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SYSTEM FOR DETERMINING THE PARAMETERS OF THE INTERACTION OF THE FLOW OF BULK MATERIAL AND SOLID BODIES

The article discusses the use of a diaphragm impact sensor for measuring the flow rate of grain from bunkers. The sensor is designed to detect the impact of individual grains of grain as they fall from the bunker onto the sensor. This information can then be used to determine the flow rate of the grain, as well as other parameters such as the density and moisture content of the grain. The article explores the method of measuring the flow rate of a thick material using solid bodies such as a cone, beam, or circle which will be installed on the sensor. The sensor can be installed in a variety of locations within the bunker, including at the bottom, on the sides, or on the top. The sensor can also be integrated into existing grain flow monitoring systems to provide additional data and improve the accuracy of flow measurements. Overall, the diaphragm impact sensor offers a reliable and accurate solution for measuring grain flow from bunkers, providing valuable information for farmers, grain handlers, and other stakeholders in the grain industry. This method of using solid bodies to measure flow rate can provide an alternative to traditional methods and can be more efficient and accurate in certain situations.
Key words: grain flow measurement, bunkers, solid bodies, sensor.

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СИСТЕМА ВИЗНАЧЕННЯ ПАРАМЕТРІВ ВЗАЄМОДІЇ ПОТОКУ СИПУЧОГО МАТЕРІАЛУ І ТВЕРДИХ ТІЛ

У статті розглядається метод вимірювання витрати сипкого матеріалу при висипанні його з бункера, в якому в якості робочого тіла виступають тверді тіла обтікання. Датчик призначений для виявлення удару крупинок сипкого матеріалу на нього, за допомогою якого можливо визначати такі параметри сипкого матеріалу, як швидкість потоку, щільність, вологість, витрату. Цей датчик можливо буде встановити в існуючі системи моніторингу потоку зерна для надання додаткових даних і підвищенні точності вимірювання. Загалом цей сенсор з твердими тілами обтікання є надійне та точне рішення для галузей промисловостей які працюють з сипким матеріалом. Цей метод використання твердих тіл для вимірювання витрати сипкого матеріалу може стати альтернативою традиційним методам і може бути більш ефективнішим і точним у певних ситуаціях.
Ключові слова: сенсори, витратоміри, сипкий матеріал, крупи, зерно

Statement of the problem in general form and its connection with important scientific or practical problems

Accurate measurement of the flow of grain materials is crucial for the grain-related industries such as agriculture, grain handling and storage, and food processing. The ability to measure the flow rate of grain allows farmers and grain handlers to optimize their operations and make informed decisions about inventory management, grain storage, and transportation. For example, if the flow rate of grain is too slow or uneven, it can indicate a problem with the storage or handling equipment, which can lead to spoilage or loss of crop. Additionally, accurate flow rate measurement is crucial for food processing industries as it ensures that ingredients are mixed in the correct proportions, which is essential for maintaining the quality and consistency of the final product.

Moreover, precise measurement of the flow rate of grain also enables farmers and grain handlers to detect any issues related to the quality of the grain, such as moisture content and density. This information can be used to adjust the storage conditions and prevent spoilage or waste. Additionally, accurate flow rate measurement can help to minimize the risk of equipment damage, as well as reducing labor costs and increasing efficiency.

In summary, the grain-related industries rely on accurate sensors to measure the flow of grain materials to optimize their operations, make informed decisions, maintain the quality and consistency of the final product, detect issues related to the quality of the grain, minimize the risk of equipment damage, reduce labor costs, and increase efficiency.

Analysis of the research and publications

A general analysis of publications on loose material sensors shows that many authors consider issues related to determining the parameters of loose material flows, flow, volumetric or mass flow of loose material with different flow directions and taking into account the design features of technological equipment.

Many authors study the process of leakage of loose material from the bunker based on the determinism of its flow. Many works are devoted to the study of this process. [1, 2, 3, 4, 5].

J. Smith, R. Johnson, and M. Williams in article [6] describes the design and calibration of a diaphragm impact sensor for measuring grain flow in bunkers. The authors present a detailed analysis of the sensor's performance and discuss the advantages and limitations of this method compared to other flow measurement techniques.

P. Patel, S. Kumar, and A. Sharma in article [7] reports on the development and validation of a diaphragm impact sensor for measuring grain flow from bunkers. The authors present experimental results for the sensor and discuss the potential applications of this method in the grain industry.

X. Li, Y. Wang, and Z. Zhang in article [8] describes the design and performance of a diaphragm impact sensor for measuring flow rate of granular materials in bunkers. The authors present a theoretical analysis of the sensor's behavior and discuss the potential applications of this method in the food processing industry.

