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THEORETICAL STUDY OF ELLIPTIC DRUM OF VERTICAL SPINDLE COTTON PICKER

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ABSTRACT: The article focuses on the structural optimization of the planetary mechanism of the spindle drum of a vertical-spindle cotton-picking machine in Uzbekistan and discusses the problems of synthesizing a new vertical-spindle drum that significantly enhances the efficiency of using spindles and increases the productivity of the machine. Utilizing the interaction characteristics of drum spindles with cotton plants and ensuring the effective functioning of spindle friction drives, it is theoretically justified that the trajectory of spindle relative motion has an elliptical shape. Special attention is given to the shape and dimensions of the directional path, ensuring the elliptical movement of the spindles. An analytical expression is obtained, and a convenient calculation algorithm is developed to automate the investigation of the influence of the dimensions of drum mechanism parts on the directional path shape and its dimensions. The theoretical results allow for preliminary conclusions regarding the dynamic processes occurring during drum operation and provide recommendations for selecting the directional path shape and dimensions.

ABSTRAK: Artikel ini memberi tumpuan kepada pengoptimuman struktur mekanisme planet bagi dram gelendong mesin pemetik kapas gelendong-menegak di Uzbekistan, serta membincangkan permasalahan dalam mensintesis dram gelendong menegak baharu yang dapat meningkatkan kecekapan penggunaan gelendong dan produktiviti mesin secara signifikan. Dengan mengambil kira ciri interaksi antara gelendong dram dan pokok kapas serta memastikan keberkesanan operasi pemacu geseran gelendong, didapati secara teori bahawa trajektori pergerakan relatif gelendong berbentuk elips. Perhatian khusus diberikan kepada bentuk dan dimensi arah laluan yang menjamin pergerakan elips gelendong. Satu ungkapan analitik telah diperoleh dan algoritma pengiraan yang sesuai telah dibangunkan bagi tujuan automasi penyelidikan terhadap pengaruh dimensi komponen mekanisme dram terhadap bentuk dan dimensi laluan arah. Dapatan teori yang diperoleh membolehkan rumusan awal dibuat berkaitan proses dinamik yang berlaku semasa operasi dram dan seterusnya memberikan cadangan dalam pemilihan bentuk serta dimensi laluan arah.

KEYWORDS: *Cotton picker, vertical spindle, planetary mechanism, directional path.*

1. INTRODUCTION

About 80% of the world's cotton is produced in India, China, the United States, Pakistan, Uzbekistan, Turkey, Brazil, Greece, and Egypt. The successful application of machinery in cotton harvesting operations depends on selecting appropriate mechanisms for the working parts of cotton pickers as shown in Fig.1. In addition, it is always necessary to address the analysis of the system, including geometric, kinematic, and dynamic aspects, and continuous improvement of its characteristics. The activities and research conducted in this regard are extensive and diverse in the field of application.

We will dwell on several studies conducted on mechanisms closely related to the vertical-spindle cotton-picking machine in terms of their structural configuration and working principles. Note that the two-shaft module is widely used in light industrial technological machines. The work is devoted to elucidating the principles of distributing friction forces in a dual-shaft module. Its working shaft covers are made of materials with different hardness, which are widely employed in various industrial sectors. In addition, in [1], the advantages of an asymmetric two-shaft module are substantiated.

In [2], the issue of utilizing toothed-lever differential mechanisms in technological machines was discussed. In this technological process, the distance between the axes of the working shafts changes with a roller. Such mechanisms are widely used in agricultural machinery and light industrial technological equipment. In addition [2], information about the principle of operation of the new device developed by the authors is presented. The possibility of reducing the variability of the kinematic characteristics of side-by-side shafts by using the device was also justified.

Figure 1. Vertical spindle Cotton Picker.

The work [3] studied a comparative analysis of two types of gear-lever transmission mechanisms in agro-technological machines with drum working bodies. For this, the centroid method was used to derive an analytical expression for the dependence of the kinematic chain parameters of the mechanism. Based on this, the kinematic parameters of the toothed chain were obtained, and computational experiments were conducted. The obtained results established that their transmission ratios also change with the change of the distance between the axes of the leading and driven shafts. The work [4] is devoted to the mathematical modeling of the shape of contact curves of two-roller technological module rollers. The proposed contact curve equation allows the technological module's theoretical research under different operating conditions.

