MATHEMATICAL MODELING OF COTTON–AIR SEPARATION DYNAMICS IN THE SEPARATOR WORKING CHAMBER

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Annotation

The article presents the results of the study of the laws of motion of cotton particles in the working chamber of the separator, located along the inlet pipe of the vacuum valve. When the change in the displacement of the cotton pieces in the horizontal and vertical directions over time was studied, it was found that the cotton pieces entering from the inlet pipe fell into the vacuum valve in about 0.4 s. From the results obtained, it can be seen that the main part of the cotton pieces falls on the front of the vacuum valve. The established laws can be used in the design of new constructions of cotton separators.

Keywords

cotton, separator, pneumatic equipment, pipe, vacuum valve, separation process, air flow.

Introduction. The cotton separator is one of the main elements of the pneumatic transport equipment, which is responsible for separating the cotton from the air flow carrying it, taking it out of the equipment and transferring it to the next process. In this direction, one of the important issues in the separator working chamber is to increase the efficiency of the equipment by maintaining its original quality and reducing process energy consumption in the process of separating the cotton piece from the air flow without damaging it.

In the existing separators, it is observed that the work efficiency is not at the required level, as a result of which the cotton pieces stick to the surface of the separator mesh. Accordingly, a separator located along the vacuum-valve inlet pipe was designed, which eliminated the existing shortcomings, which are allowed to increase dramatically the efficiency of the separator.

Figure 1 shows an improved construction scheme of the cotton separator, which includes the inlet pipe 1, the mesh surfaces on the side walls of the separation chamber 2, the shaft 3, the pulley 4, the shafts fastened to the 5 nets, the cotton suckers attached to the 6 mesh surfaces, 7 Vacuum air intake pipes, 8 Vacuum valve located perpendicular to the working chamber, 9 Vacuum valve shaft, 10 blades, 11 elastic material attached to the edge of the blades, 12 belt, 13 reducer, 14 clutch, it consists of 15 shafts and bearings mounted on shafts. This construction is the object of study and we study the movement of cotton in this separator.

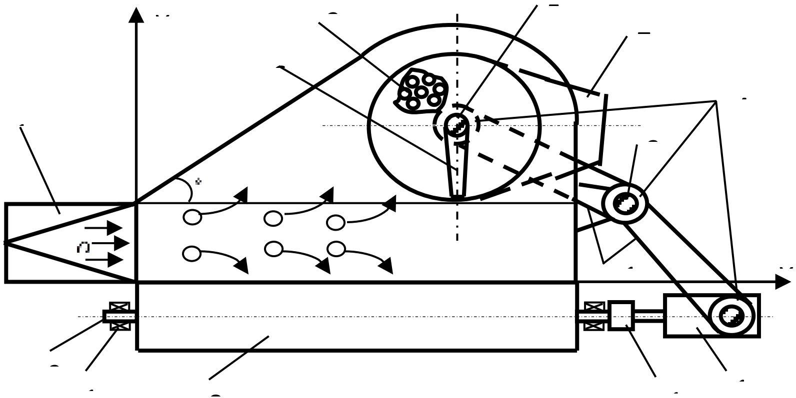


Figure 1. Improved design of the separator

1. To study the laws of motion of cotton raw materials in the separator chamber.

We consider the movement of a piece of cotton with air as two interconnected systems (Figure 2).

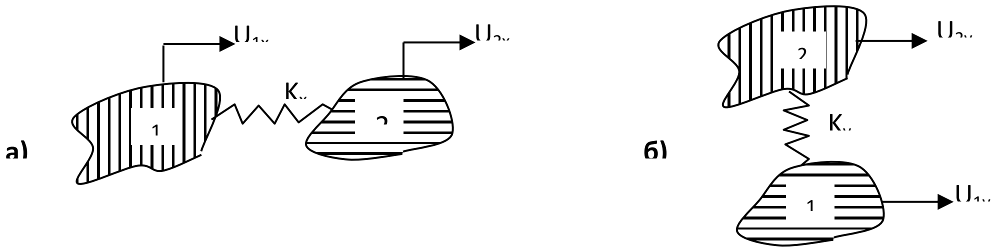


Figure 2. The movement of a piece of cotton in conjunction with air.

