конструктивні рішення за допомогою чисельних та експериментальних методів. На основі отриманих результатів та проведеного аеродинамічного аналізу повітряних потоків була розроблена конструкція зерносушарки нового покоління TORNUM серії REX. Втрати тиску, розподіл потоку агента сушіння та розподіл температури в камері гарячого повітря в зерносушарці безперервної дії зі змішаним потоком були досліджені за допомогою CFD (Computational Fluid Dynamics). Потік у сушарці розглядався як усталений, ламінарний і турбулентний. Важливо, щоб зерно було рівномірно висушене, оскільки нерівномірне сушіння може призвести до псування кінцевого продукту під час зберігання. В графічних практичних матеріалах статті наведено проектування шахтних зерносушарок TORNUM REX, загальний вигляд руху повітряних потоків в зерносушарці серії REX, епюри швидкості повітряних потоків в зерновій шахті, епюра розподілення повітряних потоків в спектрі температур в зерносушарці серії REX, епюра утворення агенту сушіння під час змішування з рекупераційним повітрям в зерносушарці серії REX. Встановлено, що різний розподіл температури на вихідних секціях може призвести до неправильного сушіння або пошкодження кінцевого продукту, що вплинуло на зміну конструкції сушарки. Для зменшення втрати тиску та підвищення рівномірності потоку, що надходить у підкамеру лінійного газового пальника запропоновано новий дизайн секції змішування повітря та направляючі лопатки в різні конструкції камер гарячого повітря. Такий підхід в моделювання з використанням CFD можна застосовувати у нових технологічних процесах, а також оцінювати й оптимізувати вже створені звичайні системи.

Ключові слова: сушіння зерна, сушарка зі змішаним потоком, CFD, вимірювання витрати повітря, розподіл температур, технологія.

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DEVICE FOR CALIBRATION OF THE PRESSURE SENSOR OF GRANULAR BULK MATERIALS

Abstract

According to the plan for the implementation of the scientific and technical work "Experimental and theoretical studies of the influence of the roll of a vertical deep container on the distribution of horizontal pressure of granular bulk material on the walls of the container" (DR No. 0121U112518), which is being carried out at the Department of Mechanical Engineering of ODABA, for further research on the pressure distribution of bulk material, a pneumatic measuring system for measuring pressure of granular material on the vertical walls of storage models was developed. Pressure measurements are indirect – based on the absolute value of the movement of the sensor platform, which perceives the pressure of the bulk material, relative to the sensor body, the amount of pressure of the bulk material on the sensor was estimated. The system is multi-channel, each measuring channel consists of a bulk material pressure sensor, a channel for measuring movement of the pressure sensor platform and a recorder of this movement. The device for calibrating the pressure sensor is designed to obtain the calibration dependence of the output signal (the air pressure in the measurement chamber with pneumatic sieves) from the input signal (the value of the uniformly distributed pressure on the sensor). The device is two connected hydraulic systems filled with water. One of them consists of a pressure chamber with a flexible membrane through which the water pressure is transmitted to the sensor, and a measuring tube with a ruler to measure the water level above the membrane. The second one is a buffer tank *for water, connected to the pressure chamber of the first system by a flexible tube and can move in vertical position. Hydrosystems are interconnected, so the both of them have the same water level. The water pressure on the sensor changes by moving the buffer tank up and down. The sensor is made in accordance with the patent of Ukraine for the invention and consists of a housing connected through an annular elastic element to the sensor platform, which perceives the pressure of the bulk material. In order to exclude the impact on the measured pressure by arching in the loose material above the sensor platform, linear displacements of the sensor platform relative to the housing should not exceed 5-8 μm. Such small movements are measured by a non-contact pneumatic gauge based on a non-differential measuring pneumatic system of the manometric type with a working air pressure in the system of 7.5-10 kPa. Air pressure in the pneumatic system is measured by alcohol manometers. The device is made in the form of a two-branch rack: one branch is a measuring branch, and the other has a screw mechanism for vertical movement of the buffer tank. The accuracy of the pressure assignment on the sensor is ± 0.1 g/cm^2, and the measurement of the output signal is ± 0.5 mm.*

Keywords: granular bulk material, pressure sensor, pneumatic measurement, pressure sensor calibration point.

