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SUBSTANTIATION OF THE PROCESS OF VERTICAL TRANSPORTATION OF PIECE LOADS

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Abstract. The urgent problem of automatization of the process of products transportation with a help of vertical chutes under the influence of gravitational forces using elastic elements is considered. The interaction between the object being transported and the elastic elements is defined. Their mutual influence on the transportation speed is determined depending on the contact parameters. The analysis of the object transportation speed changing depending on friction and on the zone of their mutual contact is carried out.

Keywords: vertical chute, elastic element, small ball, beam.

Introduction

The implementation of progressive technologies of manufacture automatization is restricted by some physical factors related with objects transportation between technological equipment. That’s why it is necessary to know the principles of interaction of the objects being transported and the transporting mechanisms. The efficiency of parts transporting is directly related with relative motion of the part and with its interaction with the transporting surface. Therefore, the investigation of the dependence of the transportation speed of the object being transported on the external factors is one of the fundamental problems when carrying out the investigations of transporting systems.

Depending on the character of the load, operation principles and design features of transporting machines, the load flow may be both of continuous or batch type for loose materials and as separate piece loads. Gravitational devices, in which bulk and piece loads are being transported vertically downwards or along the inclined trajectory in vertical plane under the influence of gravitational force, belong to a wide range of facilities of ensuring such load flows [1]–[5]. These devices may be manufactured as vertical, inclined or screw (spiral) ones.

Gravitational devices are usually simple to design and operate. However, they have some disadvantages, such as transportation only from top to bottom and the limited possibilities of regulation of products transportation speed. The cross-sections of the transporting surfaces and space depend on the shape (form) of the products and on the transporting method.

The basic condition of reliable and effective operation of such chutes consists in the correct choosing of the initial speed of the load, inclination angle, cross-section shape and material of the transporting surface. Too large inclination angle may cause the dusting (pulverization, comminution) and damaging the loads. At the same time, the reducing of the inclination angle may cause the increasing of the overall sizes of the structure and of its materials consumption.

Problem statement

In the presented work, the system of products transportation in vertical chutes with elastic elements, which ensure the regulation of the transportation speed, is considered. The influence of parameters of the chute and of the elastic elements on the products transportation speed is analysed. The system of equations, which allows to describe the operation of the vertical chute taking into account its parameters, is investigated. The possibility of analysis of parameters of the chute and of friction between the elastic elements and products allows to perform the optimal determination and to ensure the necessary parameters of transportation. The analysis of factors, which influence the process of products transportation, is carried out.

Analysis of recent investigations on the subject of research

The mechanisms of hopper feeding of technological equipment in automatized manufacturing processes are similar by the operation principle, where the feeding of products under the influence of gravitational force or using the additional devices, spring, etc. is the most widespread method [6]. This allows the transportation of products in various directions and with various speeds.

Analyzing the operation of devices for gravitational transportation of loads, it is necessary to note their high productiveness and the absence of movable parts. However, the reservations concerning the galling (fretting) of the load and of the chute surface and the possibility of blockages formation while changing the conditions of transportation may take place.

If we analyze the motion (falling) of the loads in vertical chutes, we may state that the internal surface of the chute should be stepped (step-type) or spiral (helical). Vertical chutes in the form of tubes with smooth surface are used in the cases when the descent height of piece loads, which are not afraid of shock impacts, is not large taking into account the limitations on permissible noise. While transporting the loads with similar forms (shapes) and sizes, the cross-section of the vertical tube is recommended to be the same as these forms. Herewith, the air cushion is formed under the load, which damps (absorbs) impacts in its bottom position [4].

After analyzing the investigations on the subject of our research, our attention was payed to the means of descending of the piece loads in the form of vertical tubes, the internal space of which consists of elastic elements [9]. The principle of operation of such devices not only influences the motion of the body, but also ensures the opportunity to transport the products with insufficient strength.

Main material presentation

The functional diagram of such device is presented in Fig. 1. It consists of vertical square tube, inside of which the elastic elements are perpendicularly attached to the walls with the predefined spacing. The elastic properties of these elements and the friction, which occurs between them and the surfaces of the movable load, ensure the possibility of regulation of transportation speed. These elements may be manufactured of spring steel or be non-metallic.

