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MATHEMATICAL MODEL OF THE MOVEMENT OF COTTON PIPE AND HEAVY MIXTURES UNDER THE INFLUENCE OF AIR FLOW IN A PNEUMATIC PIPE SHELL

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Annotation. As is known, the problem of maximum purification of cotton from heavy impurities and other types of impurities using dust collection devices included in the pneumatic transport system of cotton ginning enterprises has been considered in many studies. However, theoretically and practically it is based on the fact that the cleaning devices created to date cannot fully perform this task.

For this reason, the authors developed an adapted design of an aerodynamic cleaning device that maximally cleans cotton from heavy and other types of impurities during the process of transporting cotton by air in front of the separator, that is, instead of its diffuser.

Key words: air flow, aerodynamics, cotton ball, heavy mixtures, pipe, diffuser, working chamber, outlet pipe, trajectory, speed, mass, centrifugal force, drag force.

Introduction.

As is known, cotton raw materials are transported from the gins to the ginning processes using a pneumatic transport system. Therefore, it is important to theoretically study the process of aerodynamic cleaning of heavy impurities and other types of impurities from cotton [1].

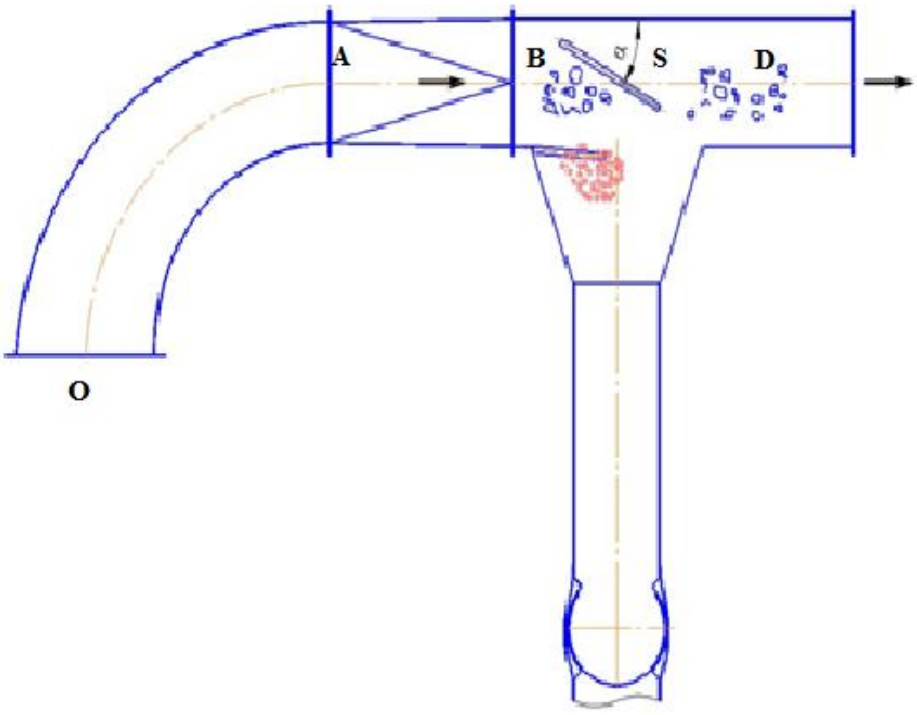


Figure 1. Scheme of the proposed aerodynamic cleaning device for cotton, which is part of the pneumatic transport system.

First of all, we present information about the forces acting on objects by the air flow. The properties of air flows, their interaction forces with objects, have been studied in depth in the science of aerodynamics. Under the influence of the flow, an aerodynamic force is created on the object depending on the flow velocity. If the flow velocity is not high, the value of this force is usually proportional to the air and object velocities [2, 3].

Let us assume that under the influence of the air flow, a piece of cotton together with heavy impurities moves continuously in the pipe (section OA), diffuser (section AB), working chamber (section BS) and outlet pipe (section SD) (Fig. 1) [4].

Let's consider the mathematical model of the process of separating heavy impurities from cotton content separately for each interval.