In this case, we usually pay attention to the movement of raw cotton air flow under the influence of aerodynamic and gravitational forces in the case of equal interconnection. Air flow speed - $V_0(м/с)$ according to the movement of cotton pieces along the axes OX, OU; $U_{1x}(t), U_{2x}(t), U_{1y}(t), U_{2y}(t)$ - we can say.

$$\dot{U}_{1x}(t),\ \dot{U}_{2x}(t)$$

$$\dot{U}_{1y}(t),\ \dot{U}_{2y}(t)$$

Air flow velocity is created in the differences between the speed of the raw cotton air parts and the speed of air flow V_0. As a result, the force that moves raw materials $F_{1x}, F_{2x}, F_{1y}, F_{2y} -$ is created. The masses of the first and second cotton pieces, m_1, m_2 respectively, are called the forces of gravity as the coefficient of elasticity between them in motion $P_1 = m_1 g,\ P_2 = m_2 g -$, and $\mu_x, \mu_y -$ the coefficient of proportionality of the force of resistance under the action of speed.

Materials and methods. It is known that because the pieces of raw cotton do not have an axis of symmetry, they fall into a downward symmetrical flow zone under the influence of gravitational force. Under the influence of air resistance, it rises again. The increase in air flow across the cross-section as a result of entering the working chamber reduces the absolute velocity of the cotton pieces. Due to the fact that the speed of the cotton pieces in the horizontal and vertical directions decreases from their flight speed, the air flow moves towards the mesh surface of the separation chamber, and the cotton pieces move towards the vacuum valve.

In the new working chamber, the location of the air-emitting mesh surfaces, at a certain distance from the direction of flow along the vertical axis, provides the following advantages:

1) Accelerates the separation of cotton particles from the air and increases the efficiency of the separator.

2) Reduces the chances of cotton pieces sticking to the mesh surface.

Taking into account the raw material of cotton and the forces acting on it, we construct a differential equation of the law of motion in the air flow based on Dalamber principle.

1-Condition. $m_1\, \text{ва}\, m_2 -$ let the mass of cotton pieces be located in a horizontal direction. (Figure 2a).

In this condition:

$$\begin{cases} m_1 \ddot{U}_{1x} + K_x (U_{1x} - U_{2x}) + 2\mu_x (\dot{U}_{1x} - \dot{U}_{2x}) = F_{1x} \\ m_2 \ddot{U}_{2x} + K_x (U_{2x} - U_{1x}) + 2\mu_x (\dot{U}_{2x} - \dot{U}_{1x}) = F_{2x} \\ m_1 \ddot{U}_{1y} + K_y (U_{1y} - U_{2y}) + 2\mu_y (\dot{U}_{1y} - \dot{U}_{2y}) = F_{1y} \\ m_2 \ddot{U}_{2y} + K_y (U_{2y} - U_{1y}) + 2\mu_y (\dot{U}_{2y} - \dot{U}_{1y}) = F_{2y} \end{cases}$$

(1) - The system of differential equations represents the law of motion of cotton particles in the separator working chamber. The aerodynamic forces acting on the cotton pieces by the air flow are as follows:

$$F_{1x} = C_1 (V_x - \dot{U}_{1x})^2, \qquad F_{2x} = C_2 (V_x - \dot{U}_{2x})^2$$

$$F_{1y} = C_1 (V_y - \dot{U}_{1y})^2, \qquad F_{2y} = C_2 (V_y - \dot{U}_{2y})^2$$

$C_1, C_2 -$ aerodynamic drag factor

Result and Discussion. The problem is in the form of a Cauchy problem, which is solved in the program MAPLE 2020 in the following initial conditions, on a computer in numerical ways.