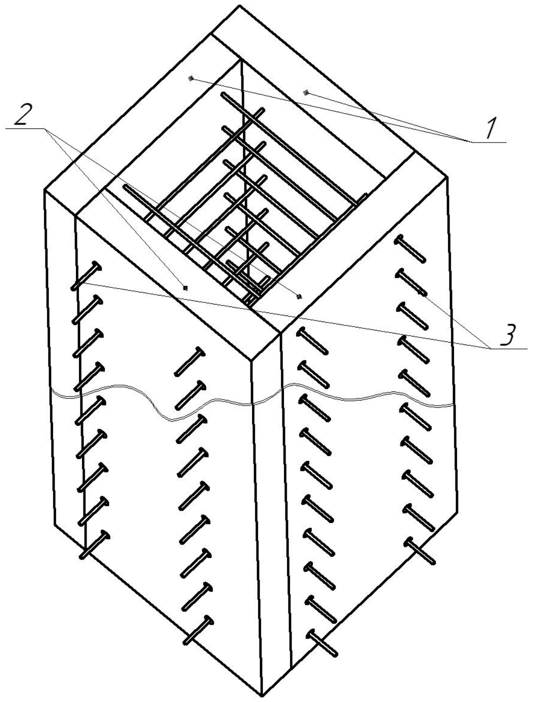

Fig. 1. Functional diagram of the vertical chute: 1 – the planes with fixed constraint of elastic elements; 2 – the planes with free attachment of elastic elements; 3 – elastic elements

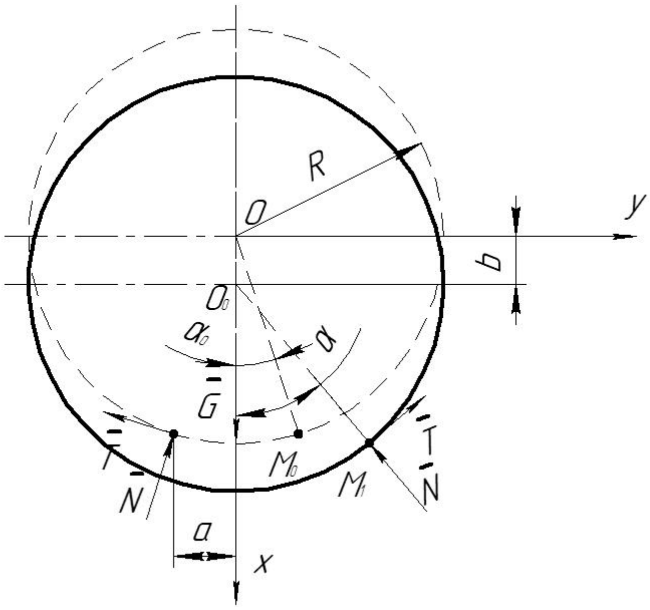

Fig. 2. The diagram of contact of the small ball with the elastic element

Let us consider the preconditions of operation of such device [7; 8]. Let us represent the motion of the body (small ball) downwards between the fixed elements as its displacement between four elastic beams (Fig. 2, Fig. 3).

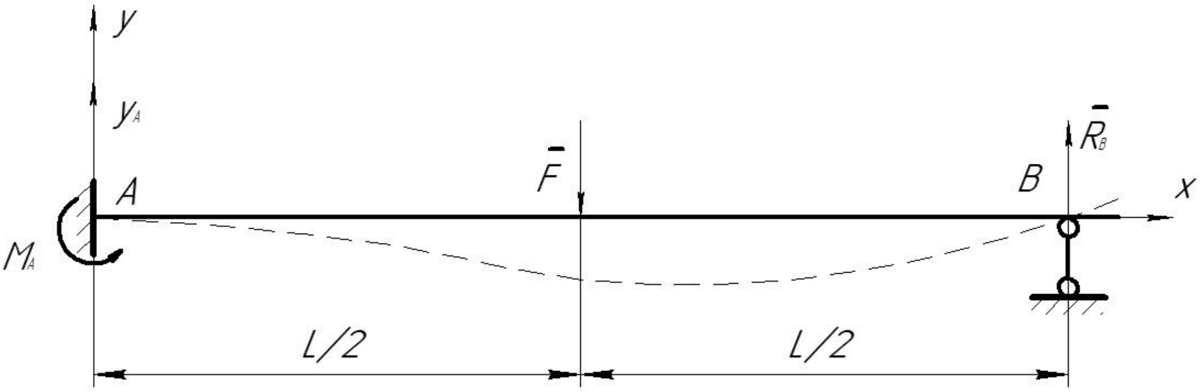

Fig. 3. *Design diagram of the elastic element deformation*

In Fig. 3, the point M_0 is the point of contact of the ball and the beam in the initial position (the beam is not deformed); the point M_1 is the point of contact of the ball and the beam, when the ball moved vertically downwards for some distance (the beam is already deformed).