2. Materials and Methods.

Professor R. Muradov and Associate Professor A. Karimov developed a mathematical model of the movement of a cotton sliver and a heavy mixture in a two-dimensional XOY system with trajectory equations, which is a mathematical model of the movement of a cotton sliver and a heavy mixture in a two-dimensional XOY system with a trajectory equation $y = y(x)$ (Fig. 1). The velocity vector of the flow is denoted by $\vec{V}_0 = \{V_{0x}, V_{0y}\}$, and the particle velocity vector is denoted by $\vec{V} = \{V_x, V_y\}$. The angle between the vector $\vec{V}_0$ and the OX axis is denoted by α_0, then we obtain equations (1).

$$V_{0x} = \left|\vec{V}_0\right| \cos \alpha_0 \qquad V_{0y} = -\left|\vec{V}_0\right| \sin \alpha_0 \tag{1}$$

The air resistance force vector $\vec{F}(V_{0x} - V_x, V_{0y} - V_y)$ According to the law of aerodynamics, the relative velocity of the particle is directed along the vector $\vec{V}_0 - \vec{V}$. If the modulus of this force is $\left|\vec{F}(V_{0x} - V_x, V_{0y} - V_y)\right|$, then the modulus of the relative velocity is:

$$\left|\vec{V}_0 - \vec{V}\right| = \sqrt{(V_{0x} - V_x)^2 + (V_{0y} - V_y)^2}$$

If we define it as , then the force exerted by the air flow can be written as the following vector.

$$\vec{F}(V_{0x} - V_x, V_{0y} - V_y) = \left|\vec{F}(V_{0x} - V_x, V_{0y} - V_y)\right|\left[\frac{V_{0x} - V_x}{\left|\vec{V}_0 - \vec{V}\right|}\vec{i} + \frac{V_{0y} - V_y}{\left|\vec{V}_0 - \vec{V}\right|}\vec{j}\right]$$

Here ($\vec{i}, \vec{j}$) are unit vectors directed along the OX and OY axes. Thus, the projections of the force exerted by the air flow on the OX and OY axes are expressed by the following formulas.

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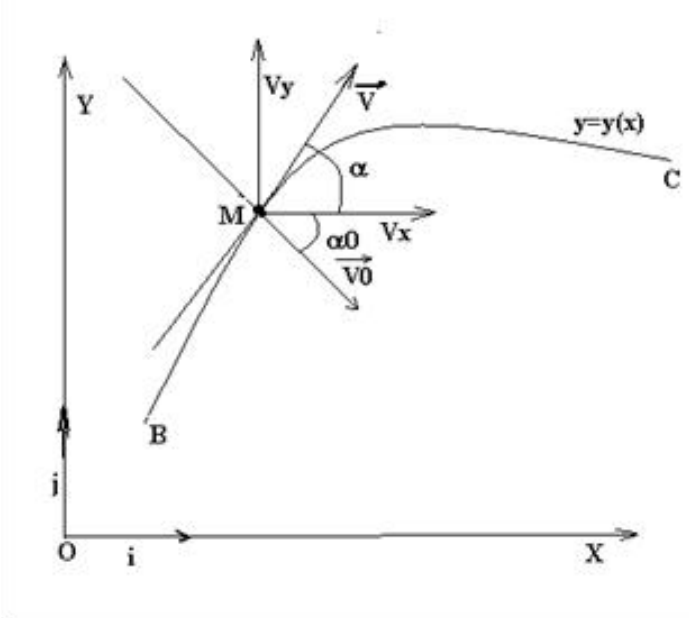


Figure 2. Scheme of movement of a piece of cotton under the influence of air flow.

$$F_x = \left|\vec{F}(V_{0x}-V_x, V_{0y}-V_y)\right| \frac{V_{0x}-V_v}{\left|\vec{V}_0-\vec{V}\right|},$$

$$F_y = \left|\vec{F}(V_{0x}-V_x, V_{0y}-V_y)\right| \frac{V_{0y}-V_y}{\left|\vec{V}_0-\vec{V}\right|} \qquad (2)$$

When the air resistance is proportional to the relative velocity, the force vector relation to the relative velocity is as follows:

$$\vec{F}(V_{0x}-V_x, V_{0y}-V_y) = C_0(\vec{V}_0-\vec{V})$$

here:

C_0 - coefficient determined by experience.

