0 to -1.

Figure 3. Change in the sawdust dosing error.

Figure 4. Change in the salt dosing error.

Figure 5. Change in the chalk dosing error.
A more in-depth analysis of the obtained equations using the capabilities of the Statgraphics software application allowed us to determine the combinations of rational values of factors that provide a value of the relative error of weighing close to zero with a confidence probability determined by the coefficient of determination $R^2$. A possible variant of the optimal tuning parameters is summarized in table 4 in decoded form, i.e. in the form in which the technological parameters are set on the touch control panel.

**Table 4. Configuration parameters.**

| Parameter | Optimum when dosing bulk materials |
|-----------|-----------------------------------|
| Sawdust   | Salt | Chalk | Whole and ground barley grain | Wood shaving |
| $N_1$, Hz | 11   | 10    | 12                             | 10           |
| $U_1$, kg | 0.11 | 0.33  | 0.29                           | 0.5          |
| $U_2$, %  | 52   | 14    | 51                             | 33           |
| $N_2$, Hz | 5    | 5     | 5                              | 5            |

The test confirmed that the search experiment allowed us to determine the combination of optimal parameter values fairly accurately. So, taking into account the possible measurement error rounding and incomplete coverage of the studied factors the following data were obtained. The relative error of weight dosing for sawdust was from 3.6-4%, salt from 6.5-7.3%, and others-up to 6%. With a screw turn step of 110 mm and a control weight of 1 kg the result met expectations. The error value can be further reduced by making additional adjustments to the process parameters through the control cabinet.
4. Conclusion
A laboratory installation for evaluating the accuracy of weight dosing has been developed including a control cabinet with a human-machine interface, three screw dispensers DH-60, DH-100, DH-120 of different capacities and a strain gauge system. For the screw dispenser DH-120 when dosing bulk materials, the rational values of the control parameters that provide the permissible values of the relative error are experimentally established. The speed of rotation of the screw shaft setting such parameters when dosing sawdust and chips is 31.24, salt and grain – 28.4, chalk –34.08 min\(^{-1}\). In the filling mode, respectively, for all but the chips the rotation speed changes to the value of 14.2 min\(^{-1}\). Thus, the DH-120 screw dispenser can achieve the required accuracy of dosing bulk materials weighing up to 1 kg by determining the rational combination of control parameters. The obtained significance of these parameters can be taken into account when developing similar systems. The presented results make it possible to expand the use of weight dosing with a screw working body in adjacent areas of production with high process accuracy. The low cost and reliability of the presented system will provide additional savings in financial costs.

References
[1] Imole O I, Krijgsman D, Weinhart T, Magnanimo V, Chavez Montes B E, Ramaioli M and Luding S 2016 Experiments and discrete element simulation of the dosing of cohesive powders in a simplified geometry. *Powder. Technol.* 287 108 doi: org/10.1016/j.powtec.2015.07.052
[2] Bulatov S, Nechaev V, Savinyh and Rucins A 2021 Research results of experimental automated system for dosing bulk materials. *Eng. Rur. Develop.* 43 199 doi: org/10.22616/ERDev.2021.20.TF043
[3] Chadha G S, Westbrink F, Schütte T and Schwung A 2018 Optimal dosing of bulk material using mass-flow estimation and DEM simulation. *IEEE International Conference on Industrial Technology* 256 doi: org/10.1109/ICIT.2018.8352186
[4] The System of Components Dosing in Compound Feed. Information Portal Soft-Agro. available at: https://soft-agro.com/kormoproizvodstvo/dozirovanie-komponentov-kombikormov.html
[5] Bulatov S Yu, Nechaev V N, Sergeev A G and Savinykh P A 2021 Results of studies of weight dosing of feed. *Machinery and Equipment for Rural Area* 1(283) 20 doi: org/10.33267/2072-9642-2021-1-20-24
[6] Jovanović A, Pezo L, Stanojlović S, Kosanić N and Lević L 2015 Discrete element modelling of screw conveyor-mixers. *Hem. Ind.* 69(1) 95 doi: org/10.2298/HEMIND130412026J
[7] Krasnov I N, Globin A N and Ryasny A V, Ru Patent No. 2.676.552 (1 January 2019)
[8] Shimuzu Y and Cundall P A 2001 Three-Dimensional DEM Simulations of Bulk Handling by Screw Conveyors. *J. Eng. Mech.* 127(9) 864 doi: org/10.1061/(ASCE)0733-9399(2001)127:9(864)
[9] Tardos G and Lu Q 1996 Precision dosing of powders by vibratory and screw feeders: an experimental study. *Adv. Powder. Technol.* 7(1) 51 doi: org/10.1016/S0921-8831(08)60891-2
[10] Kassem B E, Heider Yo, Brinz Th and Markert B 2020 A multivariate statistical approach to analyze the impact of material attributes and process parameters on the quality performance of an auger dosing process. *J. Drug Deliv. Sci. Tec.* 60 101950 doi: org/10.1016/j.jddst.2020.101950
[11] *Load Cells*. Tenso-M Weighing Company. available at: https://www.tenso-m.ru/tenzodatchiki/