Let us write down the displacement of the point *M* in the direction of coordinate axes:

$$\Delta_x = b + R\cos a - R\cos a_0;\qquad \Delta_y = R\sin a - a, \tag{1}$$

where *a* is the distance between the midpoint of the beam and the *x*-axis,

$$\sin a_0 = \frac{a}{R}.$$

The ball is influenced by the gravitational force *G*, by normal reactions *N* caused by the interaction of the ball with four beams and by the friction forces $T = fN$. Let us project these forces on the axes of Cartesian coordinate system:

$$P_x = -(N\cos a + fN\sin a) = -N(\cos a = f\sin a);\qquad P_y = -N(\sin a - f\cos a). \tag{2}$$

According to the Hook's law and to the third Newton's law, the following dependence between the forces P_x, P_y and displacements Δ_x, Δ_y takes place:

$$-P_x = c\Delta_x;\ -P_y = c\Delta_y, \tag{3}$$

where *c* is the stiffness of the beam in the case, when the force is applied in the midpoint of the beam.

Substituting the equality (3) into expressions (1) and (2), we obtain the system of linear algebraic equations relative to the variables *N* and *b*:

$$N(\cos a + f\sin a) = c(b + R\cos a - R\cos a_0);\qquad N(\sin a - f\cos a) = c(R\sin a - a). \tag{4}$$

Solving this system, we define:

$$N = \frac{cR(\sin a - K)}{\sin a - f\cos a};\ a_0 \le a \le \frac{p}{2},\qquad b = R\cos a_0 - R\cos a + cR\frac{(\sin a - K)(\cos a + f\sin a)}{\sin a - f\cos a} \tag{5}$$

where $K = \dfrac{a}{R}$ is the dimensionless structural parameter that takes into account the place of contact.

Substituting the obtained expressions into (1), we obtain:

$$\Delta_x = \frac{(R\sin a - a)(\cos a + f\sin a)}{\sin a - f\cos a}. \tag{6}$$

Let us determine the stiffness *c*, considering that one end of the beam is rigidly fixed and the other end is supported by the movable hinge. The force is applied in the midpoint of the beam.

Let us write down the equation of equilibrium state:

$$\sum M_B(F_K) = 0;\; M_A + F\frac{L}{2} - Y_A \cdot L. \tag{7}$$

From this equation, we may find:

$$M_A = Y_A L - F\frac{L}{2}.$$

Let us write down the equation of the bent beam axis according to the method of initial parameters:

$$EIy(x) = \frac{Y_A\ x^3}{6} - \frac{M_A x^2}{2} - \frac{F(x-\frac{L}{2})^3}{6}. \tag{8}$$

Let us define Y_A taking into account the fact that the deflection in the point B equals zero, i.e., $y(L) = 0$:

$$\frac{Y_A L^3}{6} - (Y_A L - \frac{F4}{2})\frac{L^2}{2} - \frac{FL^3}{48} = 0;$$

$$Y_A = \frac{11}{16}F = \mathbf{f}\ M_A = \frac{3}{16}FL.$$

Substituting $x = \frac{L}{2}$ into the formula (8), we determine the deflection of the beam in the point where the force *F* is applied:

$$EIy(\frac{L}{2}) = \frac{11}{16}\cdot\frac{FL^3}{8} - \frac{3}{16}\cdot\frac{FL^3}{8} = -\frac{7FL^3}{768}.$$

Thus, the stiffness *c* equals:

$$c = \frac{768}{7}\cdot\frac{EI}{L_3}, \tag{9}$$

where $I = \frac{pd^4}{64}$; *d* is the diameter of the beam cross-section; *E* is Young's (elasticity) modulus.

