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METHODOLOGY FOR INVESTIGATING THE CALIBRATION PROCESS OF A GRAVITATIONAL FEEDER FOR BULK MATERIALS IN FLOW

Ivan DEMKIV, Postgraduate Student
Lviv Polytechnic National University

ДЕМКІВ Іван Богданович, аспірант
Національний університет «Львівська політехніка»

The development of any manufacturing industry is not possible without the rational use of resources, so it is difficult to imagine modern production in which dosing is not used. The accuracy and productivity of dosing equipment is the basis of all known technological processes, since the quality of the final product depends on it. Belt feeders are small-sized and highly productive equipment, which is a vital necessity of continuous technological processes.

The main requirement for a belt feeder is the maximum possible accuracy at an already set speed of movement of the load (line productivity). However, one should not forget about the peculiarities of the behavior of different types of products that can be weighed.

The weighing accuracy of a belt feeder also depends on its design features, namely on the accuracy of the drive, tension or support rollers, the quality of the belt, and the design of the strain gauge assembly.

Experiments on calibration in statics and the behavior of the feeder in dynamics will allow us to evaluate possible behavior options during operation in real conditions.

The purpose of the experiments is the initial setup of the experimental setup for further research into the relationship of belt speed / product type / dosing accuracy.

The article describes the structure of the experimental setup, the composition of the measuring part of the laboratory setup, as well as the methodology for collecting and processing experimental data.

The main attention of the experimental part is paid to the dynamic mode of operation and its impact on the strain gauge assembly. The main issues that arise in the dynamic mode are outlined, namely

Special attention is paid to the dynamic feed mode, in which the loads on the measuring element – the strain gauge sensor – change. The key problems that arise in this mode are indicated: fluctuations in the output signal (change in mass values), the influence of the product movement speed, the physical and mechanical characteristics of the product. The results of the experiments are the voltage/mass curves in the static mode and voltage/mass/speed in the dynamic mode, a comparative analysis of the measurement results.

According to the research results, an adaptive control system for a belt feeder will be developed, which can be implemented in all industries where belt feeders are used.

Keywords: *belt feeder, strain gauge unit, transportation speed, dynamic weighing, belt speed, adaptive control system, weighing.*

Eq. 2. Fig. 5. Table.4. Ref. 12.

1. Problem formulation

The development of any manufacturing industry is impossible without rational use of resources, so it is difficult to imagine modern production in which dosing is not used. The accuracy and productivity of dosing equipment are the basis of all known technological processes, since the quality of the final product depends on it.

Belt feeders are small-sized and highly productive equipment, which is a vital necessity of continuous technological processes. Achieving the maximum possible dosing accuracy is complicated by the dynamics of the product's behavior during transportation and the requirements for the accuracy of the weighing unit. Solving the problem of dosing bulk products in a continuous flow is based on determining the optimal kinematic-dynamic parameters of the belt feeder.

A feature of the operation of the belt feeder is that the establishment of a connection between the mass of the product and the output signal of the strain gauge unit - calibration, occurs in static mode, and weighing (dosing) of the target product - in dynamics. Dynamic mode of transportation is a multifactorial complex system in which the readings of the strain gauge unit are influenced by the size of particles, inertia, angle of natural slope, surface tension of the material, and design features of the belt feeder elements.

The effectiveness of a modern belt feeder will be determined by the quality of the control system, which will be based on the optimal ratio of the speed of movement to the physical properties of the product. The construction of this system is based on the collection and analysis of statistical data from planned multifactorial experiments, since such an experiment allows you to visually assess the behavior of the material and scale it to real production.

Therefore, the study of dynamic dosing with a belt feeder aims to optimize dosing accuracy, ensure reproducibility of results in different operating modes, and create prerequisites for the creation and implementation of adaptive control systems for the operation of belt feeders.

2. Analysis of recent research and publications

Analyzing the research, several main research directions can be distinguished: the influence of material behavior, the influence of the design parameters of the batcher and the control system of the batching process.