Introduction

Vertical cylindrical containers are widely used for storing granular bulk materials. Bulk materials storage structures of the tank type with the installation of a cylindrical shell on a ring foundation with hinged and immovable fastening of the shell to the foundation are common. Reinforced concrete cylindrical silos are popular: separate as well as blocked in silo housings [1-3].

During the operation, the storages can be empty or filled with loose materials, susceptible to environmental influences such as wind and air temperature. There are also cases of tilting of warehouses caused by uneven settlement of the foundations under the foundations.

As part of the scientific and technical work "Experimental and theoretical studies of the influence of the roll of a vertical deep container on the distribution of horizontal pressure of granular bulk material on the walls of the container" (DR No. 0121U112518), carried out at the Department of Mechanical Engineering of ODABA, a pneumatic measuring system for measuring the pressure of loose granular material on the vertical walls of storage models with pressure bulk material sensors with adjustable compliance according to the patent of Ukraine [4] and with non-contact pneumometers of small linear displacements was developed [5].

One of the stages of this work was the development of a device for calibrating sensors of pressure of loose granular material, that helped to determine the correlation for each sensor between the air pressure in the measuring chamber and the pressure on the sensor.The granular bulk material pressure sensor is a case in which, through an elastic element, a pressure-sensing platform is installed. The general view of the test sample of the sensor is presented in Fig. 1.

Structurally, the sensor consists of a housing 1, a platform 2 that perceives the pressure of bulk material, a cover 3, an annular elastic element, which is rigidly clamped between the bosses of the housing 1 and cover 3 at three equidistant points, and at the same three equidistant points rigidly with connected to site 2 and clamp (not visible in the photo).

Axial rotation of the platform 2 with respect to the annular elastic element makes it possible to change the flexibility of the elastic annular element. In this way, the sensitivity of the sensor changes, which allows you to adjust the sensor to measure pressure in different ranges.

Analysis of recent research and publications.

When designing warehouses for granular bulk materials, one of the most important points is information about horizontal and tangential loads - the pressure of the bulk material on the walls and bottoms of the warehouses. Such information can be given theoretically, for example, according to [1], in which it is recommended to calculate the amount of horizontal pressure of bulk material on the storage wall according to Jansen's formula [2, 3] with an increasing coefficient. The pressure of bulk material on the walls of the bunkers can be set according to [6].

The theoretical approach to the application of bulk material pressure on storage enclosure structures does not take into account, due to the complexity of the process of interaction of bulk material with the enclosure structure, when forming a column of bulk material in the container, all the features of this process [3, 7, 8]. In the literature, there is no data on the change in pressure on the enclosing structures of the storages caused by the slopes of the buildings.

Information about the pressure of bulk material on the walls of storage can also be obtained as a result of field experiments, which organization and execution are very time-consuming and expensive.

Research on large-scale models is less expensive and easier to organize and to conduct. However, in model studies, it is necessary to take into account the peculiarities of the joint operation of the bulk material and the enclosing structure of the storage, as well as very small values of the pressure of the bulk material on the walls of the models, which greatly complicates the conduct of experimental studies [8]. The purpose, tasks, research materials, methodology and obtained results at this stage are determined in the article.

Purpose and tasks. The purpose of the actual work was to develop and manufacture a device for tare pressure sensors of granular bulk material.