Among the authors who studied the flow of loose materials, we can highlight works on the topic of impact flowmeters: Schrock M.D., Oard D.L., Taylor R.K., Eisele E.L., Zhang N., Suhardjito, Pringle J.L. [9], and work on the topic of measurement of grain flow rate by x-ray methods Selcuk A., Feyzi I., Joseph N.G, Thomas S.C. [10]. Fei Zeng, Qing Wu, Xiuming Chu, Zhangsi Yue in their work [11], they considered the possibility of measuring the flow of bulk material using laser scanning on a conveyor belt, which made it possible to reduce the measurement error and increase the measurement speed compared to other methods. In another article [12], the authors H. Navid, R. K. Taylor, A. Yazgi, N. Wang, Y. Shi, P. Weckler used laser scanning to determine the flow rate of bulk material, and they came to the conclusion that using a sensor that they used it is possible to measure the grain flow rate no more than 5 kg/s with an error of 2.6%.

Introduction

The task of determining the parameters of the flow of bulk material is one of the main ones in the design of technological processes in which bulk material acts as a working fluid. The flow of bulk material is characterized by the following parameters: type of bulk material, physical, chemical and geometric properties of bulk material, the shape and dimensions of the cross section, speed, consumption, density during movement, structures and properties of surfaces that restrict the flow.

The practical solution of the problems of measuring the amount of bulk material to the fore puts forward the need to study the issues of determining the flow rate of bulk material within the boundaries of a gravitational flow. In addition, the issue related to the study of the flow formed with a free gravitational outflow as a measure for calibrating measuring transducers of the flow of bulk materials deserves attention. In the first part of this article, the process of continuously measuring the weight of the bunker as the grains flow out of it was considered.

The issues of interaction between the flow of bulk material and solid bodies flow around are associated with the creation of devices for measuring the parameters of the flow of a bulk material, for example, its flow rate.

The process of interaction between the flow of bulk material and a solid body is determined by the following factors:

- density of individual particles of bulk material;
- flow density of bulk material at the point of interaction between the flow and the solid body;
- cross-sectional area of the bulk material flow (flow diameter, diameter/area of the bunker outflow hole);
- the size and shape of a solid body, which is affected by the flow of bulk material;
- distance between the bunker outlet holes and the solid body.

The following equipment was used for the experiments:

1. Bunker - made of metal. It has an upper cylindrical part (ø 450 mm) and a lower conical part. At the bottom of the bunker there is an outflow hole with a diameter of 60 mm.
2. The transducer unit includes a solid body of the flow, a bracket on which the body of the flow is fixed and a parallelogram strain gauge force transducer of the CZL-601 type. The sensor is a beam 130 mm long.
3. Analog - digital converter WE 2110 with accuracy class 0.015. Using the RS-485 interface for 4 wires, it is connected to the sensor, and through the RS-232 interface it duplicates the data from the display to the computer.
4. Computer.

In the first part of the research, when carrying out measurements, pearl barley in the amount of 5 kilograms was used as bulk material. Were used four diaphragms with holes expiration d_A=54 mm; d_B= 40 mm; d_C= 32 mm, d_D= 22.5 mm. The number of measurements taken for each diaphragm was three. The measurement results were recorded and presented in the form of a table of numerical values and graphs. A fragment of a table of numerical values and one of the graphs is shown in Table 1 and Fig. 1.

Table 1.

Fragment of the obtained numerical values

t,s	*G,g*	*q_m, g/s*	*t,s*	*G,g*	*q_m, g/s*	*t,s*	*G,g*	*q_m, g/s*
3,1	4288	-200	3,22	4252	-300	3,34	4222	-400
3,12	4280	-800	3,24	4248	-133	3,36	4216	-300
3,14	4274	-300	3,26	4244	-200	3,38	4210	-300
3,16	4268	-300	3,28	4238	-600	3,4	4204	-200
3,18	4264	-133	3,3	4230	-400	3,42	4200	-400
3,2	4258	-600	3,32	4226	-133	3,44	4192	-400