The work [1] Živanić D, Ilanković N is devoted to the study of the influence of belt speed, tension and position of the measuring roller on the accuracy of batching. The article [2] describes a high-precision dynamic model that takes into account the uneven distribution of bulk material on the belt. The model is based on laser scanning and allows optimizing the belt speed to increase energy efficiency and operational safety.

The work of Peleg M. [3] describes methods for assessing the fluidity of powdery materials from the point of view of the influence on the accuracy of their batching. The study [4] compares different designs of belt conveyors for transporting bulk materials in order to determine the most cost-effective option.

The article [5] presents a method for optimizing the conveyor belt speed to reduce energy consumption and improve the dynamic behavior of the system when transporting bulk materials. There are also works [6] on the influence of the shape of the hopper on the flow of bulk material and the distribution of stresses at the interface of the hopper and the belt feeder. The results help to optimize the design to ensure a stable flow of material.

It is worth noting the works related to adaptive control systems [7, 8] that take into account the complex dynamics of the product flow.

The physical properties of the product should also be taken into account when formulating the requirements for dosing accuracy. Depending on the operating conditions and accuracy requirements, an appropriate calibration method should be chosen (for example, electronic calibration or the use of calibration chains). It is worth paying attention to the work that describes recommendations for calibration accuracy [9].

In work [10], a methodology for modeling and simulating the dynamic interaction of belt systems using the discrete element method (DEM) is presented.

The thesis [11] investigates the interaction of bulk materials with belt conveyor systems, including transportation, unloading and redirection. The author uses the discrete element method (DEM) and continuum mechanics to model and validate the results using laboratory experiments.

In [12], the development of an improved controller for a belt feeder is presented, which ensures accurate dosing of material in a chemical process. The system uses feedback to regulate the belt speed, compensating for changes in the density of the material.

The works listed above make it possible to outline the direction of research on belt feeders, taking into account both the properties of materials and design features. However, the goal of the study is to build an adaptive control system that would be suitable for most belt feeders by conducting in-depth experimental studies and building methodologies for these studies.

3. The purpose of the article

The purpose of the study is to substantiate and implement an experimental method for constructing static and dynamic calibration characteristics of a gravity feeder for bulk materials in a flow.

The objectives of the research are to analyze the influence of the mass and speed of product movement on the output voltage of the strain gauge; to construct the "mass - voltage" relationships in static and dynamic operating modes; to assess the influence of feed modes on the value of the output signal; to formulate recommendations for implementing the research results in production.

4. Results and discussion

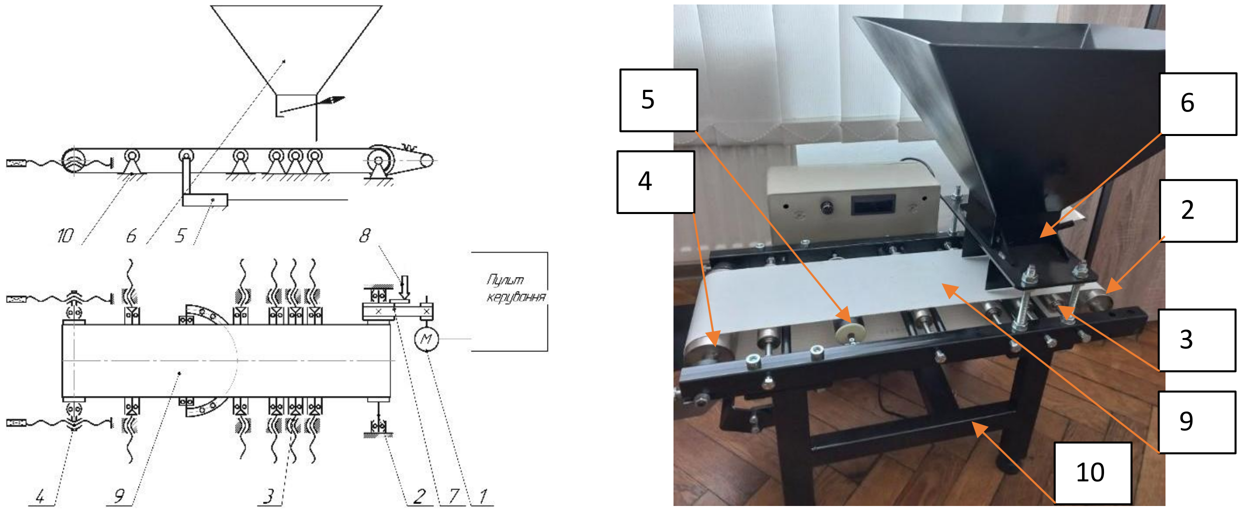
The main purpose of the study is to set up a laboratory setup to determine the parameters in static mode and compare these parameters with the dynamic mode.

