EFFECT OF PNEUMOTRANSPORT PIPE LENGTH ON STATIC AND DYNAMIC PRESSURE

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Abstract:
The article reflects the results of the research of the change of air speed and aerodynamic force on the cross-section of the pipe during the transportation of cotton by pneumatic transport. It contains conclusions and suggestions on effective management of cotton pneumatic transport process.

Keywords: cotton raw material, pneumatic transport equipment, air speed, pipe, pipe cross-section, diameter, aerodynamic force.

The process of transporting cotton by air takes place in a closed system isolated from the outside atmosphere. In order to visualize this process, we will take the simplest scheme of an aerodynamic device and first consider the laws of air movement in it . In the picture, 1- suction pipe, 2- fan (pump), 3- drive pipe.

The fan or pump is located in the center of the pneumatic equipment. When the system is at rest, that is, when the fan is not running, it is under the pressure of outside atmospheric air. In this case, the dynamic pressure is zero and the pressure inside the pipe is equal to the external atmospheric pressure:

$$P_d = 0\ ,\ P_{tot} = P_{st} = P_{atm},\ (1)$$

When the fan is activated, it draws air from the first half of the device and blows it to the other side. As a result, there is a vacuum environment (thin air) on one side of the equipment and a dense air environment (excess pressure) on the other side.

The total air pressure P_{tot} that the fan can produce is equal to the sum of the static P_{st} and dynamic P_{dyn} pressures in the pipe:

$$P_{tot} = P_{st} + P_{dyn}\ ,\ (2)$$

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However, the pressure from the pipe to the left, i.e. to the fan, is negative - P (vacuum), and the pressure after the fan, i.e. to the right, is positive + P. In this case, the static pressure Pst goes vertically from the pipe wall to its center on the suction side, and from the pipe center to its walls on the drive (blower) side. Also, the greatest pressure is at the inlet and outlet of the fan, that is, on both sides of the fan - negative at the inlet, positive at the outlet, and decreases in both directions - towards the ends of the pipe.

When the aerodynamic equipment is completely hermetic, the air flow into and out of the fan is equal:

$$Q_{into} = Q_{out}\ ,\ \text{or}\quad \vartheta_1 f_1 = \vartheta_2 f_2\ ,\ (3)$$

Here: air consumption Q_{into} entering the system, Q_{out} leaving the system, m^3/sec; , υ_1,υ_2- respectively, incoming and outgoing air velocity, m/s; f_1 and f_2 are the cross-sectional area of the inlet and outlet pipes, m_2.

Accordingly, the dynamic pressure is also constant:

$$P_{dyn} = \frac{\rho\vartheta^2}{2} = \frac{\rho\vartheta_2^2}{2} = \frac{\rho\vartheta_1^2}{2} = \text{const},\ (4)$$

In order to study the movement of air in the pipe, we imagine that a piston with a thickness dx, a flat surface, and a diameter equal to the internal diameter of the pipe is placed inside the pipe.

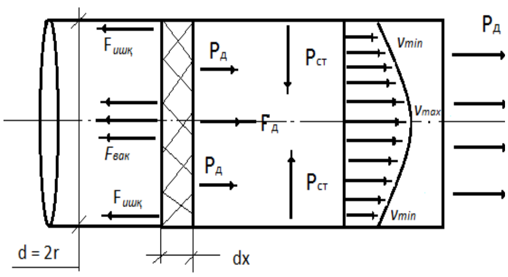

Figure 1. Air velocity and pressure directions in the pipe

In this case, the dynamic pressure of the air moving inside the pipe is evenly distributed over the surface of the piston and creates attractive aerodynamic forces. The resultant of these forces, F_a, is equal to:

$$F_a = P_д \cdot S_п\ ,\ (5)$$

Here, $P_д$ is the dynamic pressure, Pa; S_n is the piston cross-sectional area, m^2.

The cross-sectional area of the piston is equal to the cross-sectional area of the pipe, which in turn depends on the internal diameter of the pipe:

$$S_п = S_p = \pi \frac{d^2}{4}$$

The dynamic pressure, as we saw above, is proportional to the square of the air speed $P_{dyn}=0.5\ \rho\vartheta^2$ From this, the equivalent effector of the aerodynamic force can be found by the following expression:

$$F_a = \frac{\pi}{8}\ \rho(\vartheta d)^2, \quad (6)$$

This force is the maximum force that aerodynamic equipment can generate. Figure 5 shows the graph of this force and the corresponding parameters.