The following works dedicated to the improvement and increasing reliability of the spindle drums of the vertical-spindle cotton picking machine are also noteworthy. One of the factors that negatively affects the completeness of picking in the working process of a vertical spindle cotton-picking machine is the bending of cotton plants along the direction of movement of the machine. The bending of the cotton into the working slot causes the cotton bolls to be blocked by the branches from the spindles, limiting the activity of the spindles. To solve this problem and increase the machine's working speed by 20-25%, the authors of the work [5, 6] proposed a mechanism for inserting the cotton into the working slot for the cotton picking machine. They also attempted to justify its parameters theoretically. However, the experiments on this apparatus show that its reliability is much reduced because of the complexity of the drum construction.

The spindle drives of the vertical spindle cotton picking machine are reversible friction drives. Instability in the spindle's speed modes negatively affects the quality of cotton picking. The authors of the work [7] proposed a method of experimental determination of the actual speed regimes of spindles and gave recommendations for improving the drive. The work [8] experimentally studied the mechanism of friction and the deteriorating processes occurring in the friction drives of the spindles of the vertical-spindle cotton picker to increase the durability of drive belts. It also proposed covering the working surfaces of drive rollers with nanocrystals using the ultrasonic method. Experimental studies have shown that the durability of drive belts increases due to the reduction of the roughness of the working surfaces.

The results of the works [9, 10] dedicated to the theoretical study of the kinematic modes of the elliptical drums of the cotton picking machine with a vertical spindle show that this drum construction is promising. They also indicate that research work should be continued in this direction. In particular, the work considers the issue of synthesizing a structurally developed mechanism that increases the contact zone of spindles with cotton. This mechanism allows for the optimal values of their kinematic modes to be chosen based on the characteristics of the technological process of harvesting and the results of theoretical research.

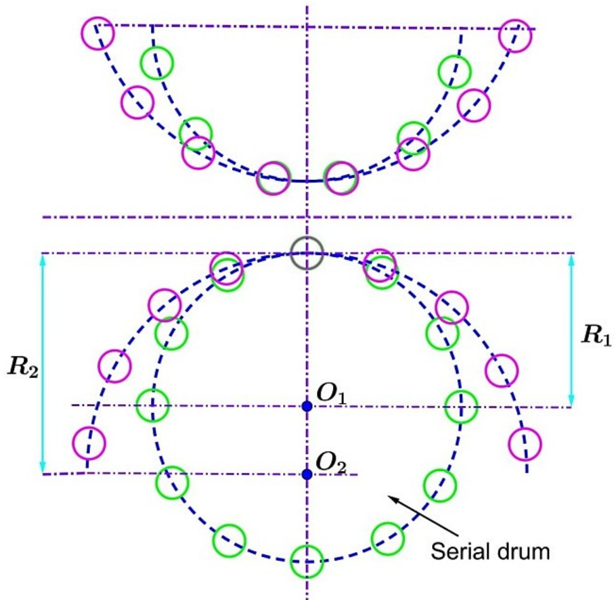
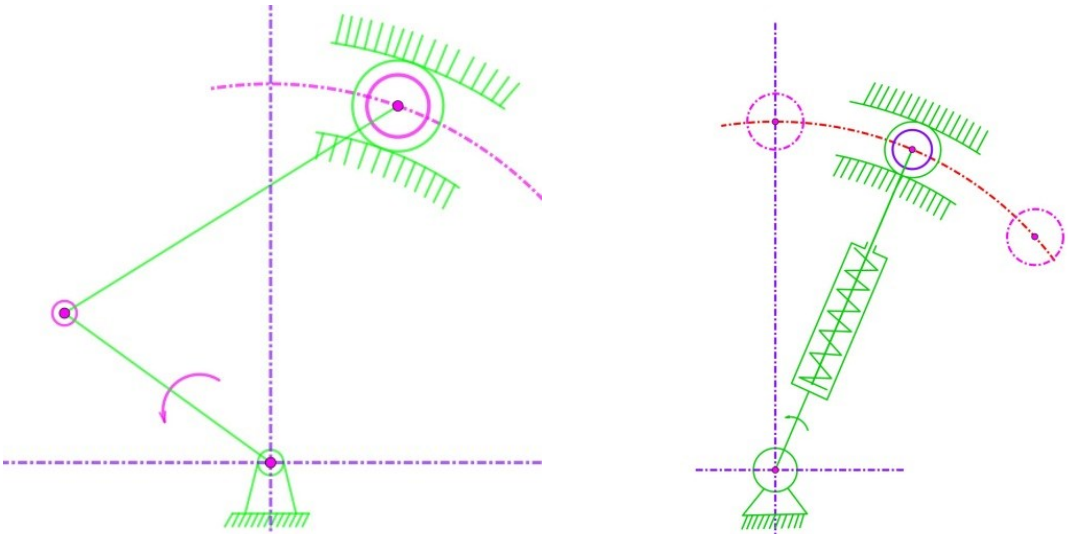