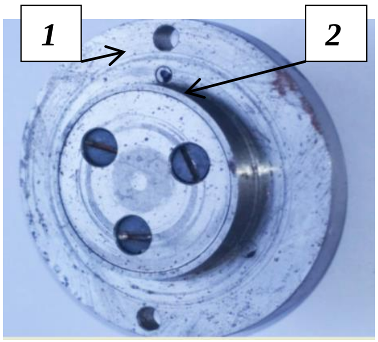
In order to achieve the goal set, it was necessary to solve the following tasks:

– among the possible options, choose a tare method that will ensure smooth loading and unloading of the sensor's receiving platform with pressure;

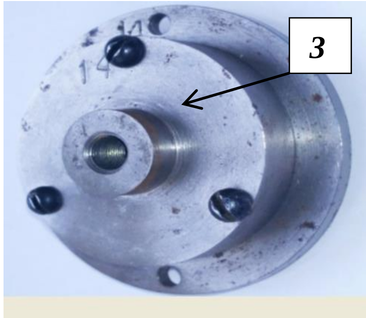
– load on the sensor during taring must be determined with an accuracy of ± 0.1 g/cm^2;

– reliable measurement of movements under the load of the receiving platform (the pressure in the measuring chamber of the pneumatic channel must be measured with an accuracy of ± 0.5 mm);

– the device must provide the ability to assess the impact on the sensor calibration process of the simultaneous operation of several calibrated pressure sensors.



а)



б)

Fig. 1. General view of the sensor:
a – view from the side of the platform of the sensor 1, which perceives the pressure of the bulk material; b - rear view

Research materials and methodology

The pressure sensor during taring must be loaded with a varying pressure, this can be ensured by installing a measuring load sensor on the receiving platform. The disadvantage of this method is an imperative to center the center of cargo mass with the center of the site to maintain the perpendicularity of the screen of the site with respect to the axis of the air flow, and this condition is not fulfilled if the centers are different. In addition, this does not ensure a smooth change of load on the sensor.

The second method adopted by us is to use the hydraulic load of the sensor platform with liquid pressure evenly distributed over the area, which is quite simple to implement, and a smooth change in the load on the sensor is achieved by changing the height of the liquid column above the sensor platform.

The use of purified water with a density of 1 g/cm^3 as a liquid provides, with a height of the water column above the sensor of 1 cm, a load on the sensor of 1 g/cm^2. Measuring the height of the water column above the sensor with a ruler, that has a division value of 1 mm, ensures the accuracy of the pressure task ± 0.1 g/cm^2.

The experience of using alcohol manometers in the system of pneumatic measurements [5, 8] with a scale with a division price of 1 mm allows to perform readings with an accuracy of ± 0.5 mm.

Research results

The schematic diagram of the developed device is shown in Fig. 2. The body of the sensor 1 is immovably fixed to the horizontal plane of the bed-base of the entire device, the base of the measuring stand 2 is installed on the sensor, in the cavity of which is located the body 3 of the pressure chamber 4 with a rubber membrane 5 and connected to a vertical measuring tube 6 with a ruler 7 for measuring the height of the water column h above the membrane. A buffer tank for water 9 is connected to the pressure chamber 4 through a fitting and a flexible tube 8. The pressure chamber 4 with the measuring tube 6 form one stationary, relative to the body of the sensor 1, vessel, with which, through a flexible tube 8, a second vessel is connected - a buffer tank for water 9. The water in these connected vessels is at the same level.

The vertical smooth movement up and down of the buffer tank 9 leads to a change in the water level in the connected vessels, a change in the height of the water column h and, as a result, a change in the value of the water pressure in the pressure chamber 4 and, accordingly, on the platform of the sensor 10 sensing. The water in the pressure chamber 4 presses through the rubber membrane 5 on the sensing platform of the sensor 10, connected annular elastic element 11 is deformed and the platform 10 moves relatively to the sensor body 1, translationally and parallel to itself, the gap between the screen 12 of the platform 10 and the measuring nozzle 13 decreases, the pressure in the measuring chamber of the pneumatic gauge increases, the column of alcohol in the alcohol manometer rises, and the pressure value on the sensor is fixed on it. Based on the obtained data, a tare curve of the dependence "pressure on the sensor-height of the alcohol column in the alcohol manometer" (ideally a straight line) is constructed. In the future, this dependence is used to convert the readings of alcohol manometers into the pressure of the bulk material measured by the sensor.

