

Analysis of Improved Kinematic Schemes in the Purification of Buttermilk from Fine Impurities

Rajabova Munira Anvarovna

Independent researcher, Termiz State University of Engineering and Agrotechnology
munirarajabova939@gmail.com

Muxammadieva Xosiyat Safaraliyeva

Independent researcher, Surkhandarya Region, Denov Institute of Entrepreneurship and Pedagogy, Manager of the Registrar's Office for Coordination of Educational Processes
muxammasiyevaX@gmail.com

Abstract: This article theoretically and experimentally investigates the efficiency of various kinematic transmission schemes used in spike drum cleaners in the process of cleaning cotton from fine impurities. The study assessed the rotational speed, torque, vibration level, heating condition, and overall efficiency indicators of the working drum based on belt drive, cylindrical gearbox, and flat belt transmission schemes. Based on calculations and experimental results, the flat belt transmission scheme was identified as the optimal solution, providing a drum rotational speed of 950 rpm, a vibration level of 2.8 mm/s, and achieving an efficiency of 93%. This solution ensures energy savings during operation, reduces asymmetric vibrations of the spike drum, and extends the service life of the working components.

Key words: cotton cleaning, spike drum, kinematic scheme, efficiency, energy saving, vibration.



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Introduction: In the initial processing of raw cotton, effective removal of fine impurities is of great importance.

Low efficiency in this process not only reduces fiber quality but also leads to increased energy consumption during production and accelerates equipment wear and tear. Therefore, improving the working components and transmission mechanisms used in spike drum cleaners is considered a pressing task.

This article presents a theoretical and experimental analysis of three different kinematic transmission schemes used in spike drum cleaners, evaluating their operational efficiency. Based on the results, the optimal scheme has been substantiated.

The design and working principles of spike drum cleaners have been extensively studied in the scientific literature [1, 2, 3].

In R. Rakhimov's research, one of the methods proposed to improve the efficiency of cleaning cotton from fine impurities was the continuous cleaning of the mesh surface by keeping its holes open.

For this purpose, brush-rubber strips were installed on the spike drum to scrape the mesh surface [1].

In the studies conducted by B. Pardayev [2], the spike drums were designed with multi-faceted coverings and reduced in diameter, while the length of the spikes was varied to ensure effective loosening of the cotton, which led to the intensive removal of impurities.

In these experiments, the first spike drum had relatively longer spikes, while the remaining four drums used progressively shorter spikes to achieve cotton loosening.

However, factors such as cotton moisture content and the degree of entanglement were not taken into account.

In the works of A. Bobomatov [3], the vibration behavior of an elastic plate under continuous impact from cotton was studied through a numerical solution of the problem. The vibration patterns of the elastic plate were determined based on this analysis.

The equations describing the vibrational motion of the elastic plate on the mesh surface were obtained under various impact conditions of raw cotton.

Research shows that the rotational speed of the working components and the power transmitted to them directly affect overall efficiency. However, in most existing schemes, due to non-optimal distribution of rotational speed and torque, power losses and asymmetric vibrations are observed. Therefore, it is necessary to develop new kinematic solutions.

During the experiments, three spike drums on the laboratory test bench were connected using belts based on different kinematic schemes (Figure 1).