Figure 2. Using a large diameter drum to increase the contact area of the vertical spindle drum spindles with the cotton.

According to the requirements of the technological process of cotton picking, the distance between the centers of the spindles on the drum of vertical spindle cotton picking machines should not be less than 60 mm [11]. This factor limits the number of spindles in a drum being mass-produced. To increase the number of spindles involved in the cotton harvest at one time, it will be necessary to increase the diameter of the drums. However, the metal and energy consumption of the cotton picking machine is high, and it is difficult to fit the machine equipped with large diameter drums between the rows of cotton as shown in Fig. 2.

As a solution to this problem, in the 1980s in Uzbekistan, the idea emerged to increase the number of spindles simultaneously involved in harvesting and expand the zone of direct contact of the working bodies with cotton. This was achieved by structurally developing the mechanism of the spindle drum of the vertical spindle cotton machine [12-14]. The idea is to change the spindles' trajectory relative to the drum apparatus from a circle to an ellipse. Fig.3 shows the structural development options of the serial drum mechanism.



(a) replacement to a crank-slide mechanism (b) replacement to a telescopic mechanism

Figure 3. Options for replacing the drum mechanism with a lever-crank planetary mechanism.

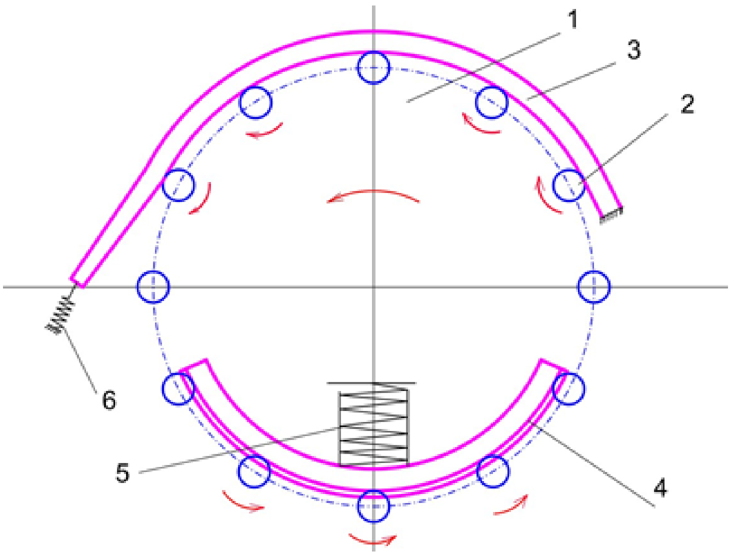


Figure 4. Series vertical spindle drum scheme: 1 is the drum; 2 is the spindle; 3 is drive belt; 4 is a reversible pad; 5 and 6 are springs.

The preparation and testing of both variants showed that option (a) was more suitable [12, 14]. There are some problems with the preparation and its use as a cotton picking drum for option (b). This can be explained, firstly, by the fact that the number of excess connections in the mechanism increases and requires very high precision in its preparation. Secondly, using a telescopic mechanism at the bottom of the drum will not fit. With this in mind, we choose option (a).