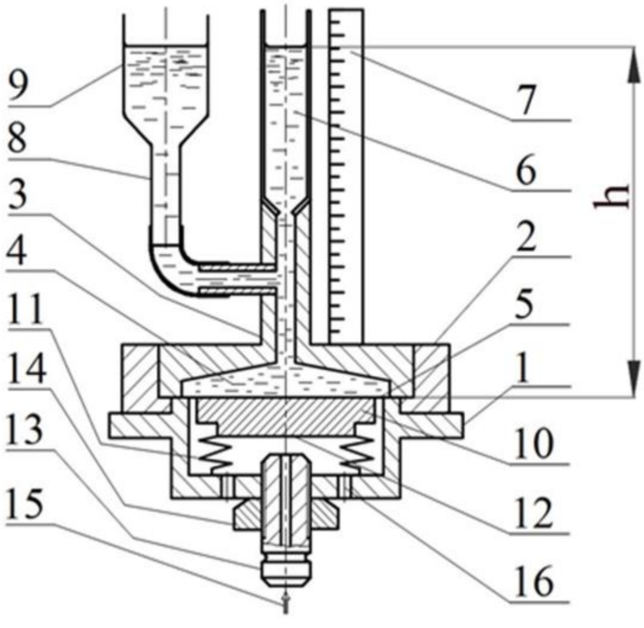


Fig. 2. Schematic diagram of the device for calibrating the pressure sensor of granular bulk material:
1 – sensor body; 2 – the base of the measuring stand; 3 – pressure chamber body; 4 – water pressure chamber; 5 – rubber membrane of the pressure chamber; 6 – measuring tube; 7 – ruler; 8 – flexible tube; 9 – buffer tank for water; 10 – the site of the sensor that perceives the water pressure; 11 – ring elastic element; 12 – the screen of the receiving platform; 13 – measuring nozzle of the pneumometer; 14 – a nut that fixes the nozzle in relation to the body 1; 15 – air flow from the measuring chamber; 16 – channels for exhaust air.

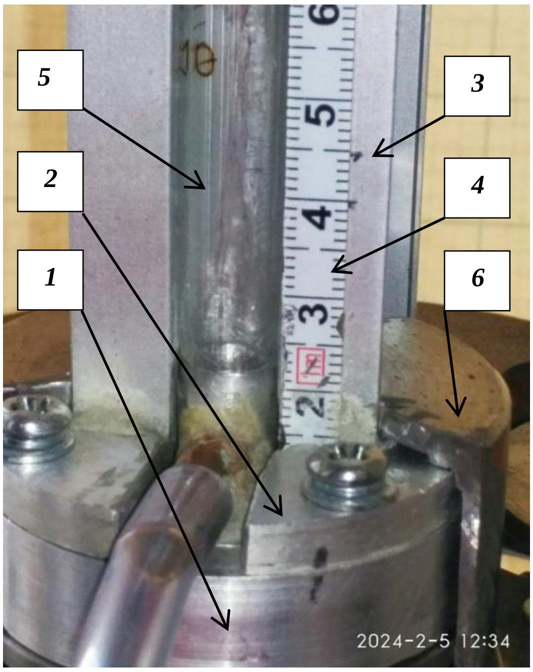


Fig. 3. Measuring branch of the rack: *1 – base of the rack; 2 – flange; 3 – rack profile ; 4 – ruler; 5 – glass measuring tube; 6 – clamp*