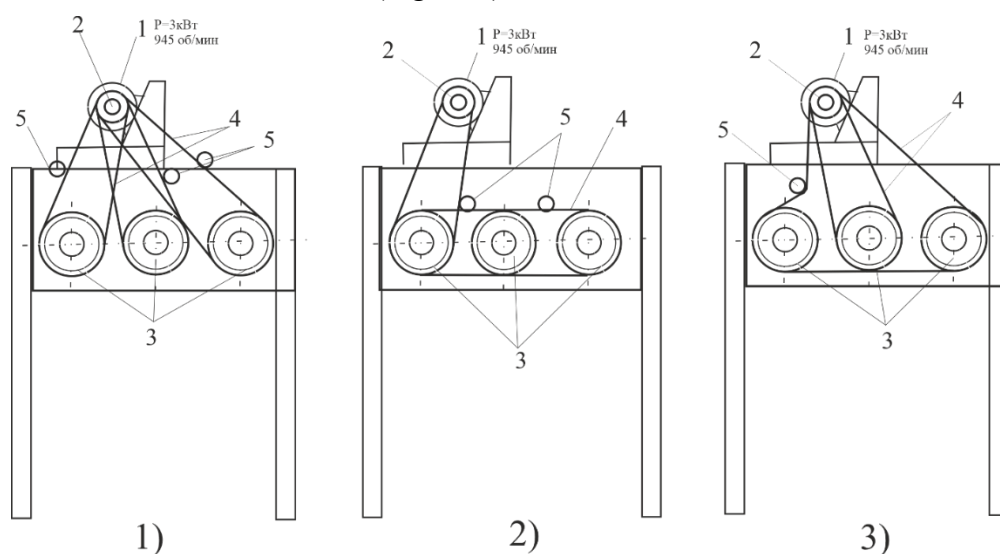


Figure 1. Analysis of three types of kinematic schemes designed to drive the proposed three spike drums.

To evaluate the system under conditions close to actual operation, the electric motors were run for 15 minutes prior to starting the experiments to preheat the system. For each scheme, tests were conducted three times, and the average values of the results were calculated.

The following instruments were used to carry out the measurements:

1. Tachometer DT-2234C+ – for measuring rotational speed (laser, non-contact).
2. Vibrometer "ViPen" – for measuring vibration levels.
3. Dynamometer/Torque sensor "Tohnichi ST2 SpinTork" – for measuring torque values.
4. Wattmeter "RS485 Modbus" – for calculating power consumption.
5. Pyrometer GM900-50950 – for measuring the heating temperature of belts and pulleys.

In each experiment, the rotational speed, vibration, belt heating, and deformation along its length were measured. Measurements were conducted during the system's 60-minute operation. Prior to testing, the electric motor was run for 15 minutes to bring the system to full working condition.

The experiments were performed in three repetitions, and the average values of the results were calculated. To simulate natural working conditions, cotton was fed to the test bench at a consistent rate of 500 kg per hour, ensuring a uniform load.

The following parameters were recorded during each test:

Electric motor speed (n_1); Spike drum speeds (n_2, n_3, n_4); Transmission efficiency η (%); Vibration (mm/s); Belt transmission temperature under load ($^{\circ}\text{C}$); Belt length change or deformation; Power consumption (W); Slip condition during rotation.

The comparative evaluation of the transmission schemes was carried out using the following indicators [4]:

Energy efficiency of power transmission:

$$\eta_{\text{Э}} = \left(\frac{n_2}{n_1} * \frac{M_2}{M_1} \right) * 100 \% \quad (1)$$

Kinematic efficiency:

$$\eta_{\text{К}} = \frac{n_{\text{реал}}}{n_{\text{назар}}} * 100 \% \quad (2)$$

Slip calculation based on rotational speeds to evaluate power losses in the belt drive.

$$S = \frac{n_{\text{назар}} - n_{\text{реал}}}{n_{\text{назар}}} * 100 \% \quad (3)$$

Rotational speeds were measured using a tachometer, while vibration, belt heating, and power were determined using specialized instruments. The presence or absence of slip during rotation was monitored through observations and calculations. However, as slip in the belt increased, both its heating and the reduction in the drum's rotational speed also increased. Therefore, the heating and rotational speed of each drum were continuously measured.

During the experiments, the output power was 2.7 kW, the motor's torque was 30.3 Nm, and the torque of the first drum was 61.4 Nm, based on which the energy efficiency was calculated.

$$\eta_{\text{Э}} = \frac{n_2}{n_1} * \frac{M_2}{M_1} = \frac{405}{945} * \frac{61.4}{30.3} = 86,8\%$$

The rotational speed of the second drum was measured at 390 rpm, with a torque of 60.6 Nm, resulting in an efficiency (η) of 82.5%.

The third drum's rotational speed was 395 rpm, with a torque of 59.8 Nm. The overall efficiency was $\eta = 82.5\%$.

Table 1. Experimental results for the first kinematic scheme

Parameters	Drum 1	Drum 2	Drum 3
Rotational speed of drums, rpm	405	390	395
Torque, Nm	61,4	60,6	59,8
Energy efficiency, $\eta_3 = \left(\frac{n_2}{n_1} * \frac{M_2}{M_1} \right) * 100 \%$	86,8	82,5	82,5
Kinematic efficiency, $\eta_k = \frac{n_{\text{реал}}}{n_{\text{назар}}} * 100 \%$	96,4	92,9	94,0
Vibration (mm/s)	1,2	1,7	2,8
Heating, °C	42	44	48
Slip, %	3,6	7,1	6,0
Belt elongation, mm	1,2	1,7	2,5

As seen from the results in Table 1, the rotational speed decreases progressively with each subsequent drum in the system, which is explained by the increase in slip and energy losses in the belts. The proportional decrease in torque leads to a reduction in efficiency. For example, in drums 2 and 3, the efficiency $\eta_e \approx 82.5\%$, which may require maintenance or repair work.