Before considering the drum based on the mechanism with the developed structure, we will briefly review the design and technological features of the currently used vertical spindle drum. In a serial drum, the spindles are positioned so the lower and upper discs can rotate around their axes. They are the planetary mechanisms' satellites, which move in reverse rotation around their axes during the process (Fig. 4).

In the proposed design, an additional link is added to the serial drum mechanism, which is converted into a planetary-claw-clamp mechanism (Fig.5). This allows the spindles to move closer to the rows of cotton.

Further, the paper is organized as follows: Section 2 presents the equation for the directing ditch and discusses some features of the mechanism in designing an elliptical drum for the distinct values of parameters. In Section 3, we present the main conclusions.

2. SYNTHESIZING THE DIRECTING DITCH

According to the structure, the mechanism can be conditionally considered as a curved-sliding mechanism in which the slide moves in a curved line. Let $OA = r$ be a crank, $AB = l$ be a rod, and C be a slider (Fig. 5).

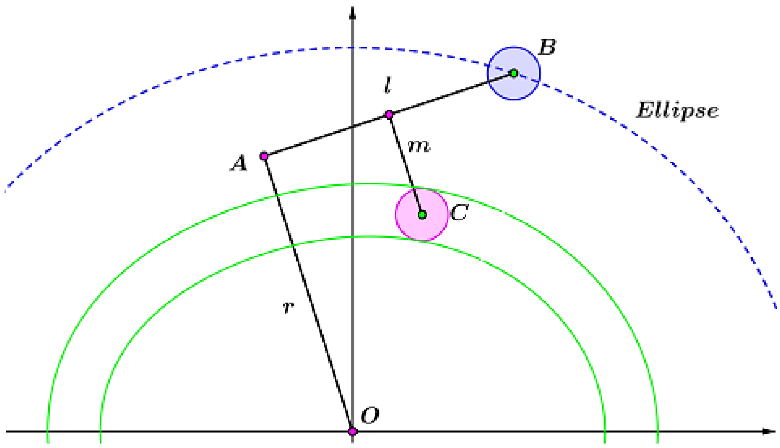


Figure 5. Additional link insertion scheme for serial drum mechanism.

In practice, this mechanism allows the desired trajectory of the spindles to be obtained. However, following the requirements of cotton picking technology using vertical spindles, it is recommended that the line forming the trajectory of the spindles be smooth, closed, and convex. In addition, to ensure the satisfactory operation of the friction drives of the spindles, the same conditions should be met [14]. As such, the ellipse was the most suitable [12]. Because of this reason, the proposed drum is called an elliptical drum.

By the condition, the point B must move along the ellipse when the point A of the crank r moves along a circle in the direction shown in Fig. 5. The results of the structural analysis of this mechanism show that when the point B moves along the ellipse, the point C, which is at a distance m from the axis of the connecting rod l, moves along a line different from the ellipse. We determine the analytical expression of the line drawn through the point C.

From the point of view of construction, the mechanism can be considered one whose roller moves along a curve (Fig. 5). We can find the spindles' trajectories for such mechanisms.

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Let the point A moves with an angular speed equal to l on the circle of radius r centered at the point O ($OA = r$) (Fig. 5) in a counterclockwise direction. We assume that the center of the spindle B with $AB = l$ moves along a specified ellipse. This ellipse is the curve passing through the center of the directing ditch. However, it is important to facilitate the service of spindles (B) to moving rollers (C) and to prevent roller fractures that may occur due to the increased distance from the boundary of the roller to its support. Therefore, it is expedient to install the directional roller (Fig. 6, point C) and the directional ditch close to the crank plane.