2-Condition. $m_1 \, ва \, m_2 -$ let the mass of cotton pieces be in a vertical position during the entry into the separator working chamber (Fig. 2b). In this case, the motion of the cotton pieces differs from the first case, in the system of differential equations, in terms of elasticity coefficients and initial conditions. Participates in the differential equation when the mass of the first piece of cotton is added to the mass of the second piece of cotton.

Hence, in this case, the law of motion of the cotton pieces in the separator working chamber under the influence of air flow is as follows:

$$\begin{cases} \overline{m}_1 \ddot{U}_{1x} + \overline{K}_x (U_{1x} - U_{2x}) + 2\overline{\mu}_x (\dot{U}_{1x} - \dot{U}_{2x}) = F_{1x} \\ \overline{m}_2 \ddot{U}_{2x} + \overline{K}_x (U_{2x} - U_{1x}) + 2\overline{\mu}_x (\dot{U}_{2x} - \dot{U}_{1x}) = F_{2x} \\ \overline{m}_1 \ddot{U}_{1y} + \overline{K}_y (U_{1y} - U_{2y}) + 2\overline{\mu}_y (\dot{U}_{1y} - \dot{U}_{2y}) = F_{1y} \\ \overline{m}_2 \ddot{U}_{2y} + \overline{K}_y (U_{2y} - U_{1y}) + 2\overline{\mu}_y (\dot{U}_{2y} - \dot{U}_{1y}) = F_{2y} \end{cases} \quad (2)$$

Mathematical model analysis.

The Cauchy problem in this case is solved numerically in the MAPLE -2020 program.

In both cases the air flow velocities $V_0 = 15 \ м/с, \quad V_0 = 20 \ м/с, \ V_0 = 25 \ м/с$ values, the corresponding motion trajectories of the cotton pieces are obtained graphically.

Figure 3a shows the trajectory of the stationary motion in the separator working chamber with the cotton pieces 1 and 2 in a horizontal position. As can be seen from the graphs, the air flow $15 \ с/м \ ва \ 25 \ с/м$ when the range changes, it can be observed that the cotton pieces fall mainly into the first half of the vacuum valve.

This process $V_{y1}(t)$ can also be observed from the fact that the velocity assumes a zero value in the range of 0.1 ÷ 0.3 m along the OX axis. The trajectory of the 2nd cotton piece is the same as that of the 1st cotton piece, we can observe the direction of the vacuum-valve towards the zero velocity along the OX axis at 0.3 ÷ 0.8 m, where the vertical velocity is zero at 0.2 ÷ 0.35 m.

Figure 3b shows the law of change of cotton pieces in the horizontal and vertical directions over time. As can be seen from the graph, at around 0.4 sec, the cotton pieces have time to fall into the vacuum valve.

Figure 3b shows the laws of motion of the separator working chamber in the vertical position of the cotton pieces 1 and 2. As can be seen from the graphs, the process of dropping the cotton pieces into the vacuum valve is observed to be a bit slower over time than in the horizontal position, but it can be seen that they fall more into the front of the vacuum valve.

Calculation of the productivity of cotton balls, the work of falling into the vacuum-valve socket:

$m_0 = m_1 + m_2 = 0{,}4 + 0{,}45 = 0{,}85\,г$ weight

$t_0 = 0{,}25$ sec drop speed

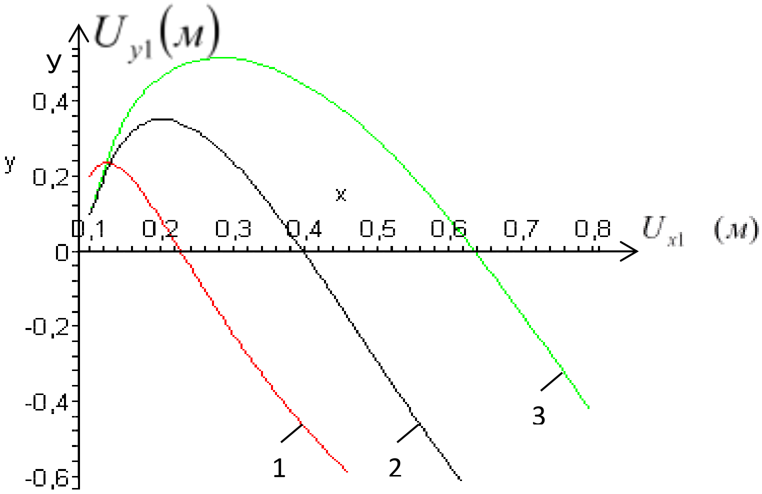
$t_1 = 1$ sec $m_1 = 3{,}4\,гр$

$t_2 = 60$ sec $t_2 = 60$

$t_3 = 1$ hour $m_3 = 1224\,0\,гр$

Taking into account the entrance surface to the working chamber of the separator, in the working chamber, it is possible to separate 19,584 tons of cotton per hour from the air.

In addition, the speed of the cotton pieces in the horizontal direction is several times smaller than the speed of sliding it, the speed in the vertical direction is reduced to zero, reducing their impact on the back of the separator, completely reducing the cases of sticking to the mesh surface.



1 – 0,22 м V_0 =15 м/с;

2 – 0,4 м V_0 =20 м/с;

Figure 3a.

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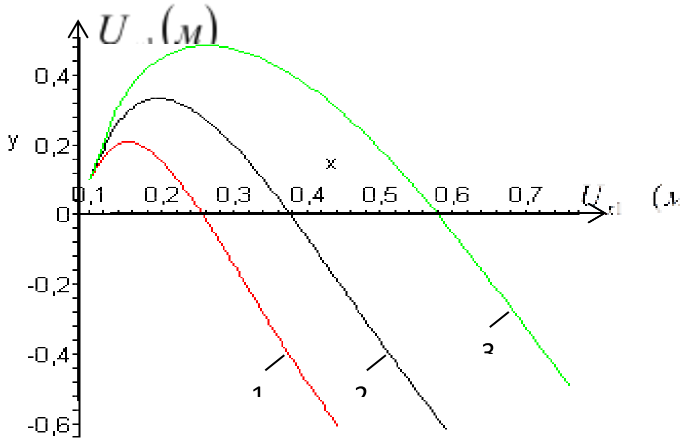

1 – 0,26 м V_0 =15 м/с;

Figure 3b.

Conclusion. The conducted study made it possible to analyze and model the dynamics of cotton particle motion inside the working chamber of a cotton separator. Particular attention was given to the section of the chamber where the inlet pipe is located along the vacuum valve, as this zone plays a critical role in determining the efficiency of the separation process. Simulation results and theoretical calculations demonstrated that cotton particles entering through the inlet undergo rapid acceleration due to the air–flow interaction. Within approximately 0.4 seconds, the majority of the cotton pieces were shown to reach and pass into the vacuum valve, confirming the high responsiveness of the separation mechanism in this section of the machine. Furthermore, it was established that the separation of the cotton mass occurs in accordance with well-defined aerodynamic and gravitational principles. A significant proportion of the cotton's total weight is discharged through the primary section of the vacuum valve. This indicates that the separator's design effectively utilizes airflow distribution to ensure that heavier particles are directed out of the working chamber at the earliest stage of the process. Such behavior not only validates the accuracy of the developed mathematical model but also highlights the separator's operational efficiency in minimizing fiber loss while maintaining continuous air circulation.

Overall, the study provides valuable scientific insight into the laws governing cotton–air separation processes. The results can serve as a foundation for further optimization of separator geometry, airflow regulation, and energy efficiency in modern cotton-cleaning technologies.

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