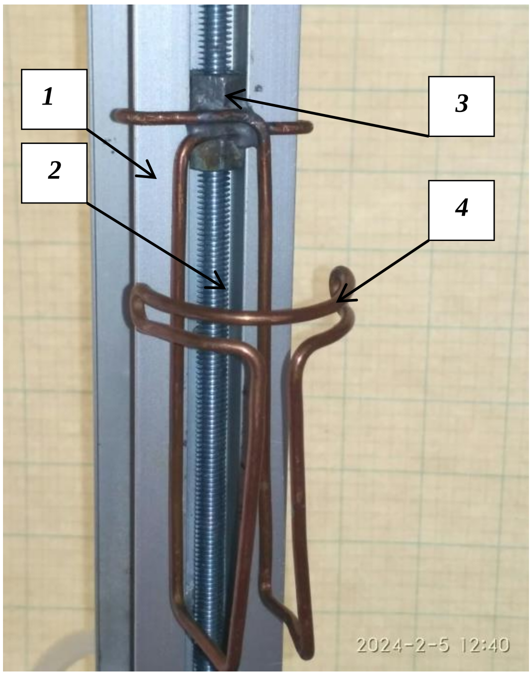


Fig. 4. Screw mechanism for vertical movement of the buffer tank for water: *1 – profile; 2 – running metric screw; 3 – elongated nut; 4 – buffer tank frame*

On Fig. 3 shows the measuring branch of the rack, which is immovably connected to the base of the device, and in Fig. 4 - screw mechanism for moving the water buffer tank.

On Fig. 5 presents a general view of the tare device. The device is made in the form of a two-pronged measuring stand, which is formed by two parallel horizontal inserts connected at four points, identical thin-walled aluminum U-shaped profiles 4, 6 with "wings" with channels 10 mm wide and 9 mm deep. In the measuring branch 4, a glass tube with a ruler on the "wing" is placed in this channel for measuring the height of the water column with a separation price of 1 mm, which corresponds to a pressure of 0.1 g/cm² above the membrane of the pressure chamber (Fig. 2), and in the other branch 6 is a screw mechanism for the vertical movement of the buffer tank 9. The profile of the measuring branch of the rack 4 in the lower part has a flange 5 located coaxially with the base of the measuring rack 3, through which, with the help of clamping 7 bolts 11, the measuring rack is immovably pressed against the base 1.

On Fig. 6 shows the screw mechanism for the vertical movement of the buffer tank for water. In the groove of the profile 1 there is an elongated nut 3 and a running metric screw 2. the wire frame for water buffer tank is soldered to nut 3. The nut 3 located in the groove of the profile cannot be turned and, when the screw is rotated, moves into the groove gradually up or down together with the buffer tank. At the same time, the water level in the hydraulic system gradually up or down together with the buffer tank. At the same time, the water level in the hydraulic system changes aswell as the water pressure through the membrane to the sensor which being tared. The device allows you to change smoothly the amount of load on the receiving platform of the pressure sensor, which is important for determining the zone of linear dependence of "movement of the receiving platform of the sensor on reading of the alcohol manometer of the pneumatic measurement system" of the direct system of measuring the displacements of the sensor platform.

The lead screw with metric thread M6×0.75 is rotated manually using the flywheel on the upper edge of

