DEVELOPMENT AND CALCULATION OF A MATHEMATICAL MODEL OF THE PATH OF MOTION OF POINTS ON THE SPINDLE IN THE ZONE OF COTTON REMOVING OF THE HARVESTING MACHINE

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Abstract. *The process of removing cotton from the spindle as it moves in the removal area of the harvesting apparatus is examined in the article. The doffers, which are one of the components of the harvesting apparatus, perform a complete removal of cotton from the spindles, clean the surface of the spindle from individual fibers and cotton leaves, and ensure a continuous supply of raw cotton removed from the spindles into the receiving chamber for its further transportation to the hopper of the cotton harvester. A computational scheme for the spindle motion in the removal zone was developed and, on its basis, the path of the points lying at the ends of the doffer brushes, and the shapes of the curves enveloping these paths, were determined. These curves can be considered the boundaries of the zone of direct interaction of the doffer with a skein of cotton on the spindle. Based on modeling the process of interaction of the cotton-carrying spindle with the doffer in the removal zone of the harvesting apparatus, a calculation formula was obtained to determine the boundary of the zone of effect of the doffer brushes on a skein of cotton wound on the spindle; numerical calculations were conducted in the MathCAD 15 programming environment. The calculation results showed that with an increase in the angular velocity of spindle rotation, the boundary of the zone of effect of the doffer brushes is significantly closer to the spindle circle, which leads to a complete removal of cotton.*

Keywords: *cotton picker, harvesting apparatus, spindles, doffers, skein of cotton, path, mathematical model.*

1. Introduction

The main factor in the economic development of agriculture in the field of cotton growing is not only the creation and implementation into the production of new promising high-yielding varieties of cotton but also the mechanization of the entire complex of cultivation and harvesting. In the decree of the President of the Republic of Uzbekistan Sh.M. Mirziyoyev, the agricultural sector occupies a special place; its main task is defined, aimed at the sustainable development of agriculture through the introduction of energy- and resource-saving science-based innovative technologies and technical means.

The components of the harvesting apparatus that significantly influence the productivity of the cotton picker are the doffers, which perform the following functions: complete removal of cotton from the spindles, cleaning the surface of the spindle from individual fibers and cotton leaves, ensuring a continuous feed of raw cotton removed from the spindles into the receiving chamber for its further transportation to the hopper of the cotton picker. Since the creation of the first cleaning apparatus, various designs of doffers have been proposed: slot, collar, disk-shaped, and drum-type with brush strips.

M.V. Sablikov, Kh.Kh. Usmankhodzhaev, A.D. Glushchenko, A.S. Sadriddinov, R.D. Matchanov, A.A. Karimov, M. Shoumarova, Kh.T. Turanov, D.M. Shpolyansky, O.S. Jabbar and others made a great contribution to the development of theory and designs of improved cotton-picking machines, harvesting devices, and doffers.

Studies by D.M. Shpolyansky, Z.Kh. Izzatova, O.S. Jabbar are devoted to the effective removal of cotton from spindles, the arrangement of the doffers relative to the spindle drum. M.V. Sablikov, M.V. Lazunov, V.M. Koltunov investigated the technological process of stripping cotton from the spindles of a harvesting apparatus based on the use of high-speed filming [1-4]. The data obtained in high-speed filming allowed them to determine the most characteristic processes in the removal zone and the characteristic types of arrangement of skeins of cotton when approaching the doffers. In their publications, D.M. Reshetov, S.S. Dmitrichenko, L.N. Rosenblum described methods for assessing the durability of parts under dynamic loading considering material fatigue. The issues of modeling dynamic processes in the area of cotton stripping from spindles were dealt with by A.D. Glushchenko, Kh.T. Turanov, M.A. Ismanov. They found that when the doffer interacts with the spindle, cyclic dynamic impacts occur on the device drive.

As is known, the relative movement of cotton when it is removed from spindles is determined by the teeth' shape and arrangement on the spindle [4]. Disk doffers, due to impacts of shoulders (protrusions) on the removed cotton, affect the skeins of cotton along the entire parameter of the spindle cross-section. It is necessary that the direction of impact corresponds to the location of teeth and consistently affects all areas of the cotton strip. In this case, the relative velocity of the doffer shoulders (protrusions) is of significant importance. If the direction of this velocity coincides with the direction of the spindle teeth, then the removal efficiency increases significantly.

According to previous studies [5-8], a sharp decrease in the circular velocity of a continuously rotating spindle in front of the disk doffer allows the skein of cotton to be torn off from the toothed surface of the spindle due to inertia forces; this leads to an increase in the completeness of cotton removal from the spindles of the harvesting apparatus.