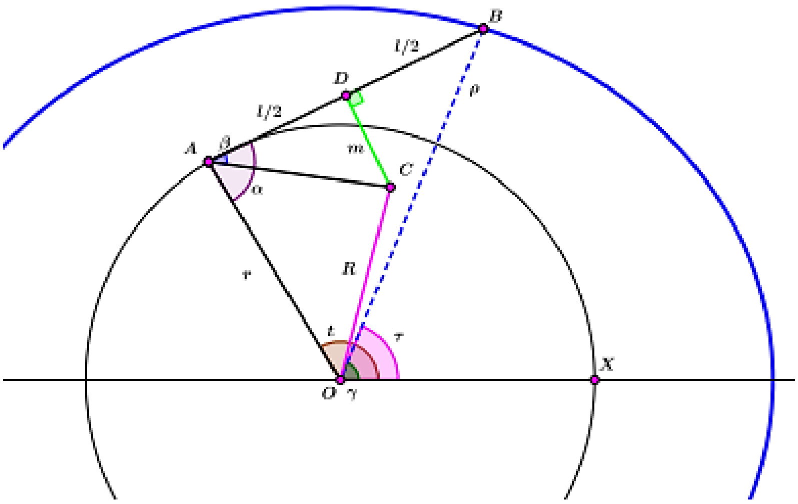

Figure 6. Scheme for determining the shape of the directing ditch.

The results of the structural analysis of this mechanism show that when the point B moves along the ellipse

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1, \; a > b \tag{1}$$

where a and b are given numbers, and they are the lengths of half of the major and minor axes of the ellipse, respectively, the point C moves along a curve that differs from the ellipse. Let us find an analytic formula that describes this curve, that is, the trajectory of the point (C).

For constructional reasons, the point C is at a distance DC=m from the connecting rod AB along its perpendicular bisector (Fig. 6), that is, $AB \perp DC$ and $AD = DB$. The length of the connecting rod AB is l.

Denote

$$\angle BOX = \tau, \; \angle AOX = t, \; \angle DAC = \beta, \; \angle COX = \gamma, \; OB = \rho, \; OC = R \tag{2}$$

where the points O and X are in a horizontal line. We assume that the angle τ is given, and we find the coordinates of the point C. We have, the coordinates of the point B,

$$x_B = \rho Cos\tau, \; y_B = \rho Sin\tau \tag{3}$$

Since the point B moves along the ellipse (1), substituting x_B and y_B in (3), into the equation (1) we have

$$\frac{\rho^2 Cos^2\tau}{a^2} + \frac{\rho^2 Sin^2\tau}{b^2} = 1, \tag{4}$$

where $\rho = \frac{ab}{(a^2 Sin^2\tau + b^2 Cos^2\tau)}$, which is the equation of the ellipse, Eq. (1), in polar coordinates.

Since $\angle AOB = t - \tau$ and $AB = l$, we obtain from the triangle AOB by the law of cosines that

$$l^2 = r^2 + \rho^2 - 2r\rho Cos(t - \tau). \tag{5}$$

This implies that $t = \tau + arcCos\frac{r^2+\rho^2-l^2}{2r\rho}$. Next, we find the angle $\angle OAB = \alpha$. To this end, we find from the triangle AOB by the law of cosines that

$$\alpha = arcCos\frac{r^2+l^2-\rho^2}{2rl} \tag{6}$$

We obtain from the right triangle ACD that

$$\beta = arctan\frac{2m}{l} \tag{7}$$

Applying the law of cosines to the triangle AOC gives

$$R^2 = OA^2 + AC^2 - 2OA \cdot AC \cdot Cos\,(\alpha - \beta) \tag{8}$$

where $OA = r$ and $AC = \frac{1}{2}\sqrt{l^2 + 4m^2}$. Therefore, using Eq. (8),

$$R = (r^2 + \frac{l^2}{4} + m^2 - r\sqrt{l^2 + 4m^2}\,Cos\,(\alpha - \beta))^{1/2} \tag{9}$$

Next, to determine $< COX = \gamma$ we consider the triangle AOC. Since $< AOC = t - \gamma$, by the law of cosines, we obtain $cos(t - \gamma) = \frac{R^2+r^2-AC}{2rR}$. And, hence,

$$\gamma = t - arccos\frac{R^2+r^2-AC^2}{2rR} = t - arccos\frac{4R^2+4r^2-l^2-4m^2}{8Rr} \tag{10}$$