The modulus of this force is expressed by this formula,

$$\left|\vec{F}(V_{0x}-V_x, V_{0y}-V_y)\right| = C_0\sqrt{(V_{0x}-V_x)^2+(V_{0y}-V_y)^2} \qquad (3)$$

its projections on the coordinate axes are as follows

$$F_x = C_0\sqrt{(V_{0x}-V_x)^2+(V_{0y}-V_y)^2}\,\frac{V_{0x}-V_x}{\left|\vec{V}_0-\vec{V}\right|} = C_0(V_{0x}-V_x) \qquad (4)$$

$$F_y = C_0\sqrt{(V_{0x}-V_x)^2+(V_{0y}-V_y)^2}\,\frac{V_{0y}-V_y}{\left|\vec{V}_0-\vec{V}\right|} = C_0(V_{0y}-V_y) \qquad (5)$$

formulas (4) and (5) can be used in practice when the air flow rate is low.

Now, let's assume that the strength of the air current is proportional to the square of the relative velocity, that is:

$$\vec{F}(V_{0x}-V_x, V_{0y}-V_y) = C_1(\vec{V}_0-\vec{V})^2$$

here:

C_1 - coefficient found by experiment.

We find the modulus of a vector using the property of its square:

$$\vec{F}(V_{0x}-V_x, V_{0y}-V_y) = C_1[(V_{0x}-V_x)^2+(V_{0y}-V_y)^2]$$

in this case, the equation takes the following form:

$$F_x = C_1[(V_{0x}-V_x)^2+(V_{0y}-V_y)^2]\frac{V_{0x}-V_x}{\sqrt{(V_{0x}-V_x)^2+(V_{0y}-V_y)}} =$$

$$= C_1(V_{0x}-V_x)\sqrt{(V_{0x}-V_x)^2+(V_{0y}-V_y)^2}\ ,(6)$$

$$F_y = C_1[(V_{0x}-V_x)^2+(V_{0y}-V_y)^2]\frac{V_{0y}-V_y}{\sqrt{(V_{0x}-V_x)^2+(V_{0y}-V_y)}} =$$

$$= C_1(V_{0y}-V_y)\sqrt{(V_{0x}-V_x)^2+(V_{0y}-V_y)^2} \qquad (7)$$

Formulas (6) and (7) are appropriate for high-velocity flows.

Based on the above equations, we calculate the solution of the following problems.

Now, let us consider the following problem. Let us assume that the cotton ball is in equilibrium at time t=0 and the air flow equation at $t>0$ acts on the cotton ball along the trajectory $\sqrt{R^2-(x-R)^2}$. Let us study the law of motion of the cotton ball. Let the air flow vector make an angle $\gamma = f(x)$ with the $0x$ axis. Let us assume that the air flow force is proportional to the relative velocity. In this case, the projections of the air flow forces on the OX and OY axes will be as follows [3, 4].

$$F_x = C_0\sqrt{(V_{0x}-V_x)^2+(V_{0y}-V_y)^2}\,\frac{V_{0x}-V_x}{|\vec{V}_0-\vec{V}|} = C_0(V_0\cos\gamma - V_x) \qquad (8)$$

$$F_y = C_0\sqrt{(V_{0x}-V_x)^2+(V_{0y}-V_y)^2}\,\frac{V_{0y}-V_y}{|\vec{V}_0-\vec{V}|} = C_0(V_0\sin\gamma - V_y) \qquad (9)$$

Here:

$$\cos\gamma = 1/\sqrt{1+f'^2(x)}\ ,\quad \sin\gamma = f'(x)/\sqrt{1+f'^2(x)}$$

$$\gamma = f' = \frac{\dot{R}-x}{\sqrt{R^2-(x-R)^2}}$$

Taking the mass of the particle as m, we formulate the differential equation of its motion under the influence of the air flow and its own weight [5,6,7]:

$$m\ddot{x} = m\dot{v}_x = F_x - F_{mcx}\sin\gamma, \qquad (10)$$

$$m\ddot{y} = m\dot{v}_y = F_y + F_{mcy}\cos\gamma \qquad (11)$$

here:

F_x, F_x- is the aerodynamic drag force of the air flow, F_{mcx}, $F_{mcy}-$ is the centrifugal force generated by the air flow.

$$F_x=\frac{C_0}{R}\left(v_0\sqrt{R^2-(x-R)^2}-Rv_x\right);\ F_y=\frac{C_0}{R}\left(v_0(R-y)-Rv_y\right)-mg;$$

$$F_{mcx}=\frac{(v_0-\sqrt{v_x^2+v_y^2})\sin\gamma}{R};\ F_{mcy}=\frac{(v_0-\sqrt{v_x^2+v_y^2})\cos\gamma}{R};$$

$$\sin\gamma=1-\frac{x}{R};\qquad \cos\gamma=\frac{\sqrt{R^2-(x-R)^2}}{R};\qquad (12)$$