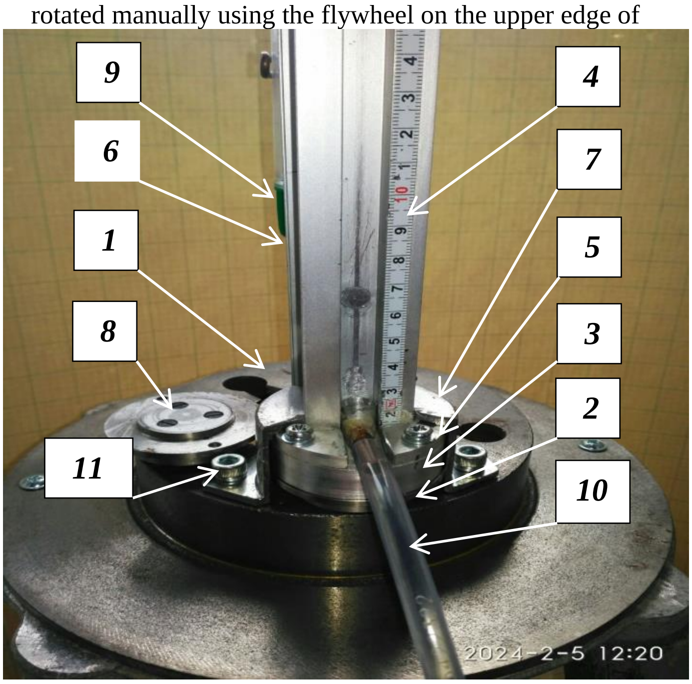


Fig. 5. Taring device as a whole: *1 – base-base of the device; 2– sensor to be tared; 3– the base of the measuring stand; 4– measuring branch of the rack with a recording tube and ruler; 5– flange of the measuring branch of the rack; 6 – branch of the rack with a mechanism for moving the buffer tank; 7 – clamp; 8 – control pressure sensor; 9– buffer tank for water; 10– flexible tube connecting the pressure chamber with the buffer tank for water; 11– the bolt for fastening the clamp to the base 1*

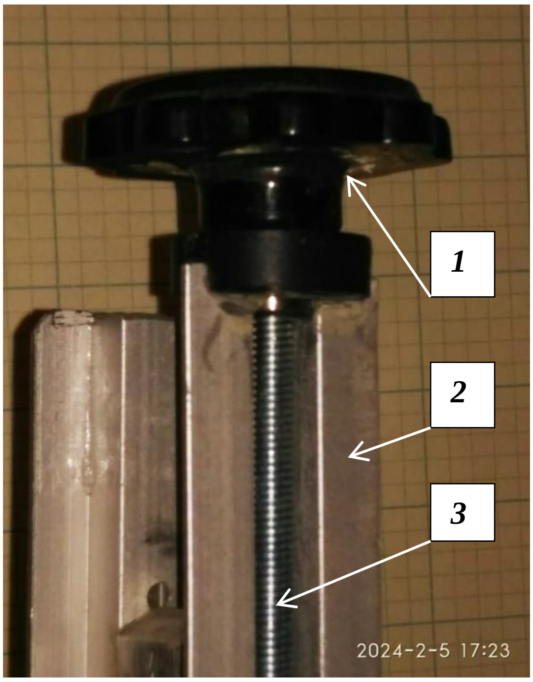


Fig. 6. Flywheel of the running screw drive: *1 – – handwheel; 2 – profile of the buffer tank movement tank drive branch; 3 – running screw*

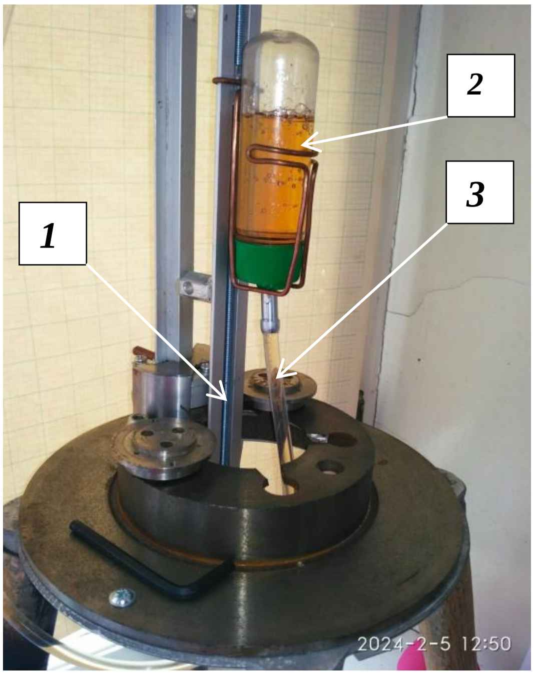


Fig. 7. General view of the water buffer tank: *1 – lead screw; 2 – container with water; 3 – pressure chamber connection tube with water tank*

the screw (Fig. 6), a copper frame for the buffer tank is soldered to the elongated nut (Fig. 4).

In Fig. 7 shows a general view of the buffer tank in the frame.

