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THEORETICAL STUDY OF THE ECCENTRIC-TYPE EXPERIMENTAL VACUUM VALVE DESIGN

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Abstract:

This article theoretically analyzes the shortcomings observed during the operation of SS-15 type separators used in the cotton-cleaning industry, particularly the energy losses caused by air leakage into the vacuum valve system and its impact on the quality of raw cotton. Furthermore, an experimental eccentric-type vacuum valve design was developed, and its efficiency was analyzed with respect to angular velocity, number of blades, and inclination angle.

Keywords: Separator, pneumatic transport system, raw cotton, energy efficiency, experimental design, eccentric vacuum valve, blade angle, filling coefficient.

Introduction

. Although SS-15 type separator devices operate more efficiently than their analogues, they also have inherent drawbacks. These factors play a significant role in the process of separating cotton from the airflow. The most significant issue is the damage caused to the cotton seed when the seed cotton enters the working chamber at high speed and strikes the surface. Additionally, during the cleaning of cotton adhered to the mesh surface of the SS-15 separator using scrapers, some free fibers detached from the seeds are carried away by the airflow and released into the external environment.

In a pneumatic transport device with a productivity of 15 t/h, fiber loss amounts to 2.46 kg/h, and in low-grade cotton this reaches 4.14 kg/h [2]. During the rough ginning process, mature fibers easily separate from the seed under small forces, and a certain amount of these fibers pass through the mesh along with the suctioned air stream. Moreover, passive impurities within the cotton mass move chaotically inside the working chamber and mix with the raw cotton, becoming active. This further complicates the cotton-cleaning process.

The main reason for this is uneven airflow. The falling of cotton from the vacuum valve blades and the backflow of air into the cells between the blades significantly affects the air drawn from long distances. Changes in airflow, in turn, influence cotton movement. To solve these problems, air must enter the working chamber in a uniform manner.

One of the most important requirements for pneumatic transport systems and their components is maintaining vacuum conditions and ensuring airtightness. That is, external air must not be allowed to enter through gaps. This is particularly important in areas where the pressure difference between the inside and outside of the device is large, such as sections connected to the fan. Air leakage increases power consumption and reduces the reliability of the separation process due to the vacuum valve [3]. Excessive air suction into the separator body is mainly caused by the operating principle of its vacuum valve [4].

The primary function of the vacuum valve is to discharge material from the device to the external environment while maintaining airtightness. Cotton separated from the airflow moves downward into the cells between the valve blades and exits due to the rotary motion of the vacuum valve. However, air returns through the cells, negatively impacting the overall separation process.

The rotational frequency of the vacuum valve is 90 rpm [5]. This means each cell rotates 1.5 times per second. In other words, 0.12 m³ of air per second leaks through one cell. With a pneumatic transport system consuming 75 kW of energy, the airflow rate equals 23,040 m³/h. One separator may allow 432 m³ of air leakage per hour. Although this figure is relatively small compared to 23,040 m³, cotton-cleaning factories typically use four separators. If the conveying distance increases, more separators may be added. In such cases, the total air leakage reaches 1,728 m³/h. This amount corresponds to 7.5% of the airflow of the VTS-12M fan that consumes 23,040 m³/h. Additionally, air leakage in separators results in a loss of 5.6 kW of electrical energy. When calculated per day and per month, this leads to significant energy losses. Research indicates the necessity of improving the vacuum valve of the separator.

As shown in Figure 1, one separator loses 432 m³/h of air, and with four separators this reaches 1,728 m³/h. The total air leakage increases proportionally with the number of separators.