Taking into account formulas (10) and (11) and (12), we write them as follows:

a) for a piece of cotton:

$$\begin{cases}\ddot{x}=\frac{C_0}{Rm}\left(v_0\sqrt{R^2-(x-R)^2}-Rv_x\right)-\frac{\left(v_0-\sqrt{v_x^2+v_y^2}\right)}{R}\left(1-\frac{x}{R}\right)\\ \ddot{y}=\frac{C_0}{Rm}\left(v_0(R-y)-Rv_y\right)+\frac{\left(v_0-\sqrt{v_x^2+v_y^2}\right)}{R}\frac{\sqrt{R^2-(y-R)^2}}{R}\end{cases}\qquad (13)$$

The initial conditions of this system are: at t=0

$$x(0)=x_0;\ y(0)=y_0;\ \dot{x}(0)=v_{0x};\ \dot{y}(0)=v_{0y}.\qquad (14)$$

b) for a heavy mixture [7]

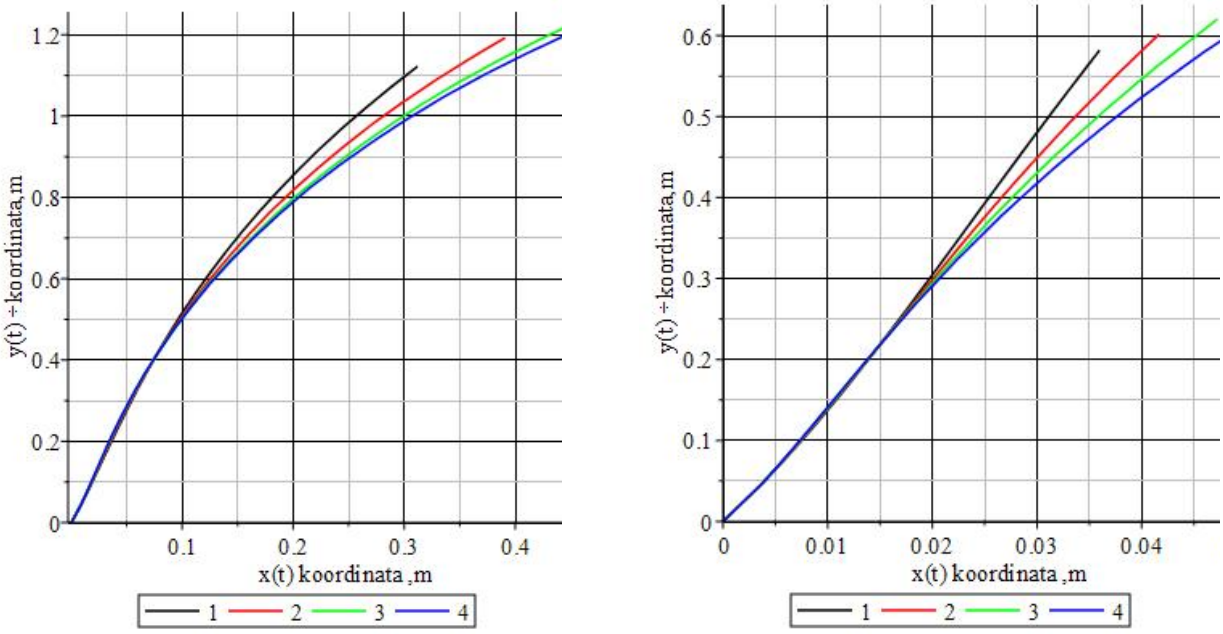
$$\begin{cases}\ddot{x}=\frac{C_0}{Rm_t}\left(v_0\sqrt{R^2-(x-R)^2}-Rv_x\right)-\frac{\left(v_0-\sqrt{v_x^2+v_y^2}\right)}{R}\left(1-\frac{x}{R}\right)\\ \ddot{y}=\frac{C_0}{Rm_t}\left(v_0(R-y)-Rv_y\right)+\frac{\left(v_0-\sqrt{v_x^2+v_y^2}\right)}{R}\frac{\sqrt{R^2-(y-R)^2}}{R}\end{cases}\qquad (15)$$

The initial conditions of this system are: at t=0

$$x(0)=x_{t0};\ y(0)=y_{t0},;\ \dot{x}(0)=v_{t0x};\ \dot{y}(0)=v_{t0y}.\qquad (16)$$

