Optimization of Bush-Guiding Efficiency in Vertical-Spindle Cotton Pickers Through Elliptical Drum Design: A Simulation-Based Study

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Abstract. This work is dedicated to studying the influence of the design features of the elliptical drum of a vertical-spindle cotton picker machine on the efficiency of the spindles. The interaction of individual pressing sectors of the new drum with cotton bushes in the working gap of the cotton picker is investigated. The "GeoGebra" dynamic mathematics software, which is open-source, was used to simulate the movement of the spindles and the pressing sectors of the elliptical drum. The software allows virtual manipulation of the geometric dimensions of the drum's structural elements. By simulating the movement of the spindles and the pressing sectors of the elliptical drum, a comparison was made of the impact characteristics on the cotton bushes by the spindles and the pressing sectors of both the elliptical and standard drums. A computer graphical method was developed to assess the effectiveness of the pressing sector's impact on the cotton bushes as they are introduced into the working chamber. It was found that by controlling the geometric parameters of the pressing sector and other dimensions of the elliptical drum, the bush-guiding capability of the vertical-spindle cotton picker machine can be significantly improved.

1 INTRODUCTION

In Central Asia, the cotton harvesting period is extended by at least 15-20 days, making the organization of a one-time harvest of this valuable raw material more challenging. This extended period complicates the effective use of high-performance horizontal-spindle cotton harvesting machines (HS CHM), which, due to the high activity of their working parts, collect cotton from both mature and immature bolls, thereby reducing the quality of the harvested raw material (Yakubov et al., 2024a). Conversely, vertical-spindle cotton harvesting machines (VS CHM) selectively collect cotton only from mature bolls, providing an advantage in terms of quality. However, the VS CHM, which are currently produced in small batches in the Republic of Uzbekistan, struggle to compete with HS CHM in terms of collection completeness and productivity, particularly in high-yield scenarios (more than 35-45 centners per hectare) (Yakubov et al., 2024b). Extensive theoretical and experimental studies have identified that the primary reason for the low collection completeness of VS CHM is the limited contact area of the spindles with the cotton plants and the insufficient number of spindles simultaneously engaging with the cotton bolls during harvesting (Rizaev, 2017; Ravutov, 2019).

Another issue affecting the efficiency of VS CHM is the steep angle at which cotton plants enter the working chamber, which causes an accumulation of plant mass in front of the working slot. This accumulation complicates the even distribution and proper orientation of the cotton bolls on the spindles within the impact zone (Ravutov, 2019; Turanov et al., 2021a). According to the current technological

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scheme of the VS CHM, as the machine moves along the cotton rows, the spindle drums—installed in pairs on the machine—are supposed to pull the plants into the working slot in a vertical position. However, this does not occur as expected because the spindles in the working zone rotate in the opposite direction relative to the drum, preventing the plants from entering the working chamber vertically. Consequently, the plants are forcibly introduced into the working chamber, leading to crop losses and damage to the plant elements before they fully enter the chamber. Many studies focusing on the interaction between the spindles and the cotton plants at the entry point into the working chamber, as well as the issue of plant mass accumulation in front of the machine's working chamber, have attributed these problems to the design features of VS CHM (Abdazimov et al., 2011; Shoumarova et al., 2022; Shoumarova et al., 2023). These studies suggest that addressing these issues within the current serial designs of VS CHM is challenging. To facilitate the entry of plants into the working chamber in a vertical position, previous research recommended altering the direction of spindle rotation around their axes in this zone. Specifically, friction drives of the spindles were modified: a reverse rotation block replaced the direct rotation belt in the collection zone, and a direct rotation belt was installed in another section. Field tests of this modified spindle drive yielded positive results regarding plant entry into the working chamber. However, due to a decrease in the angular speed of the spindles by approximately 20% and reduced spindle activity in this zone, no significant improvement in collection completeness was observed (Rizaev, 2017; Rizaev, 2022).