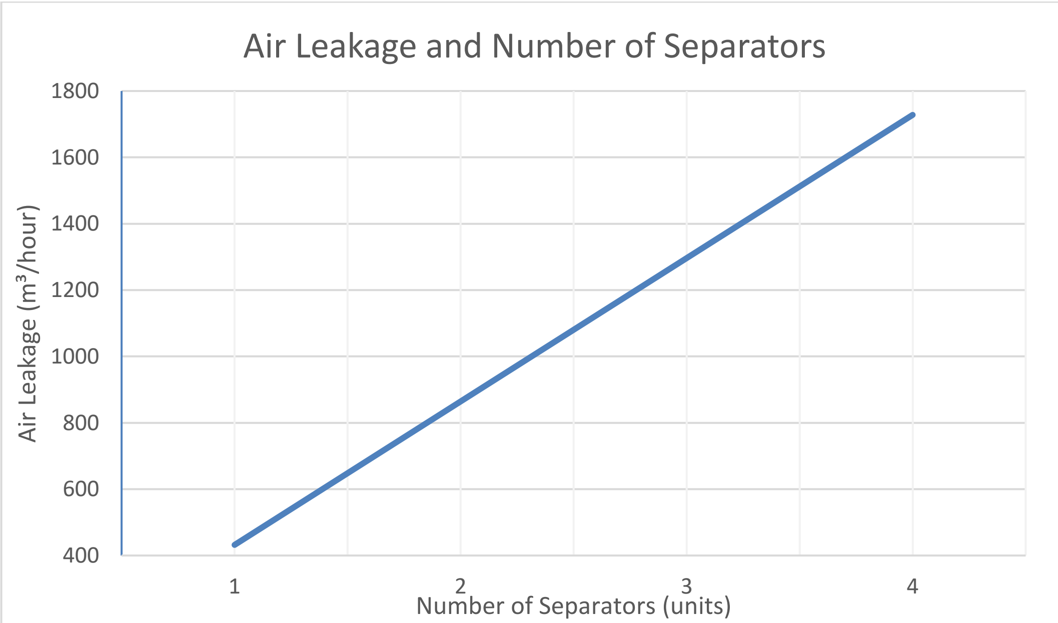

Figure 1. Influence of number of separators on air leakage

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Figure 2 shows that each separator causes 5.6 kW/h energy loss due to air leakage. When four separators operate, the total energy loss reaches 22.4 kW/h, which equals 537.6 kW/h per day and 161,280 kW/h per month—a substantial loss.

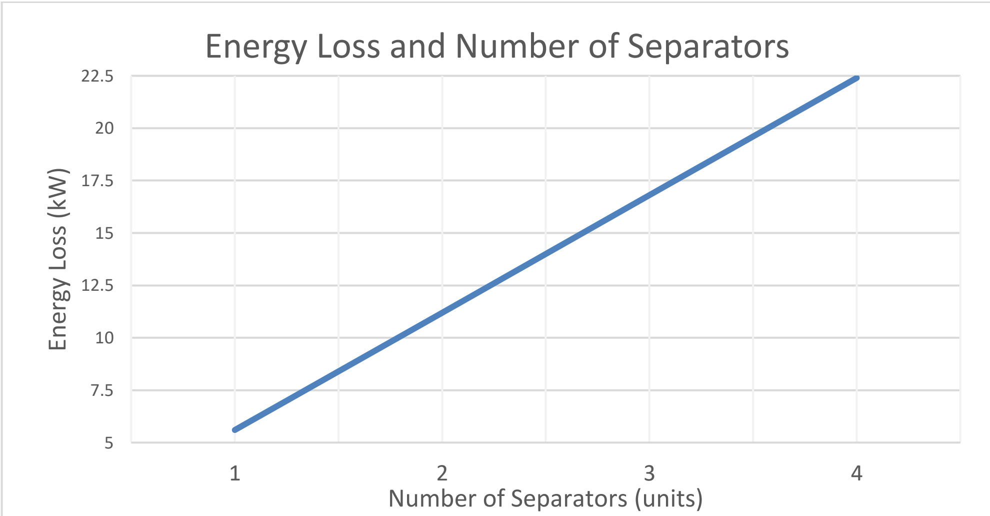

Figure 2. Influence of number of separators on energy consumption

To theoretically analyze the operation of the vacuum valve, we examine the filling process of a prismatic volume of length L (equal to blade length). The section (cell) is expressed using the central angle L and the central angle corresponding to the valve loading region.

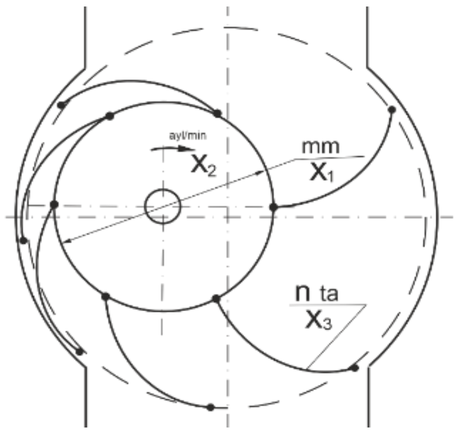

Figure 3. Scheme of the proposed experimental eccentric-type vacuum valve

According to the technical characteristics, the separator productivity is 15 t/h, and the vacuum valve angular velocity is 1.53 rev/s (92 rpm). High blade angular velocity reduces the filling coefficient of the cells, leading to increased energy consumption and seed damage.