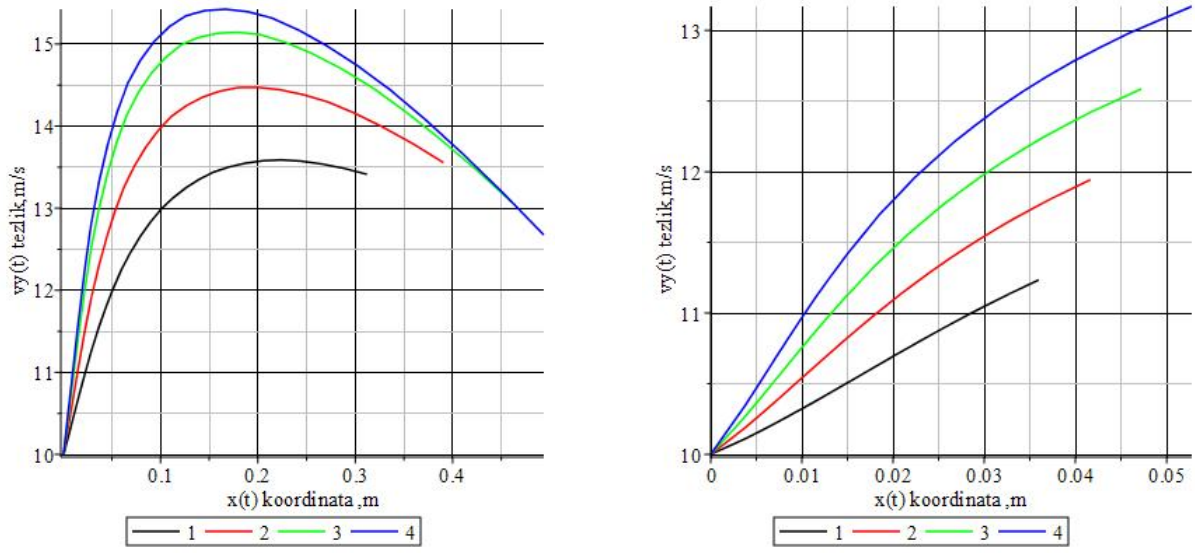
3. Results.

Since systems (13) and (15) consist of trivial differential equations, we use a numerical method to determine the solutions. The corresponding graphs were obtained in the MAPLE-17 program [8].



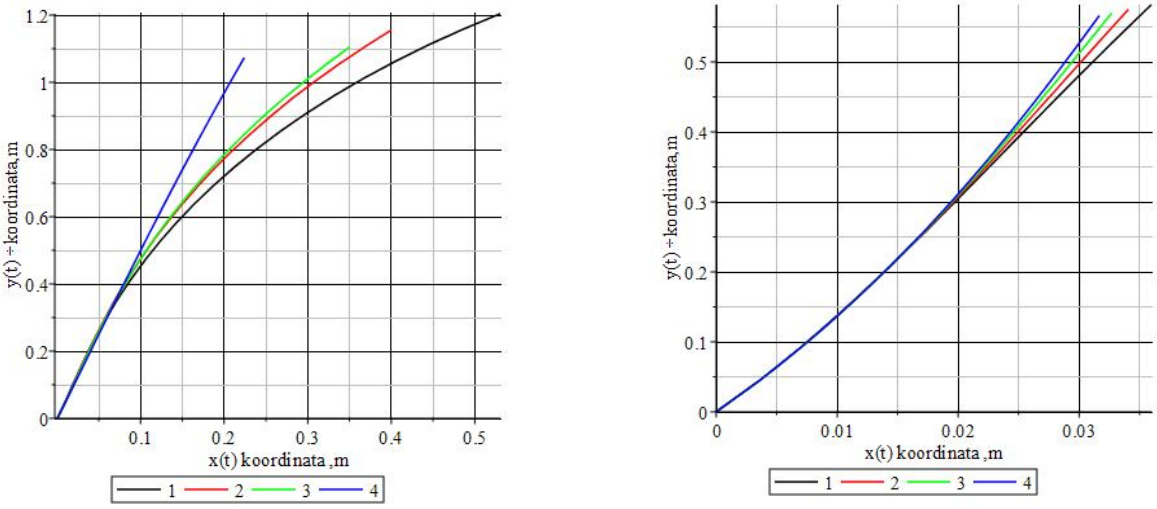
a) b)