The vibration indicators were 2.8 mm/s according to the GOST ISO 10816-3:2002 standard [5], indicating the need for monitoring. An increase in vibration may be associated with insufficient belt tension or installation defects of the pulleys.

Additionally, the heating of the belts caused their elongation and material fatigue. An elongation of 2.5 mm exceeded the normal limit by more than 2%, indicating the need for constant retensioning of the belts.

Overall, the experimental results indicate that when the drums are connected according to this scheme, it is difficult to maintain uniform belt tension, resulting in increased slip and heating. This leads to a decrease in operational efficiency and excessive energy consumption.

Continuing the experiments, the second kinematic scheme was tested, in which Belt 1 connects pulleys 1 and 2, while Belt 2 connects pulleys 2 and 3, transmitting motion to a single pulley (see Figure 1-(2)). The experimental results are presented in Table 2 below.

Table 2. Experimental results for the second kinematic scheme

Parameters	Drum 1	Drum 2	Drum 3
Rotational speed of drums, rpm	410	400	395
Torque, Nm	59,0	57,5	55,0
Energy efficiency, $\eta_3 = \left(\frac{n_2}{n_1} * \frac{M_2}{M_1} \right) * 100 \%$	84,5	80,3	75,9
Kinematic efficiency, $\eta_k = \frac{n_{\text{реал}}}{n_{\text{назар}}} * 100 \%$	97,6	95,2	94,0
Vibration (mm/s)	3,2	3,5	4,1
Heating, °C	42	46	50
Slip, %	2,4	4,8	6,0
Belt elongation, mm	2,2	3,1	3,8

The experimental results indicate that the second kinematic scheme is operable; however, regular maintenance is required for its effective use. Energy efficiency decreased from 84.5% to 75.9%, while kinematic efficiency dropped from 97.6% to 94.0%. Vibration levels ranged from 3.2 to 4.1 mm/s, indicating a shift towards the upper limit of the normal range. Heating values also increased from 42°C to 50°C.

This situation indicates a risk of developing dynamic malfunctions in the transmission components, making continuous preventive measures essential to ensure uninterrupted operation.

The experiments continued by testing the third kinematic scheme (Table 3).

Table 3. Experimental results for the third kinematic scheme

Parameters	Drum 1	Drum 2	Drum 3
Rotational speed of drums, rpm	415	405	410
Torque, Nm	60,2	59,1	60
Energy efficiency, $\eta_{\Sigma} = \left(\frac{n_2}{n_1} * \frac{M_2}{M_1} \right) * 100 \%$	87,3	83,6	85,9
Kinematic efficiency, $\eta_K = \frac{n_{\text{реал}}}{n_{\text{назар}}} * 100 \%$	98,8	96,4	97,6
Vibration (mm/s)	2,9	3,1	3,6
Heating, °C	39	42	45
Slip, %	1,2	3,6	2,4
Belt elongation, mm	1,9	2,5	3,1

The results show that the rotational speeds of the drums remained stable (415–405–410 rpm) with minimal variation. The torque was also maintained around 59–60 N·m, ensuring a consistent load distribution. Energy efficiency ranged from 83.6% to 87.3%, and kinematic efficiency ranged from 96.4% to 98.8%, indicating higher values compared to the previous schemes.

The vibration level was between 2.9 and 3.6 mm/s, which did not exceed the requirements of GOST ISO 10816-3:2002 [5]. Heating ranged from 39°C to 45°C, and belt elongation remained within acceptable limits. Slip was between 1.2% and 3.6%, staying within the technical standard ($\leq 4\%$).

The experimental results indicate that the third kinematic scheme reduces energy losses while ensuring stable and reliable power transmission. Vibration and heating levels in the belts remain within acceptable limits, thereby guaranteeing the continuous operation of the transmission system.

Conclusion. It has been proven that the transmission scheme in spike drum cleaners used for removing fine impurities from cotton significantly affects operational efficiency.

Experimental results identified the transmission in the third scheme as the most optimal solution due to its stable rotational speed, low vibration levels, and high efficiency. This scheme ensures energy savings during operation, reduces asymmetric vibrations of the spikes, and extends the service life of the working components.

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