During the motion of the ball, the forces acting upon it perform the work. The work of the gravitational forces may be calculated by the following formula:

$$A_1 = G \cdot b = GRb_1, \tag{10}$$

and the work of forces P_x and P_y may be found by the corresponding equation:

$$A_2 = -c(\frac{\Delta_x^2}{2} + \frac{\Delta_y^2}{2}) - c\int_{a_0}^{a} \Delta_x R\sin\frac{da}{a}.$$

Taking into account the expressions for Δ_x and Δ_y, we may write down:

$$\begin{aligned} A_a = -GRC_1(\frac{1}{2}(\frac{(\sin a - K)(\cos a + f\sin a)}{\sin a - f\cos a})^2 + \frac{1}{2}(\sin a - K)^2 + \\ + \int_{a_0}^{a} \frac{(\sin a - K)(\cos a + f\sin a)}{\sin a - f\cos a}\sin a\, da = -GR_1C_1A_3, \end{aligned} \tag{11}$$

where $b_1 = \frac{b}{R}$; $c = \frac{G}{R}\cdot C_1$.

In the initial position, the speed of the ball equals V_0. Thus, according to the theorem about the change of the kinetic energy of a rigid body at its transversal motion, the following formula takes place:

$$\frac{mV^2}{2}-\frac{mV_0^2}{2}=A_1+4A_2=GR(b_1-4C_1A_3)\,. \qquad (12)$$

On the basis of this formula, we may define the speed:

$$V=\sqrt{gR}\cdot\sqrt{2(b_1-4C_1A_3)+V_1^2}\,, \qquad (13)$$
$$V_0=\sqrt{gR}\cdot V_1\,.$$

Since for arbitrary value of the angle a in the range of $a_0 \le a \le \frac{p}{2}$ the inequality $\frac{V_1^2}{2}+b_1-C_1A_3 \ge 0$ should be realized, so the parameter C_1 must be equal to the smallest value of the ratio b_1 to A_3:

$$C_1=\min\left(\frac{b_1 a+\frac{V_1^2}{2}}{4A_3 a}\right). \qquad (14)$$

If we know C_1, we may calculate the necessary stiffness value of each beam:

$$c=\frac{G}{R}C_1\,,$$

and determine the diameter of the cross-section of the beam:

$$d=\sqrt[4]{\frac{7CL^3}{12p\,E}}\,. \qquad (15)$$

Solving the problem for various values of structural parameter $K=\frac{a}{R}$ and friction coefficient f, we obtain the following results presented in Figs. 4-6.

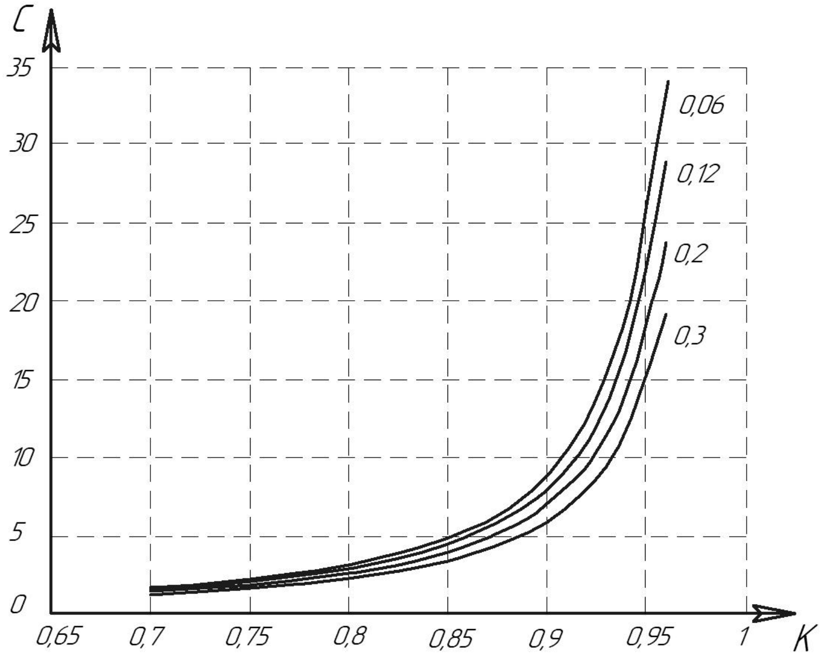

Fig. 4. *The dependence of the stiffness of elastic elements C on the structural parameter K for various values of the friction coefficient f = 0.3…0.6*