Finally, we find the coordinates of the point C as shown in Equation (11)

$$x_C(\tau) = R(\tau)Cos\gamma(\tau), \qquad y_C(\tau) = R(\tau)Sin\gamma(\tau) \tag{11}$$

We discuss why x_C and y_C depend on τ in these formulas. By (4) ρ is expressed in terms of τ, that is, $\rho = \rho(\tau)$. Equation (5) shows that time t depends on τ and ρ , and so by the (4) parameter t can be expressed only in terms of τ, that is, $t = t(\tau)$. The equation (6) allows us to conclude that α depends on τsince ρ is expressed in terms of τ. Equation (7) shows that β is constant, since r and l are given numbers. By equation (9) R depends on α, and so R can be expressed in terms of τ, that is, $R = R(\tau)$. Finally, by equation (10) γ can be expressed in terms of τ, that is, $\gamma = \gamma(\tau)$.

$$\rho = \rho(\tau), \quad t = t(\tau), \quad \alpha = \alpha(\tau), \quad R = R(\tau), \quad \gamma = \gamma(\tau) \tag{12}$$

In reality, τ varies depending on t. But here we are using the inverse relationship, that is, t varies dependently on τ. This is because we want to obtain only the trajectory of the point C.

Note that if τ varies depending on t, then the radius OA rotates in anti clockwise direction with unit angular speed, and the angular speed of OC. In general, it is not constant. Conversely, if t varies dependently on τ, then the radius OC rotates in anti clockwise direction with unit angular speed, and the angular speed of OA. In general, it is not constant. To find the trajectory of the point C, both options work and therefore, we can use the option where t varies depending on τ.

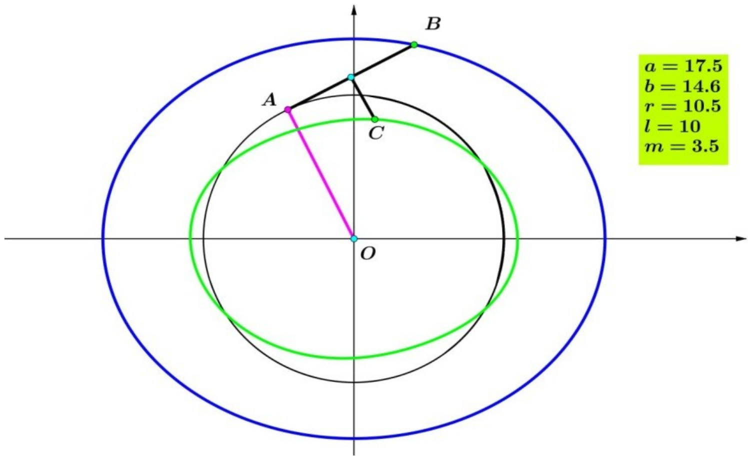

Figure 7. Directing the ditch when $a = 17.5,\ b = 14.6, r = 10.5, l = 10, m = 3.5$.

The elliptic drums furnished by the cotton picking mechanism must move along the cotton plant rows, and this circumstance is reflected in traditional circular drums. To guarantee this condition in a new elliptic drum, we make the half axis of the ellipse equal to the radius of the traditional circular drum, that is, $b = R$ =14.6 cm. Note that the diameter of the circular drum for the current cotton picking machine is $D = 2R = 29.2$ cm. For the various values of the parameter a from the interval (14.6 cm, 20 cm), we study the trajectory of the point C.