According to research, when the vacuum valve of the cotton separator runs idle (1.53 rev/s), it consumes 5.7–5.9 kW of electricity; under load this increases to 6.7–7.9 kW. During normal separator operation, the required power for the vacuum valve reaches 9.6–10.3 kW. Therefore, the standard 7.5 kW motor of the SS-15A separator is replaced with an 11 kW one.

Transporting cotton along the vacuum valve walls requires 0.8–2.2 kW of power. Various forces acting on the cotton during this movement result in 0.18–0.4% seed damage.

Proper fiber loosening is crucial for the correct operation of the vacuum valve. Not all incoming cotton enters the cells; some becomes caught on the blades and rotates along the valve housing, causing significant resistance. Figures 4 and 5 illustrate how different inclination angles α of the vacuum valve profile affect the motion of cotton particles.

From Figure 4, increasing α reduces the transition time of the blade profile from horizontal to vertical—from about 8 seconds to 3–4 seconds.

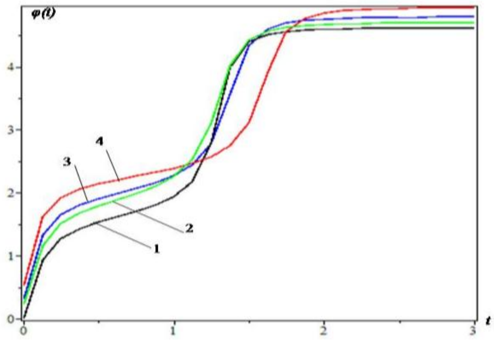

Figure 4. In the AV zone, the time variation φ(t) of the rotation angle of the cotton particle motion vector around the separator axis is presented for four distinct values of the vacuum-valve profile inclination angle α.

α=0°; 2- α=14°; 3- α=20°;4- α=30°.

This accelerates the movement of cotton to the next stage and decreases the travel path within the same time frame (Figure 5), reducing stagnation inside the valve.

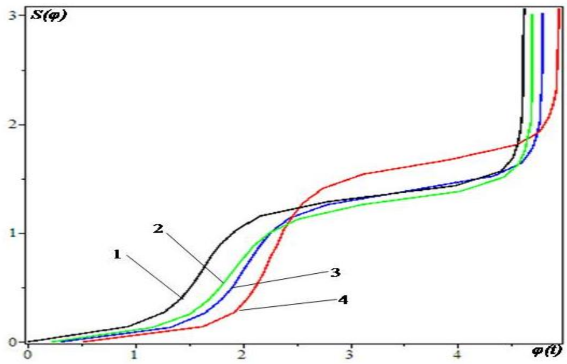

Figure 5. In the AV zone, the graph illustrates the variation of the cotton particle path length as S(t) a function of the rotational angle φ(t) around the separator axis, evaluated for four different values of the vacuum-valve profile inclination angle α .

The results show that as the angular velocity ω of the vacuum-valve profile around the separator axis increases, the distance traveled by the cotton particles within the same time interval decreases. Consequently, this leads to the cotton particles remaining within the vacuum-valve profile region. When the vacuum-valve blades are positioned at an angle of relative to the axis, the transition of the cotton particles to the next stage becomes faster. Since the angular velocity of the cotton particles with respect to their own center of gravity is significantly lower than the angular velocity of the rotating blades, the Coriolis force arising in the motion dynamics is almost negligible.

To perform a theoretical analysis of the vacuum-valve operation, we examine the filling process of a prismatic volume with length , which corresponds to the vane length. The section (cell) is expressed through the central angle, and β- central angle, which corresponds to the loading zone of the vacuum-valve.

In the separator, the flow of raw cotton continuously enters the vaned drum sections (cells) at a speed V, while the drum rotates with an angular velocity ω.

The amount of cotton falling into one section (cell) during the time interval Δt is:

$dq=\rho vltR\omega\Delta t$

Here: q-the bulk density of the raw cotton, kg/m³; R-the radius of the drum (section/cell), m.

The filling of one section (cell) occurs within the time interval $0\leq t \leq (B+L)/\omega$. During the interval $\beta/\omega\leq t \leq (\beta+\alpha)$, the raw cotton enters in a uniform amount, which is equal to:

$$q_1=\int_0^{a/\omega} \rho VlR\omega t dt = \frac{1}{2}\rho VlR\frac{d^2}{\omega^2} \qquad (1)$$

Within the interval $\alpha/\omega\leq t \leq \beta/\omega$, the cross-sectional area through which the material passes remains constant; therefore, the amount of cotton entering during this interval is given by:

$$q_2 = \rho VRl(\frac{\beta}{\omega} - \frac{\alpha}{\omega}) \qquad (2)$$

Thus, the amount of raw cotton entering a single section (cell) during its passage through the loading zone is:

$$Q_m=\frac{\rho VlR(\alpha^2 - \alpha + \beta)}{\omega} \qquad (3)$$

The volume of cotton entering the section (cell) is determined by the following formula:

$$V_m=\frac{Q_m}{\rho} = \frac{VlR(\alpha^2 - \alpha + \beta)}{\omega} \qquad (4)$$