Further studies (Turanov et al., 2021b) proposed incorporating a special plant guiding mechanism into the drum design. This mechanism not only prevents the plants from tilting forward during harvesting but also ensures proper orientation of the cotton bolls on the spindles in the working zone. While the modified machine with the plant guiding mechanism showed some improvement in agronomic performance, field tests revealed frequent breakdowns of the mechanism's elements.The aforementioned studies indicate that the drawbacks of VS CHM can be mitigated by using elliptical drums. Our previous theoretical research on the kinematics and dynamics of the elliptical drum has shown that employing elliptical drums significantly enhances the machine's agronomic performance and spindle efficiency, while retaining all the benefits of the vertical-spindle cotton harvesting principle (Ravutov et al., 2023a). Prior research in this area primarily focused on the structure and kinematics of the elliptical drum mechanism, with some attention given to its dynamics (Ravutov et al., 2023b; Bahadirov et al., 2021). A comparative analysis of spindle activity between the serial drum and the elliptical drum revealed significant advantages in favor of the elliptical drum (Ravutov et al., 2022; Ravutov et al., 2023b).

2 MATERIALS AND METHODS

On the elliptical drum, each spindle is mounted on a separate cassette and has a separate pressing sector, which are also very important structural elements of the drum. By changing the geometric parameters of the links of the elliptical drum mechanism, the kinematic mode of the spindle and the pressing sector can be controlled (Bahadirov et al., 2021).

Another distinctive feature of the elliptical drum is the variability of the spindle speed modes in the working zones. Thus, when the spindle enters the collection zone, it has one speed, and when it exits the zone, it has another. Moreover, unlike the serial drum, the relative speed of the spindle has an increasing characteristic (Bahadirov et al., 2021). These and other kinematic and structural features of the elliptical drum complicate the analysis of the impact pattern of the working parts on the cotton plants to some extent, and it is convenient to obtain initial information through direct observation of the working parts' movements (Bahadirov et al., 2021; Ravutov et al., 2023b). Traditionally, such observations were conducted using high-speed filming of the process (Sablikov, 1985). This method provides a real picture of observations; however, it requires careful preparation of experimental resources and significant time and labor for processing the obtained results.

This study is dedicated to examining and comparatively analyzing the interaction features of the spindles and pressing sector of elliptical and serial drums with elements of the cotton plant.

Recently, simulating the movement of mechanical system parts using various computer programs has become popular among designers of new machines. The use of simulation programs often eliminates the need for labor-intensive and costly experimental studies (Amanov et al., 2019).

In the existing technology, the elements of cotton plants first encounter the spindles and pressing sectors of the drum, and they begin to interact. The efficiency of the cotton harvesting apparatus largely depends on the rationality of this interaction.

To simulate the movement of the spindles and the pressing sector, we used the open-source dynamic mathematics software "GeoGebra." This software allows simulating the movement of the spindle and the drum's pressing sector by adjusting the dimensions of the ellipse's major and minor axes and other structural elements. By changing the dimensions of the axes, it is possible to achieve the trajectory of the spindles along the circumference (the circumference being a special case of the ellipse).

For convenience in comparing the movement characteristics of the spindles and pressing sectors of the serial and elliptical drums, as well as for reasons of unifying the dimensions and construction of the serial apparatus, the main dimensions of the elliptical drum are identical to those of the serial drum: the number of spindles for both drums is the same—N=12 units; the minor axis of the ellipse b=14.6 cm, equal to the radius of the serial drum (Rb=14,6 cm); the radius of the spindle r1=1,45 cm; the radius of the pressing sector r2=3,2 cm; the coverage angle of the pressing sector β=1500 (Figure 1).

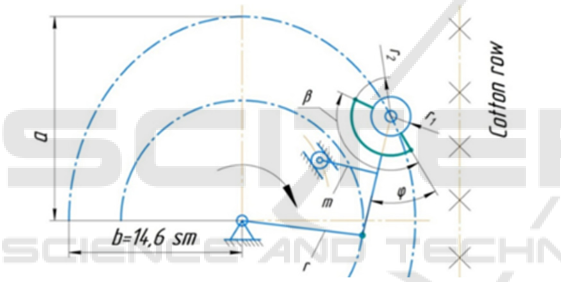

Figure 1: Parameters of the elliptical drum.