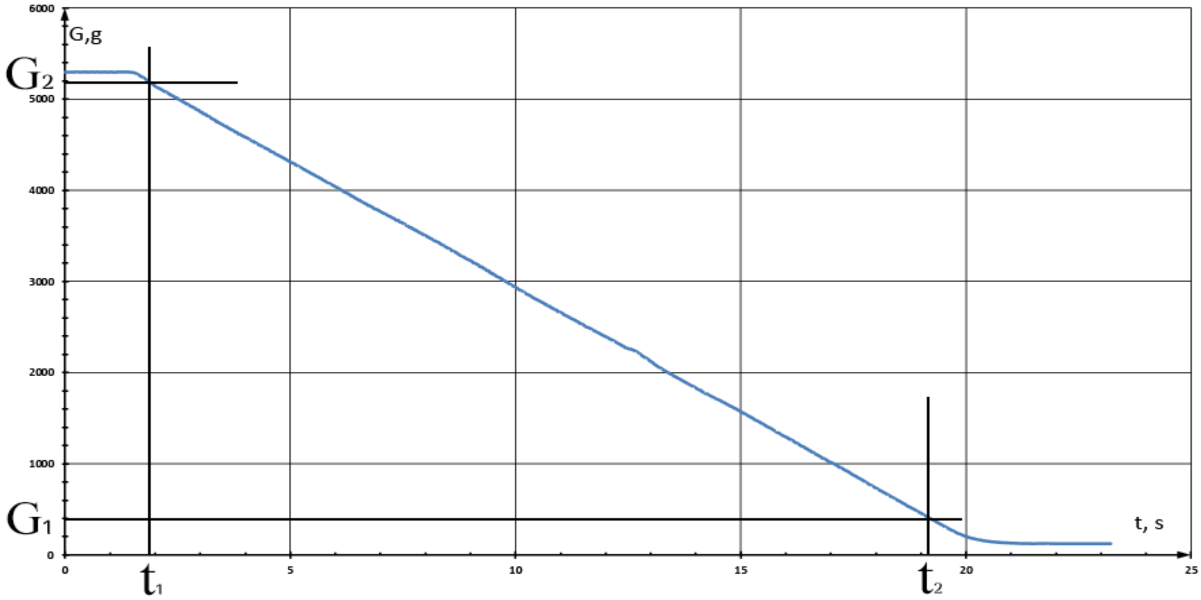

Fig. 1. Graph of change in the weight of the bunker when the bulk material runs out

There were processed data of all spills in the t1 and t2 ranges. The boundaries of the considered range correspond to the beginning and end of the linear dependence of G on t.

In the second part of our research, experiments were carried out using solids. The measurements were carried out under the following conditions:

– bulk material: pearl barley in the amount of 5 kg;
– diameters of the outlet hole - 54, 40, 32, 22.5 mm;
– solid bodies: cones A1, A2; beams B1, B2, discs C1, C2. Their shapes and sizes are shown in Fig. 2.

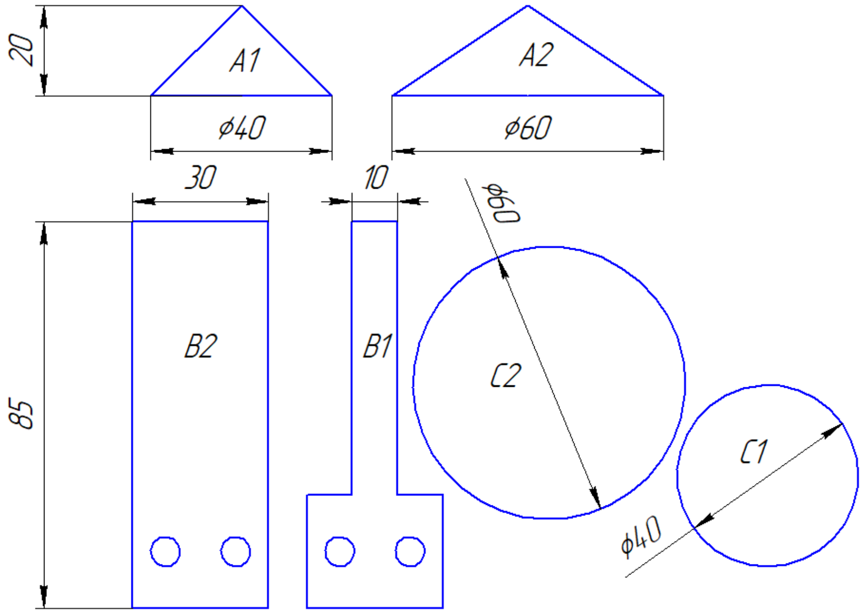

Fig. 2. Solid bodies

Sprinkling for one outflow hole and a solid body was carried out three times. The measurement results were recorded in the form of a table of numerical values and graphs. A fragment of the table of numerical values and one of the graphs are shown in Table 2 and Fig 3.

Table 2.

Fragment of the obtained numerical values

t, c	*F, г*	*t, c*	*F, г*	*t, c*	*F, г*	*t, c*	*F, г*
10	54	10,26	56	10,47	56	10,67	58
10,03	54	10,3	56	10,48	56	10,69	58
10,05	54	10,31	56	10,52	56	10,7	58
10,06	54	10,33	56	10,53	56	10,73	58
10,09	54	10,34	56	10,55	56	10,75	58
10,11	54	10,38	56	10,56	56	10,77	58
10,12	54	10,39	56	10,59	58	10,8	58
10,14	56	10,41	56	10,61	58	10,81	58
10,17	56	10,42	56	10,63	58	10,83	58
10,25	56	10,45	56	10,66	58	10,84	58