The comparative characteristic will be the basis for the initial optimization of the ratio of movement speed/type of cargo.

The general structural diagram of the belt feeder is shown in Fig. 1.a. The basis of the design of the belt feeder is a belt conveyor.

The product to be studied is loaded into the hopper (6). The hopper (6) is equipped with a slide valve with a scale. The product unloading zone from the hopper (6) to the belt (9) is equipped with support rollers (3). The belt (9) is driven by a stepper motor (1) through a drive roller (2) and a tension roller (4). The stepper motor has the ability to change the shaft rotation frequency.

The mass parameters are measured using a strain gauge assembly (5). The assembly (5) consists of a bracket, a strain gauge and a dynamically balanced roller. The transport speed is measured using a pulse sensor (8). All components are mounted on a common frame (10).



a –structural diagram *b – general appearance*

Fig. 1. Belt dispenser

To calibrate the belt feeder, a laboratory setup was assembled, which included a power supply, a strain gauge amplifier, and an oscilloscope for analog signal processing (Fig. 2).

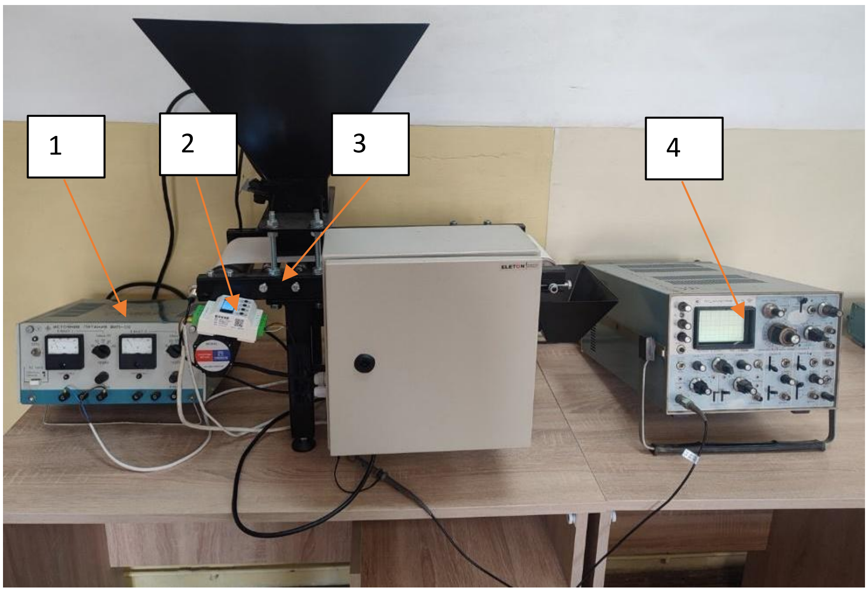


Fig. 2. General view of the laboratory setup:
1 – power supply; 2 – strain gauge; 3 – belt dispenser; 4 – oscilloscope

The sequence of research was as follows:

- Connecting and configuring the strain gauge amplifier to output an analog signal (0…5 V);
- Calibration of the strain gauge assembly with a reference load with a nominal value of 1 kg (Fig. 3.b.);
- Obtaining voltage values from the mass of the reference load in static mode;
- Obtaining voltage values from the mass of the reference load in dynamic mode at different drive shaft rotation frequencies;
- Recording of research results (Tables 1).