The GeoGebra program allows for varying the dimensions of any link in the elliptical drum mechanism and conducting visual observations of changes in technologically important output parameters. In our simulation experiment, only the angle φ, determining the position of the pressing sector, and the major axis a of the elliptical drum were varied. By decreasing the size of a, a circle with a radius equal to the radius of the serial drum can be obtained, amin=b=Rb=14,6 cm. To simulate the orientation of the bolls to the working parts during the process of introducing cotton plants into the working chamber, primary attention was paid to observing the movement characteristics of the spindle and the front edge of the pressing sector (Figure 2).

As a result of the simulation, it can be noted that when the spindle center moves along the ellipse, the front edge of the pressing sector moves along a line different from the ellipse (quasi-ellipse - shown in Figure 2, green line). The size and shape of this line depend on the angle φ and the major axis a. The GeoGebra program allows simulating the effects of the spindles and the pressing sector on the plants for any possible values of these factors.

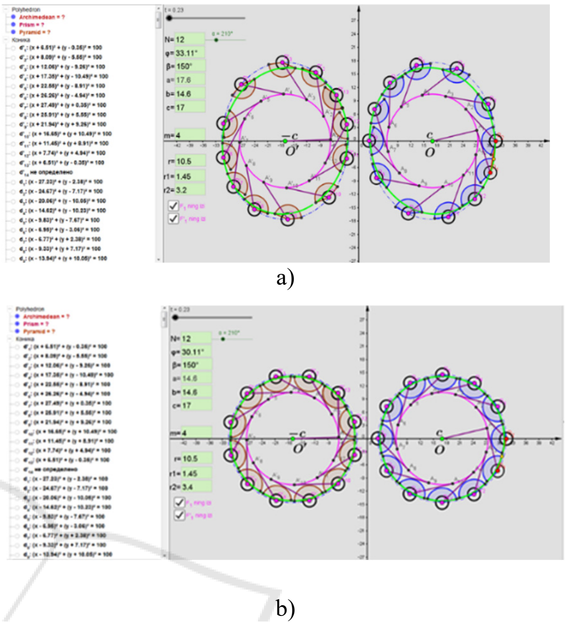

Figure 2: Simulation fragments of spindle and pressing sector movement using GeoGebra dynamic mathematics software; a - elliptical drum; b - drum view at amin=b=Rb=14,6 cm (serial drum); dashed line – trajectory of spindle center movement; green line – trajectory of the front edge of the pressing sector movement; numbers on the left green background – controlled geometric parameters of the mechanism.

From Figure 2a, it can be observed that with the elliptical trajectory of the spindle in the entry part of the working chamber, the front edges of the pressing sectors form projections. After the central part of the working chamber is passed, these projections move away from the cotton row into the internal contour of the drum. As the angle φ and the major axis a increase, the size of the projection and the intensity of its impact on the plant elements also increase. With a rational choice of parameters φ and a, such activity of the pressing sector can facilitate the pulling of cotton plant elements during machine operation.

In contrast, on the serial drum, the trajectory of the pressing sector edge forms a circle concentric with the spindle center trajectory, meaning that the edges of the pressing sector remain passive relative to the cotton row. In this case, the shape and size of the trajectory of the pressing sector edge depend only on the angle φ (Figure 3b).

Figure 3 shows a schematic of the interaction between the pressing sector of the elliptical drum and a cotton boll. It is easy to see from the diagram that the edge of the pressing sector of the right drum, with its complex movement, tends to compress the boll towards the spindle of the left drum, creating an additional condition for the reliable penetration of the spindle tooth into the cotton segment. The simulation using GeoGebra clearly demonstrates this process.