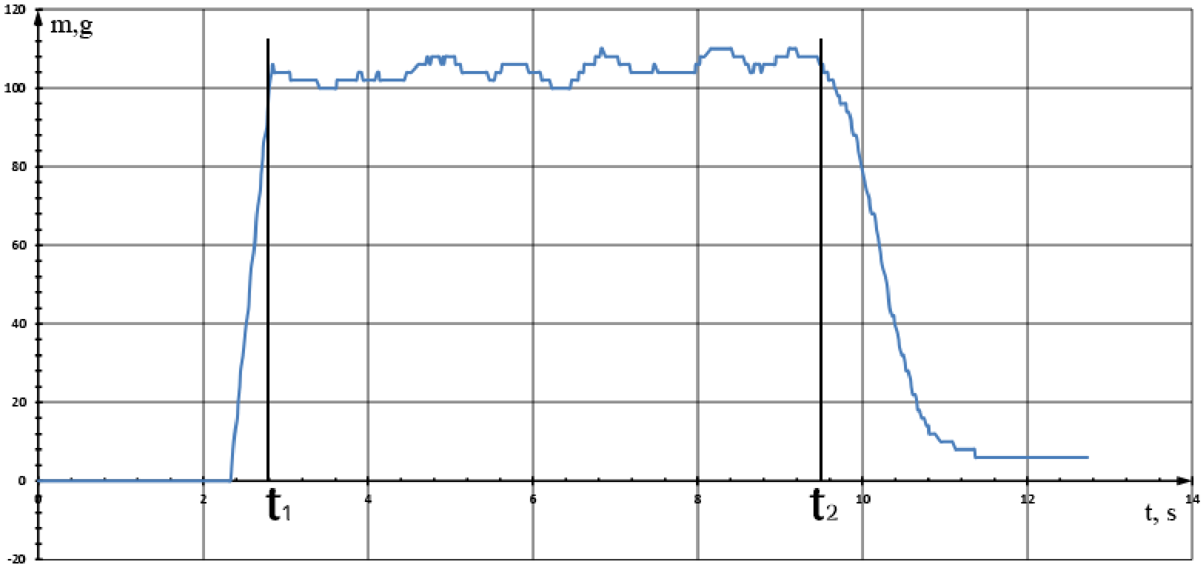

Fig. 3. Graph of the change in the acting force on solid bodies in time

The most interesting for us are the horizontal sections of the graphs. In figure 2, this is the range from t1 to t2. For each of the combinations (outflow hole - solid body), taking into account all the obtained numerical values of the three dimensions, the following were determined:

- arithmetic mean value of the force acting on the bluff body:

$$F_{cp} = \frac{\sum_{i=1}^{n} F_i}{n} \quad (1)$$

standard deviation:

$$\sigma = \pm\sqrt{\frac{\sum_{i=1}^{n} (\Delta F_i)^2}{n-1}} \quad (1)$$

variation coefficient:

$$K = \pm\frac{100\sigma}{F_{cp}} \quad (3)$$

The obtained numerical values of F_{cp}, σ, K for the studied combinations are shown in Table 3.

Table 3.

Measurement results

Solid Bodies	*Expiration hole, mm*	F_{cp}, g	*σ, g*	*K, %*
Cone A1	22,5	13,01	1,84	13,99
	32	25,83	1,71	6,65
	40	43,78	2,01	4,50
	54	93,90	3,15	3,35
Cone A2	22,5	13,21	1,38	10,59
	32	29,31	1,73	5,95
	40	51,60	2,20	4,18
	54	118,26	2,74	2,31
Beam B1	22,5	10,33	1,32	12,80
	32	19,19	1,68	8,74
	40	35,28	1,51	4,29
	54	63,86	2,86	4,51
Beam B2	22,5	14,99	1,84	12,22
	32	32,62	2,02	6,20
	40	53,74	2,33	4,33
	54	101,04	3,46	3,39
Disk C1	22,5	16,14	1,70	10,49
	32	36,97	1,87	5,03
	40	60,16	2,68	4,47
	54	131,41	3,33	2,55
Disk C2	22,5	18,29	1,90	10,16
	32	38,96	2,40	6,08
	40	70,62	3,29	4,69
	54	165,89	3,55	2,16

Conclusions from this study and prospects for further development in this direction

After measurements, the following conclusions can be drawn:

- with an increase in the diameter of the hole, the outflow will increase the flow rate;
- the highest value of the confidence interval is observed at Ø 54 mm and also with a standard deviation;
- there is no clear pronounced dependence on the diameter of the outflow to the flow rate of bulk material.
- the greatest forces in the interaction of the flow of bulk material and bluff bodies were obtained using disks.
- the smallest value of the spread of force within the limits of ±3σ occurs when the beam B1 and the hole Ø 22.5 mm are combined.
- the most variable force acting on the solid body is observed when using disks.

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