According to the formula $v = \frac{\pi * D * n}{60 * 10000}$, m/s we determine the linear speed of movement of the cargo in dynamic mode.

a – strain gauge assembly

b – calibration with a reference load

Fig. 3 Static calibration of the belt feeder

Table 1

Recording of research results

D = 62, mm	n = 60 rpm	n = 40 rpm	n = 20 rpm
v, m/s	0,195	0,13	0,065

The results of laboratory tests are given in Tables 2 and 3.

Table 2

Static calibration

Mass value, g	Voltage, V
50	0,23
100	0,51
150	0,73
200	1,01
250	1,23
300	1,51
350	1,73
400	2,01
450	2,24
500	2,51
550	2,76
600	3,02
650	3,23
700	3,49
750	3,74
800	3,99
850	4,23
900	4,49
950	4,74
1000	5,01

Table 3

Dynamic operating mode

	Mass value, g	Belt speed m/s		
		0,195	0,13	0,065
Voltage, V	50	0,2	0,21	0,21
	100	0,45	0,48	0,48
	150	0,62	0,65	0,7
	200	0,9	1,1	1,1
	250	1,15	1,17	1,21
	300	1,45	1,47	1,51
	350	1,65	1,68	1,69
	400	1,97	1,99	2,01
	450	2,15	2,18	2,2
	500	2,35	2,3	2,5
	550	2,68	2,72	2,74
	600	2,95	2,98	3
	650	3,15	3,18	3,21
	700	3,37	3,3	3,3
	750	3,68	3,71	3,72
	800	3,9	3,95	3,96
	850	4,19	4,2	4,2
	900	4,35	4,4	4,44
	950	4,68	4,7	4,71
	1000	4,89	4,8	4,92

Based on the obtained data, we construct graphs of the dependence of voltage on mass in static and dynamic modes.

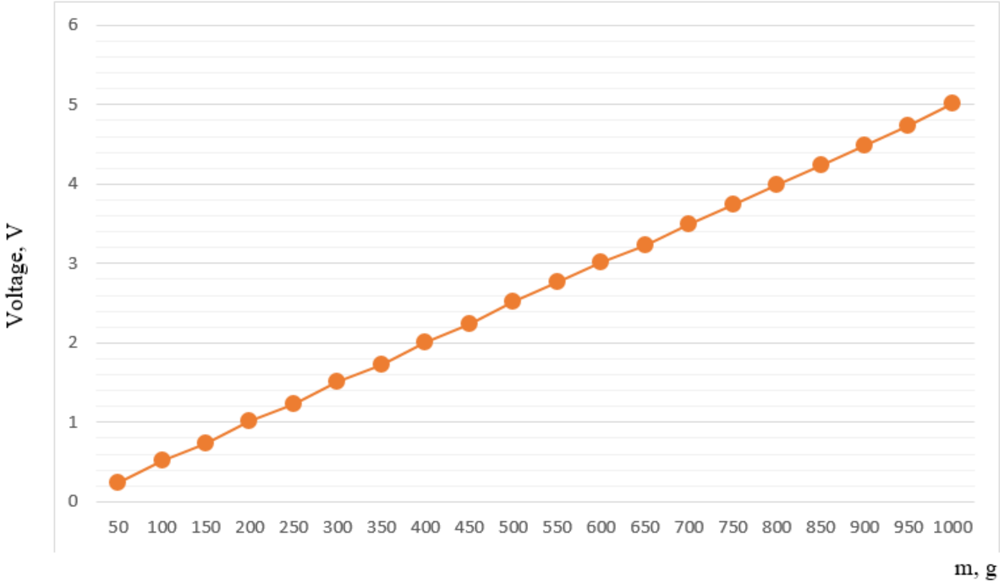


Fig. 4. Graph of voltage dependence on reference mass in statics

Calibration in static mode shows an almost linear dependence of voltage on mass. With an increase in mass by every 50 g, the voltage increases by an average of ≈ 0.25 V

The resulting curve is described by the least squares method, following the equation:

$$U = k \cdot m + Uo, \tag{1}$$

where slope coefficient k = 0.00496 V/g; offset (U_o) = -0.017 V

Equation (1) will take the form:

$$U = 0{,}00496 \cdot m - 0{,}017$$

where U – value of the reference mass voltage; m – value of the reference mass.