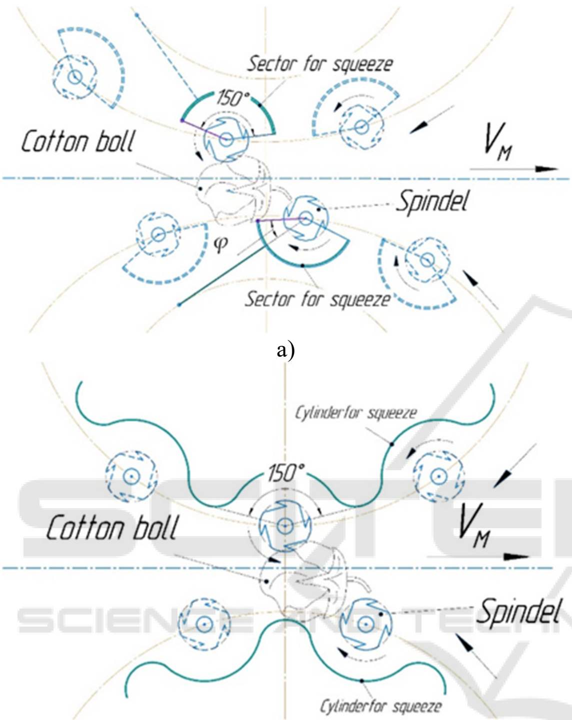

Figure 3: Diagram of the impact of the pressing sector of elliptical and serial drums on a cotton boll: a - Apparatus with elliptical drums; b - Apparatus with serial drums.

3 RESULTS AND DISCUSSION

Based on the visual observation of the spindle and pressing sector movement characteristics, it was determined that the approach or departure of the sector edge from the central line of the working slot in the transverse direction is related to changes in the angle φ and the major axis of the ellipse a. Specifically, increasing the angle φ can increase the extent of the projection of the front edges of the pressing sector towards the working slot. In this case, adjacent spindles and the front edge of the pressing sector of opposite drums create a zigzag space (zones Z) in the entry part of the working chamber, which positively affects the process of introducing the cotton plants into the working zone (Figure 4). A similar effect can be achieved by increasing the major axis a of the ellipse; however, unlike the parameter φ, changing this parameter significantly impacts the spindle speed modes, especially in transitional zones (Yakubov et al., 2024). It should be noted that in the serial apparatus, the effect of forming zones Z, which would facilitate the introduction of plants into the working chamber in a vertical position, is absent.

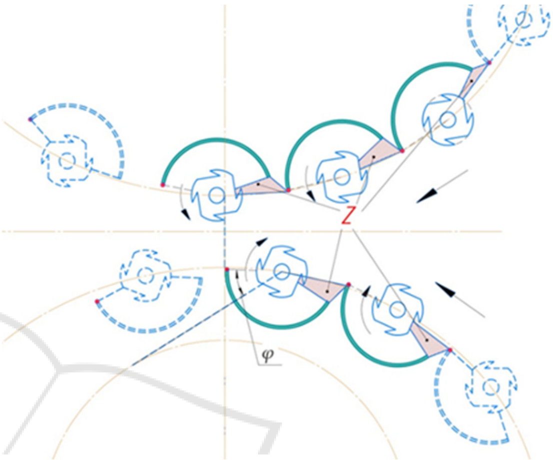

Figure 4: Formation of the zigzag space Z in the working slot of the apparatus with elliptical drums.

4 CONCLUSIONS

1. Ensuring the introduction of cotton plants into the working chamber in a vertical position within the design of a serial vertical-spindle apparatus is challenging. Introducing additional devices or other structural changes into the drum design may complicate the drum structure or reduce the machine's performance.
2. The movement characteristics of the pressing sectors of the elliptical drum, in terms of interaction with cotton plants in the working zone, are significantly advantageous compared to the serial drum. The front edges of the pressing sectors of the elliptical drum are more active in the working chamber, and this phenomenon can be utilized to facilitate the introduction of plants into the working chamber in a vertical position.
3. The degree of activity of the pressing sector of the elliptical drum depends on the size of the major axis of the ellipse a and the angle of the pressing sector's position φ.

REFERENCES

Abdazimov, A.D., Sadriddinov, A.S., & Tulaev, A.R., 2011. *Phase discrete modeling of harvesting apparatus processes during controlled movement of cotton bolls*. Tashkent: Izdat. Nas. Library of Uzbekistan named after A. Navoi.