If we pay attention to the graphs, at the same air velocities, a relatively large aerodynamic force is generated in pipes with a large diameter. Also, as the speed increases, the difference between the magnitude of the generated force becomes sharper. This is probably the reason why the industry switched to pipes with a diameter of 400-450 mm. Because when the pneumatic transport equipment was first used in the industry of our country, the diameter of the pneumatic transport pipe was 305 mm. Later, as the productivity of production and, accordingly, the productivity of machines increased in the industry, there was a need to increase the productivity of the pneumatic transport equipment, and the industry solved the problem by increasing the diameter of the pipe, despite the high consumption of materials and energy.

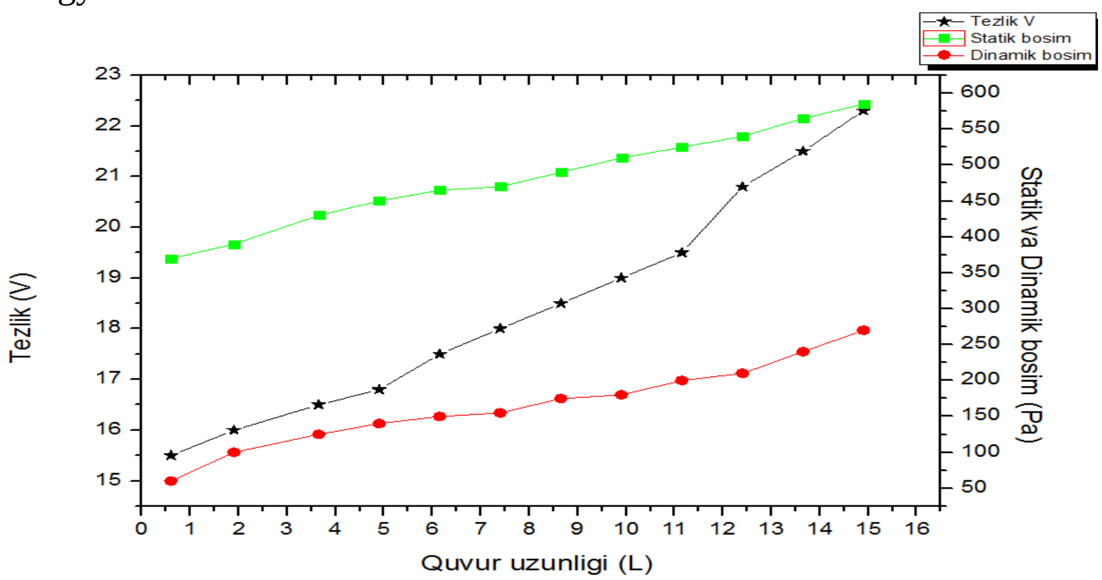

Figure 2. pipe length static, dynamic pressure graph

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However, in the current energy shortage, this solution is not justified, and the industry is gradually moving to the use of smaller diameter pipes, and our previous research [1] has theoretically justified this move.

This, in turn, causes a loss of air pressure.

In the driving (blower) part of the pneumatic transport, there is this force - the pressure forces and the gravity of the air are directed perpendicular to the pipe wall, and therefore the normal reaction force opposite to the gravity of the air also creates the friction force.

Therefore, in our opinion, a suction device uses less energy than a blower to deliver the same volume of air to the same distance. However, in any case, when the air flow moves inside the pipe, its wall layer interacts with the fixed wall and loses its energy and speed due to the properties of adhesion and viscosity.

This condition creates a tangential (attempt) stress (τ) on the pipe wall directed against the air flow. It is determined by Newton's equation in laminar (quiet) flow for liquids and gases:

$$\tau = \mu \frac{\partial \vartheta}{\partial y}, \quad (7)$$

Here: $\frac{\partial \vartheta}{\partial y}$ is called the velocity gradient and shows how the velocity is distributed along the radial axis. In laminar flow, the velocity distribution resembles a parabola (sometimes likened to the shape of a projectile) along the flow. Transportation of cotton in pneumatic transport, as noted above, occurs mainly in turbulent flows. In this case, the speed is distributed more evenly across the pipe section (Fig. 4).