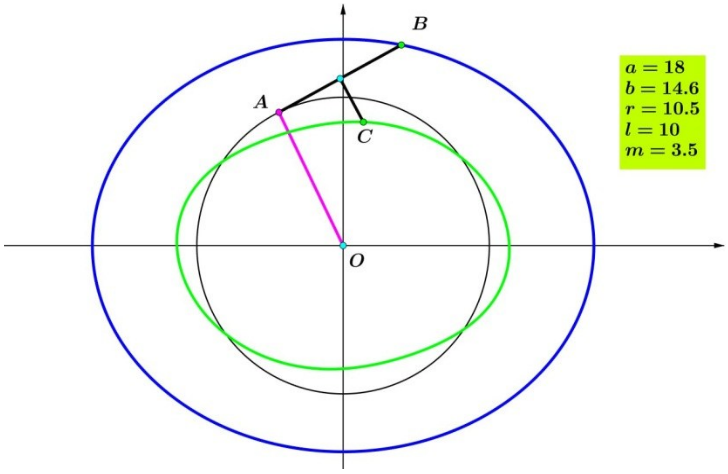

Figure 8. Directing the ditch when $a = 18,\ b = 14.6, r = 10.5, l = 10, m = 3.5$.

From the point of view of construction, we choose the length of the connecting rod AB of the elliptic drum to be equal to l=10 cm, the radius of the crank OA to be equal to r =10.5 cm, and the distance of the roller C from the connecting rod to be equal to m =3.5 cm. The numerical experiment was conducted for the distinct values of the semi-major axis a of the elliptical drum. The trajectories of the point C are illustrated in Fig.7 for a=17.5 cm, in Fig.8 for a =18 cm, and in Fig.9 for a=19 cm.

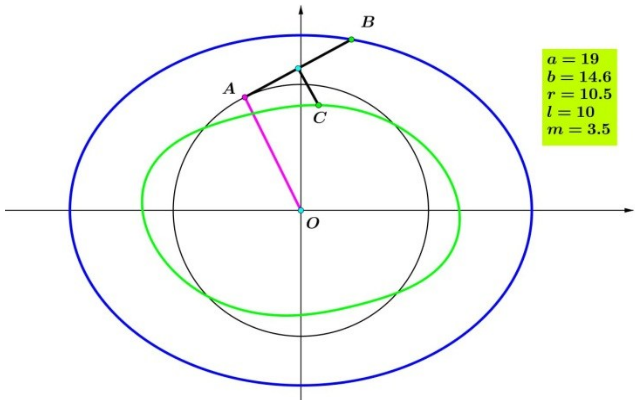

Figure 9. Directing the ditch when $a = 19,\ b = 14.6, r = 10.5, l = 10, m = 3.5$.

In the mechanism of the drum, the arc of trajectory of the spindle, where the spindle contacts the cotton plant, can be enlarged by increasing the major axis of the ellipse a. We can see, however, that if we increase the major axis of the ellipse, the shape of the trajectory of the point C gets to differ from the ellipse. Also, the difference between the curvatures of the spindle's trajectories gets larger in the picking and passage zones. This may cause an additional vibration and complicate the drum's operation. Therefore, it is important to consider the mechanism's features when designing an elliptical drum.

3. CONCLUSION

In the present paper, we have theoretically studied the elliptic drum of a vertical spindle cotton picker. The study allows us to draw the following important conclusions.

1. Through the structural development of the mechanism of the cotton picking drum with a vertical spindle, it is possible to develop a new (elliptic) drum that increases both the contact zone of the spindles with the cotton and the number of spindles participating in picking.
2. An effective analytical expression describing the change of the shape and dimensions of the guide ditch was obtained for the structurally developed mechanism of the elliptical drum, depending on the dimensions of other links of the mechanism.
3. Mathematical software allows for the automation of calculations and the visual observation of the size and shape changes that occur in the mechanism guide ditch when the geometric dimensions of the mechanism links change. It is an effective tool at the drum design stage.
4. Calculation experiments using the obtained analytical expression show that the value of the semi-major axis of the ellipse in the elliptical drum increases. In addition, the trajectory of the point C (guide ditch) deviates from the shape of an ellipse (quasi-ellipse), and the differences in the guide ditch curvature radii in the places corresponding to the movement trajectories in the pick-up and transition zones of the spindles get larger.
5. The formation of differences in the radii of curvature of the guide ditch of the new mechanism, synthesized based on the structural development of the drum mechanism, can cause dynamic movements in the mechanism. This means studying its kinematic and dynamic properties is necessary to use the mechanism in technological machines.
6. The research results are essential for using elliptical drums in vertical spindle cotton picking machines.

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