Amanov, A., Sembiring, J.P.B.A., & Amanov, T., 2019. Experimental investigation on friction and wear behavior of the vertical spindle and v-belt of a cotton picker. *Materials,* 12(5), 773. https://doi.org/10.3390/ma12050773.

Bahadirov, G., Ravutov, S., Abdukarimov, A., & Toshmatov, E., 2021. Development of the methods of kinematic analysis of elliptic drum of vertical-spindle cotton harvester. *IOP Conference Series: Materials Science and Engineering,* 1030(1), 012160. https://doi.org/10.1088/1757-899X/1030/1/012160.

Ravutov, S.T., 2019. Problems of increasing the efficiency of the vertical spindle cotton picker. *Problems of Mechanics,* Tashkent, 4, 51-55.

Ravutov, Sh.T., Rizayev, A.A., & Rajapbaev, U.A., 2023a. Enhancing cotton harvesting efficiency through elliptical drum design: A comparative analysis of spindle performance in the working area. *IOP Conference Series: Earth and Environmental Science,* 1231, 012005. https://doi.org/10.1088/1755-1315/1231/1/012005.

Ravutov, Sh.T., Ibragimov, G.I., Shokirov, S.Sh., & Komilov, Sh.J., 2023b. Synthesis of the contour and dimensions of the guiding channel of an elliptical drum according to the operation conditions and kinematic regimes. *IOP Conference Series: Earth and Environmental Science,* 1284, 012015. https://doi.org/10.1088/1755-1315/1284/1/012015.

Ravutov, Sh.T., Rizayev, A.A., & Rajapbaev, U.A., 2022. On the issue of increasing the efficiency of the spindles of a vertical-spindle cotton picker. *IOP Conference Series: Earth and Environmental Science,* 1112, 012043. https://doi.org/10.1088/1755-1315/1112/1/012043.

Rizaev, A.A., 2017. Research and creation of worker organs of a cotton cleaner with high efficiency. Tashkent: FAN.

Rizayev, A., Alimova, D., & Alimov, B., 2022. Modeling spindle drive device of the cotton harvester. *IOP Conference Series: Earth and Environmental Science,* 1112, 012042. https://doi.org/10.1088/1755-1315/1112/1/012042.

Sablikov, V.M., 1985. Cotton pickers. Moscow: Agropromizdat.

Shoumarova, M., Abdillayev, T., & Yusupov, S. A., 2022. Parameters of the stabilizer of the poly-V belts of the drive of vertical spindles for stable cotton harvesting performance. *IOP Conference Series: Earth and Environmental Science,* 1076(1), 012020. DOI: 10.1088/1755-1315/1076/1/012020.

Shoumarova, M., Abdillayev, T., Duskulov, A.A., & Yusupov, Sh.A., 2023. The need for instrumental measurement of the traction force of the friction drive of the vertical spindles of the cotton harvesting machine. *E3S Web of Conferences,* 443, 04014. DOI: 10.1051/e3sconf/202344304014.

Turanov, K., Abdazimov, A., Shaumarova, M., & Siddikov, S., 2021a. Type analysis of a multiloop coulisse mechanism of a cotton harvester. *Advances in Intelligent Systems and Computing*, 1258, 290–305. https://doi.org/10.1007/978-3-030-57450-5_27.

Turanov, K., Abdazimov, A., Shaumarova, M., & Siddikov, S., 2021b. Mathematical modeling of a multiloop coulisse mechanism of a vertical spindle cotton harvester. *Advances in Intelligent Systems and Computing,* 1258, 306–321. https://doi.org/10.1007/978-3-030-57450-5_28.

Yakubov, K., Ravutov, S., Masharibov, A., Kadirov, İ., 2024a. Theoretical substantiation of the parameters of the Debris removal device of the cotton picker apparatus. BIO *Web of Conferences*, 116, 01017. https://doi.org/10.1051/bioconf/202411601017.

Yakubov, K., Ravutov, S., Atakhanov, İ., Radjabov, R., 2024b. Theoretical justification of the parameters of the improved transport corridor of the cotton harvester apparatus. *BIO Web of Conferences*, 116, 01013. https://doi.org/10.1051/bioconf/202411601013.