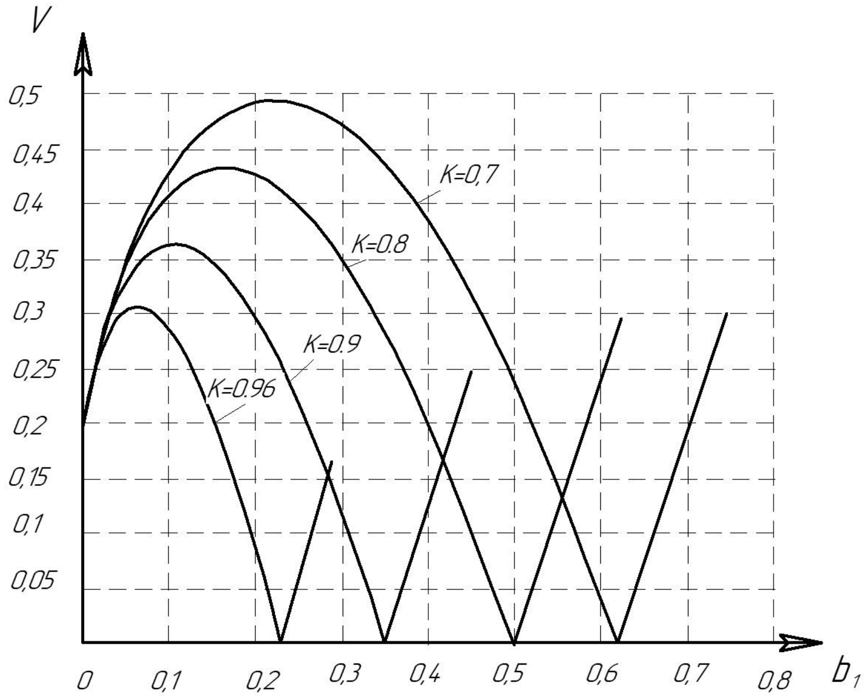

Fig. 5. *The dependence of the transportation speed V on the structural parameter b_1 for the constant value of the friction coefficient f = 0.1*

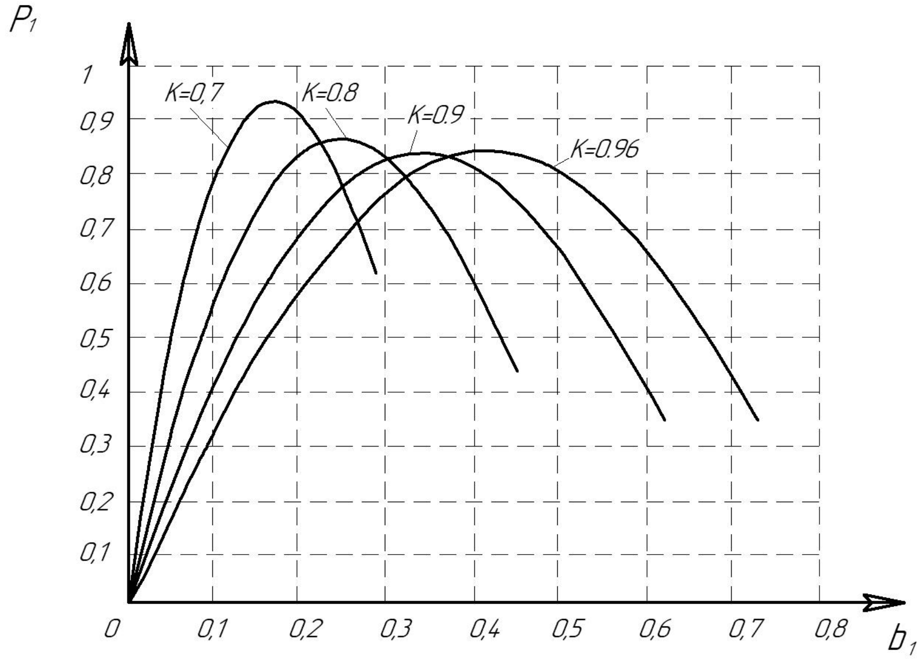

Fig. 6. *The dependence of the elasticity force of elements P_1 on the structural parameter b_1 for the constant value of the friction coefficient f = 0.1*

Conclusions

The process of calculation of the vertical chute for transporting the ball parts taking into account the parameters of elastic elements is considered. This allows the determination of the basic characteristics of the chute on the stage of its designing.

The proposed technique of calculation may be used for designing of the transporting systems and will allow to effectively define the parameters of vertical chutes and to automatize the corresponding technological processes, in which they will be operating.

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