We determine the volume of a section (cell) as follows:

$$V_{ya}=\frac{1}{2}(R^2 - r^2)l\sin\alpha \qquad (5)$$

here: r-radius of the vacuum-valve shaft, m;

We determine the filling coefficient ψ as follows:

$$\psi = \frac{Vm}{V я} = \frac{2VR(\alpha^2 - \alpha + \beta)}{\omega(R^2 - r^2)\sin\alpha} \qquad (6)$$

Taking into account the dependence of the material feed speed V on the production capacity P_s:

$$V = \frac{\Pi_c}{2\rho R l \sin\frac{\alpha}{2}} \qquad (7)$$

To determine the filling coefficient of the vacuum-valve section (cell) with raw cotton, we take:

$$\psi = \frac{\Pi_c(\alpha^2 - \alpha + \beta)}{\omega\rho l(R^2 - r^2)\sin\alpha \sin\frac{\alpha}{2}} \qquad (8)$$

A six-blade vacuum valve was used in the separator. Later, in order to reduce the amount of air entering the vacuum valve, it was replaced with an eight-blade model.

Using formula (2.43), the filling coefficients of the vacuum-valve sections (cells) corresponding to the separator productivity at different angular velocities of the bladed drum were determined.

Conclusion. The calculation results are presented in table 1. (In the calculations we take: $\alpha = 45^0 : \beta = 90^0 : \rho = 50\frac{кг}{м^3} : l = 1{,}7m : R = 0{,}3m : r = 0{,}07m$)

Values of the vacuum-valve filling coefficient at different production capacities

Table 1

Filling coefficient, ψ	**Ishlab chiqarish unumdorligi, P_s, t/soat**		
	10	**15**	**20**
ω=9,6c^{-1} n=92 ayl/daq	0,088	0,13	0,17
ω=6,28c^{-1} n=60 ayl/daq	0,13	0,20	0,26
ω=4,7c^{-1} n=45 ayl/daq	0,18	0,26	0,34

According to the technical specifications of the separator, its operating productivity is 15 t/h, and the angular velocity of the vacuum valve is 1.53 rev/s (92 rpm), which is equal to that of the drum. At higher angular velocities of the blades, the filling coefficient of the sections (cells) becomes lower. This, in turn, leads to increased energy consumption in the pneumatic system and causes seed damage in the raw cotton.

References

1. Abdullayev A.A., Mamatov B.S. Paxta tozalash mashinalarida pnevmatik transport tizimlarining energiya samaradorligi. – Paxtachilik va toʻqimachilik sanoati ilmiy jurnali, 2018, №3, 45–52-b.

2. Karimov S.A., Tursunov O.M. Separator vakuum-klapanlarida havo sizib kirishining texnologik jarayonga ta'siri. – Texnika fanlari axborotnomasi, 2017, №4, 33–38-b.
3. Suyunov U.K. Paxta bo'lakchalarining pnevmatik separatorlarda harakatini matematik modellashtirish. – Muhandislik tadqiqotlari jurnali, 2021, №1, 41–49-b.
4. SS-15A tipidagi paxta separatorlari. Texnik tavsif va ekspluatatsiya qo'llanmasi. – Toshkent: "O'zpaxtasanoat", 2016.
5. Ismoilov J.J., Rahmonov D.T. Paxta tozalash separatorlari vakuum-klapanlarini takomillashtirish masalalari. – Andijon mashinasozlik instituti ilmiy axborotlari, 2020, №2, 87–94-b.
6. Лялин А.И., Иванов В.П. Пневматический транспорт волокнистых материалов. – Москва: Машиностроение, 2015.
7. Гуляев В.Н. Вакуумные клапаны и шлюзовые затворы пневмотранспортных систем. – Санкт-Петербург: Политехника, 2014.
8. Bulanov V.A., Smirnov P.I. Influence of blade number and rotational speed on air leakage in rotary valves. – Applied Mechanics and Materials, 2019, Vol. 887, pp. 112–118.
9. Rogers S., Maynard K. Design and optimization of rotary airlocks. – London: Elsevier, 2013.
10. Zhang H., Liu Y. Energy losses and material damage in pneumatic conveying of agricultural products. – Biosystems Engineering, 2018, Vol. 170, pp. 1–9.