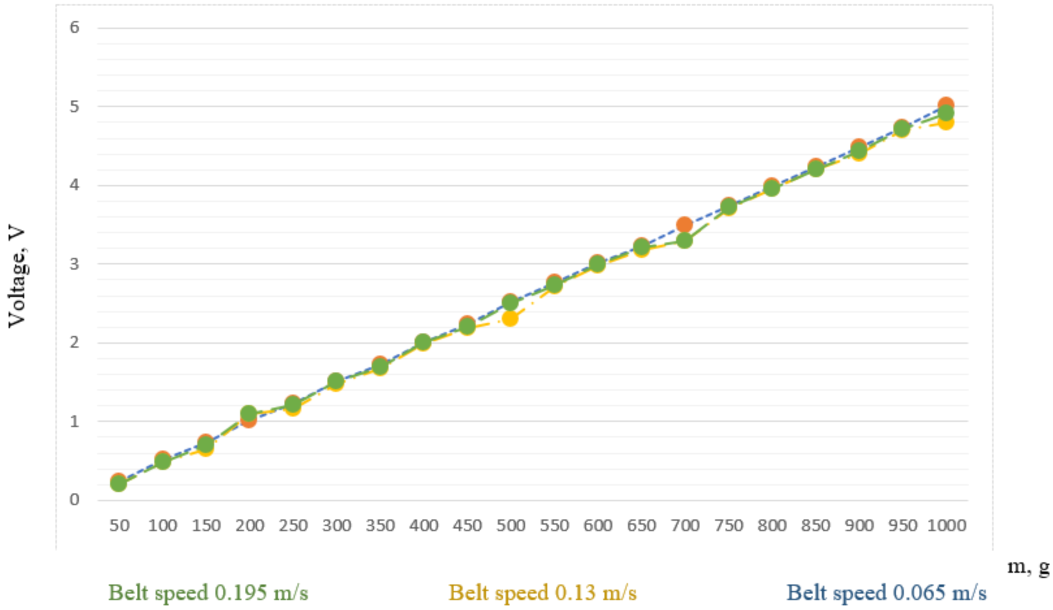


Fig. 5. Graph of voltage dependence on reference mass in dynamics

All three graphs in dynamics demonstrate linearity. This means that the strain gauge and the measuring stand work stably, and the mass of the load on the belt is proportional to the voltage value. At the lowest speed (0.065 m/s), the voltage indicators are slightly higher than at higher speeds for the same mass. This can be explained by the fact that at higher speeds the material may not have time to fully compress due to the effect of inertial unloading, which reduces the pressure.

The optimal transportation speed can be considered the speed at which there is the smallest error relative to the static mode.

$$\mathrm{A}(v) = \frac{1}{n}\sum_{i=1}^{n} \left(U_{dyn}^{(i)}(v) - U_{stat}^{(i)}\right)^2 , \quad (2)$$

where U_{stat} –output voltage in static, V; U_{dyn} –output voltage in the speaker, V; v – tape speed

The values of the calculated standard errors are given in Table 4.

Table 4

Standard error values

v, м/с	0,195	0,13	0,065
$\mathrm{A}(v)$	0,0144	0,0136	0,0125

The results show that when the speed is reduced, the dynamic measurements approach the static values, which is the expected result. However, for each type of product, the transport speed will be selected individually. This will allow us to recognize the optimal ratio of dosing accuracy to productivity.

5. Conclusion

The result of the research is the development and experimental justification of the method for calibrating a belt feeder in static mode, and checking the convergence of readings in static and dynamic. A belt feeder is a rather complex mechanical system, where the output voltage of the strain gauge is influenced by both the design features of the feeder itself and the properties and behavior of the product at different transport speeds. Therefore, it is important to achieve maximum accuracy in setting operating parameters and correctly take into account the influence of external factors such as transport speed and physical properties of the material.