Figure 3. Variation of the trajectory of the cotton sliver (a) and heavy mixtures (b) in the OA-range with different aerodynamic drag coefficients:
1.c=0.2; 2.c=0.3; 3.c=0.4; 4.c=0.45;



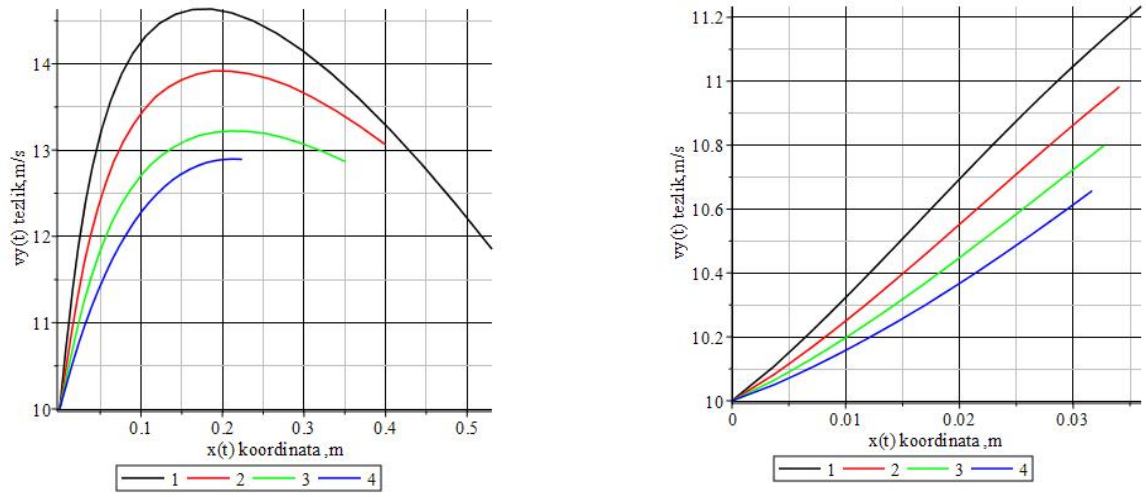
a) b)

Figure 4. Variation of the vertical velocity of cotton sliver (a) and heavy mixtures (b) in the x-coordinate at different aerodynamic drag coefficients in the OA-interval: 1.c=0.2; 2.c=0.3; 3.c=0.4; 4.c=0.45;



a) **b)**

Figure 5. Variation of the trajectory of the cotton sliver (a) and heavy impurities (b) in the OA-range depending on different mass values: 1.mp=0.01; 2.mp=0.015; 3.m_p=0.02; 4.m_p=0.025; 1.m_t=0.06; 2.m_t=0.072; 3.m_t=0.084; 4.m_t=0.096;



a) **b)**

Figure 6. Variation of vertical velocity of cotton sliver (a) and heavy mixtures (b) in the x-coordinate at different masses in the OA-interval; 1.mp=0.01; 2.mp=0.015; 3.mp=0.02; 4.mp=0.025; 1.mt=0.06; 2.mt=0.072; 3.mt=0.084; 4.mt=0.096;

4. Conclusion.

The graphs in Figures 3-6 show the laws of the trajectory of movement of cotton slivers and heavy mixtures in the OA gap of the pneumatic transport pipeline, as well as the laws of their

change in speed. In particular, the graphs in Figure 3 show that the effect of the change in the aerodynamic drag coefficient on the trajectory becomes significant for cotton slivers starting from the OA gap height of 0.6 m, and for heavy mixtures starting from 0.3 m.

If we pay attention to the change in vertical velocities along the horizontal coordinate (Fig. 4), the speed of the cotton sliver changes as it approaches the highest part of the OA interval, reaching a maximum value, that is, by a difference of 5 m/s and 5.5 m/s, and then decreases. For heavy mixtures, this process occurs 10% slower than for the cotton sliver. Figures 5 and 6 show the trajectory of the movement of the cotton sliver and heavy mixtures in the OA interval with different masses, and the laws of change in their speeds. An increase in mass leads to a decrease in speeds, and the speed of the cotton sliver is higher than the speed of heavy mixtures, and their largest value corresponds to the A-section.

According to the results of the theoretical study of the movement of cotton pieces and heavy mixtures in the working chamber of the aerodynamic cleaning device, it was determined that the speed of cotton in the transition part of the pipe regularly increases, and the speed of heavy objects decreases.

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