The distribution of the speed in the turbulent regime along the cross-section of the pipe has been studied by many scientists [2,3,4]. Among the proposed equations, the following equations can be accepted as the closest to practice and convenient to use:

$$\vartheta = \vartheta_{max}[1 - \frac{y}{r}]^{\frac{1}{m}} \quad , (8)$$

$$\vartheta = \vartheta_{max}(y/r)^{n}, \quad (9)$$

Here: $-\vartheta$- speed at any point along the radial axis from the center of the pipe, m/s; ϑ_{max}- speed in the center of the pipe, m/s; y is the distance to the point where the speed is determined (radial coordinate), m; r – pipe radius, m; m and n are

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experimental numbers.

Let us consider equation (8). For pneumotransport processes, m = 7 is taken. Therefore, this speed distribution is called the 1/7 power distribution law.

If Y = 0, $\vartheta = \vartheta_{max}$ (velocity at the center of the pipe), if y = r, (velocity at the pipe wall). Therefore, the air flow does not pass uniformly along the pipe. The air layer in the center of the pipe flows faster, and further away from the center it flows more slowly. In this case, if the amount of air flow is not measured by the average speed, an error occurs in the calculations. According to Altshul's studies, the speed in laminar flows is $\vartheta_{ўрт} = 0.5\, \vartheta_{max}$, and in turbulent flows, the speed is equal to the average speed when y = 0.223 r

$\vartheta = \vartheta_{max}[1 - \frac{0.223\ r}{r}]^{\frac{1}{7}} = 0.965\, \vartheta_{max}$,(10) .

It can be seen from the equation that according to the accepted relation (3.8), in turbulent flows, the velocity at any point of the flow is close to the velocity at the center of the flow. That is, in a turbulent flow, the average speed is almost equal to the maximum speed! However, our measurements have shown that this is not the case (more on this later).

Let's consider equation 9. According to Altschul [3]

$n = 0.9\sqrt{f}$, (11)

Here, f- is the coefficient of pipe hydraulic resistance. Considering that f = 0.015 for new pipes when Re = (3.9÷ 5.2) $\cdot 10^{-5}$:

$\vartheta = \vartheta_{max}\left(\frac{y}{r}\right)^{0.11}$, (12)

When y= 0.223 r

$\vartheta_{ўрт} = 0.848 \cdot \vartheta_{max}$, (13)

If we pay attention to the graphs, while the (maximum) speed in the center of the pipe is the same, the speed in front of the pipe wall in a small-diameter pipe is greater than in a large-diameter pipe, that is, in small-diameter pipes, the air velocity in turbulent flows is distributed more evenly across the cross-section of the pipe. Also, the average speed of the air depends on the (maximum) speed in the center of the pipe, and as the diameter of the pipe increases, the difference between the maximum and average speeds increases, and as it becomes smaller, the difference in speeds decreases.

It can be concluded from what has been seen that due to the resistance forces acting on the air in the pipes by the pipe walls, the speed is not evenly distributed over the cross section of the pipe. Therefore, it is necessary to use the value of the average speed of the air in the calculations of the pneumotransport process.

Based on the analysis, we can make the following conclusions:

1. At the same air speed, a relatively large aerodynamic force is generated in pipes with a large diameter. Also, as the speed increases, the difference between the magnitude of the generated force becomes sharper.
2. Due to the effect of resistance forces on the air by the pipe walls, the air velocity is uniformly distributed along the cross section of the pipe, as a result, the aerodynamic force serving to transport products in pneumatic transport is not distributed uniformly, but the force is the smallest near the pipe wall, and has the largest value in the center of the pipe. Therefore, it is necessary to use the value of the average speed of the air in the calculations of the pneumotransport process.
3.In turbulent flows, the average air speed in the pipe depends on the (maximum) speed in the center of the pipe, and as the diameter of the pipe increases, the difference between the maximum and average velocities increases, and as it decreases, the difference in speeds decreases, that is, in small-diameter pipes, the air velocity is distributed more evenly across the cross section of the pipe.

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