The length of the profiles ensures the vertical movement of the buffer tank with the task of smoothly adjustable water pressure in the pressure chamber from 2.0 to 75.0 g/cm^2, which ensures with a margin the task of water pressure in the pressure chamber when calibrating the pressure sensors of bulk materials.

Conclusions:

1. Based on the analysis of the requirements for the system for measuring the pressure of bulk material on the walls of a deep container, a hydraulic method of applying pressure to the sensor during its taring was selected, which allows loading the sensor with evenly distributed pressure and smoothly changing the pressure on the sensor during taring.

2. A device for calibrating the pressure sensor of granular bulk material with a hydraulic loading method and a pneumatic system for registering the pressure value was developed and constructed.

3. The manufactured device allows you to tare the sensor with a smooth change in the pressure value from 2.0 to 75.0 g/cm^2 with an accuracy of ± 0.1 g/cm^2.

4. The device allows you to perform calibration of the pressure sensor, taking into account the mutual influence on the calibration process up to four sensors of the pressure measurement system of bulk material, that work at the same time.

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ПРИСТРІЙ ДЛЯ ТАРУВАННЯ ДАТЧИКА ТИСКУ ЗЕРНИСТИХ СИПКИХ МАТЕРІАЛІВ

Анотація

Згідно з планом виконання науково-технічної роботи «Експериментально-теоретичні дослідження впливу крену вертикальної глибокої ємності на розподіл горизонтального тиску зернистого сипучого матеріалу на стінки ємності» (ДР № 0121U112518), що виконується на кафедрі машинобудування Одеської державної академії будівництва та архітектури (ОДАБА), розроблена пневмовимірювальна система вимірювань тиску зернистого сипучого матеріалу на вертикальні стінки моделей сховищ для проведення подальших досліджень розподілу тиску сипучого матеріалу. Вимірювання тиску непрямі – за абсолютною величиною переміщення майданчика датчика, що сприймає тиск сипучого матеріалу, відносно корпусу датчика, оцінювалась величина тиску сипучого матеріалу на датчик. Система багатоканальна, кожен вимірювальний канал складається з датчика тиску сипучого матеріалу, каналу вимірювання переміщення майданчика датчика тиску та реєстратора цього переміщення. Пристрій для тарування датчика тиску призначений для отримання тарувальної залежності вихідного сигналу – тиску повітря в камері вимірювання пневмосистеми, від вхідного сигналу – величини рівномірно розподіленого тиску на датчик. Пристрій являє собою дві сполучені гідросистеми, заповнені водою. Одна складається з камери тиску з гнучкою мембраною, через яку тиск води передається на датчик, і вимірювальної трубки з лінійкою для вимірювання рівня води над мембраною. Друга є буферну ємність для води, з'єднану гнучкою трубкою з камерою тиску першої системи і має можливість плавного вертикального переміщення. Гідросистеми з'єднані між собою, тому вода в них знаходиться на одному рівні. Тиск води на датчик змінюється переміщенням буферної ємності вгору-вниз. Датчик виконано згідно з патентом України на винахід та складається з корпусу, з'єднаного через кільцевий пружний елемент із майданчиком датчика, що сприймає тиск сипучого матеріалу. Для виключення впливу склепоутворення в сипучому матеріалі над майданчиком датчика, на величину вимірюваного тиску, лінійні переміщення майданчика датчика щодо корпусу не повинні перевищувати 5-8 мкм. Такі малі переміщення вимірюються безконтактним пневмовимірником на основі недиференціальної вимірювальної пневмосистеми манометричного типу з робочим тиском повітря в системі 7,5-10 кПа. Тиск повітря у пневмосистемі вимірюється спиртовими манометрами. Пристрій виконаний у вигляді двогілкової стійки: одна гілка – вимірювальна, в другій розміщений гвинтовий механізм вертикального переміщення буферної ємності. Точність завдання тиску на датчик становить ± 0,1 г/см^2, а вимірювання вихідного сигналу ± 0,5 мм.

Ключові слова: зернистий сипучий матеріал, датчик тиску, пневмовимірювання, пристрій для тарування датчика тиску.

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