Analysis of the research results made it possible to obtain the law of change of the voltage/mass dependence, and to predict the strain gauge readings with respect to this law when the mass of the material changes, which provides the possibility of integrating the system into modern automated lines with real-time control.

Dynamic experiments have shown that for each specific type of product it is possible to select the optimal transportation speed to achieve maximum weighing accuracy, which is the basis of the adaptive control system.

In order to optimize the operation of the batcher, the optimal speed for a specific type of product was determined for which the root mean square error between dynamic and static data is minimal, which is confirmed by calculations according to formula 2.

The developed adaptive control system based on experimental data can be adapted to all industries where belt batchers are used.

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МЕТОДОЛОГІЯ ДОСЛІДЖЕННЯ ПРОЦЕСУ КАЛІБРУВАННЯ ГРАВІТАЦІЙНОГО ДОЗАТОРА ДЛЯ СИПКИХ МАТЕРІАЛІВ У ПОТОЦІ

Розвиток будь якої виробничої галузі не можливий без раціонального використання ресурсів, тому увагу важко уявити сучасне виробництво, в якому не використовується дозування. Точність та продуктивність дозуючого обладнання є основою всіх відомих технологічних процесів, оскільки від цього залежить якість кінцевого продукту. Стрічкові дозатори являють собою малогабаритне та високопродуктивне обладнання, яке є життєвою необхідністю безперервних технологічних процесів.

Основною вимогою до стрічкового дозатора є максимально можлива точність при вже встановленій швидкості переміщення вантажу (продуктивності лінії). Проте не варто забувати про особливості поведінки різних типів продукту, що може підлягати зважуванню.

Точність зважування стрічкового дозатора залежить також від його конструктивних особливостей, а саме від точності привідних, натяжних чи підтримуючих роликів, якості стрічки, конструкції тензовимірювального вузла.

Експерименти щодо калібрування в статиці та поведінка дозатора в динаміці дадуть змогу оцінити можливі варіанти поведінки під час експлуатації в реальних умовах.

Метою проведення експериментів є початкове налаштування експериментальної установки для проведення подальших досліджень співвідношення швидкість стрічки / тип продукту / точність дозування.

В статті описано будову експериментальної установки, склад вимірювальної частини лабораторної установки, а також метод методологію збору та обробки експериментальних даних.

Основна увага експериментальної частини приділена динамічному режиму роботи та його впливу на тензовимірювальний вузол. Окреслено основні питання, що виникають при динамічному режимі, а саме

Особлива увага приділена динамічному режиму подачі, при якому змінюються навантаження на вимірювальний елемент — тензометричний датчик. Зазначено ключові проблеми, що виникають у такому режимі: флуктуації вихідного сигналу (зміна значень маси), вплив швидкості переміщення продукту, фізико-механічні характеристики продукту. Результатом проведення експериментів є криві напруга/маса в статичному режимі та напруга/маса/швидкість в динамічному режимі, порівняльний аналіз результатів вимірювань.

Згідно з результатами досліджень буде розроблено адаптивну систему керування стрічковим дозатором, яка може бути впроваджена в усіх галузях промисловості, де використовуються стрічкові дозатори.

Ключові слова: *стрічковий живильник, тензометричний блок, швидкість транспортування, динамічне зважування, швидкість стрічки, адаптивна система керування, зважування.*

Рис. 8. Літ. 23.

INFORMATION ABOUT THE AUTHORS

Ivan DEMKIV – Postgraduate Student of the department of Machine Design and Automotive Engineering, Lviv Polytechnic National University (12 Stepan Bandera Str., Lviv, Ukraine, 79013, e-mail: ivan.b.demkiv@lpnu.ua, https://orcid.org/0009-0009-6704-9574).

ДЕМКІВ Іван Богданович – аспірант кафедри проєктування машин та автомобільного інжинірингу, Національного університету «Львівська політехніка» (вул. Степана Бандери, 12, м. Львів, Україна, 79013, e-mail: ivan.b.demkiv@lpnu.ua, https://orcid.org/0009-0009-6704-9574).