However, cotton is not completely removed from the spindles. About 40% [9] of raw cotton that falls to the ground consists of individual pappus. In addition, a small part of the wound cotton remains on the spindle. It should also be noted that during the cotton harvesting process, the spindles interact not only with raw cotton fibers but also with green leaves, branches, and unripe bolls. As a result, spindle activity and the completeness of cotton picking are reduced. To eliminate these factors, cotton is removed from the spindles by knocking off and combing out. That is, knocking off the cotton, the doffer, on which eight brush strips are located vertically at even intervals, simultaneously cleans the surface of the spindle.

Thus, the development of technological and technical solutions to ensure the effective functioning of the "drum-cotton-carrying spindle-doffer" system is a relevant scientific problem. In this regard, mechanical-mathematical and dynamic modeling of the process of interaction of the cotton-carrying spindle when passing through the removal zone of the harvesting apparatus was the basis for solving this problem.

The purpose of the study is to develop and calculate a mathematical model of the path of points on the spindle in the removal zone to determine the boundaries of the zone of doffer effect on cotton under epi- and hypo-cyclic movements of the spindle in the harvesting apparatus.

2. Research methods

When performing numerical calculations, classical modeling methods are used to determine the path of points on the spindle in the removal area of the harvesting apparatus based on analytical mechanics, the theory of mechanisms and agricultural (cotton harvesting) machines. Computational experiments with graphical constructions of patterns of changes in the parameters under study are presented in the *MathCAD 15* programming environment.

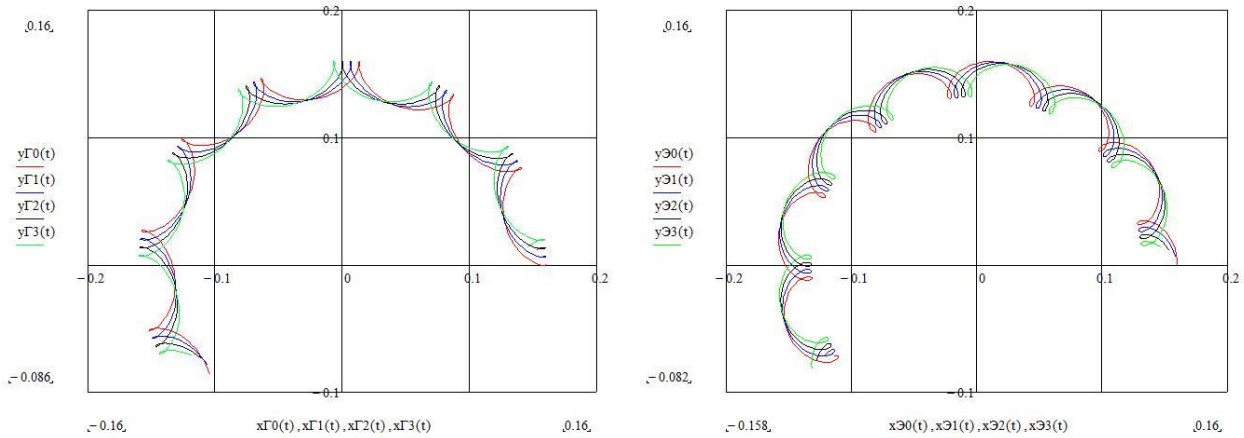
3. Research results and their discussion

To study the process of removing cotton from a spindle by knocking off or combing out, it is necessary to study the movement of the doffer relative to the spindle. In this regard, a calculation scheme for the movement of the spindle in the removal zone was developed and, on its basis, the path of the points lying at the ends of the doffer brushes and the shapes of the curves enveloping these paths were determined. These curves can be considered the boundaries of the zone of direct interaction of the doffer with a skein of cotton wound on the spindle.

As a result of constructing the paths of the doffer's movement relative to the spindle at time intervals Δt, it is clear that the paths of the relative movement of the center of a circle of the doffer are shortened epi-hypo-cycloids. The parametric equations of the path of the center of a circle of the doffer relative to the *ox*- and *oy*-axes can be represented as [1]:

$$\begin{cases} x = R_б \cdot \cos(\omega_б t) + R \cdot \cos(\varphi \pm \rho_m t) \\ y = R_б \cdot \sin(\omega_б t) + R \cdot \sin(\varphi \pm \rho_m t) \end{cases}, \qquad (1)$$

where $R = R_б + r_ш + r_c$, $\rho_m = \omega_ш \pm \omega_б$. Here $R_б$ is the radius of the drum, $r_ш$ is the radius of the spindle, r_c is the radius of the doffer, $\omega_ш$ is the angular velocity of the spindle, $\omega_б$ is the angular velocity of the drum, signs (+) and (–) determine the movement of the spindle along the epicycloid and hypocycloid, respectively, in the removal zone of the harvesting apparatus (see Fig.1).



(a) **(b)**

Fig. 1. Graph of the path of the center of a circle of the doffer relative to the coordinate axes ox and oy, where (a) is the epi-cyclic movement, (b) is the hypo-cyclic movement

Let us determine the value of the central angle τ, which characterizes the boundaries of the zone of effect of the doffer on cotton wound on the spindle (see Fig. 2) [1].

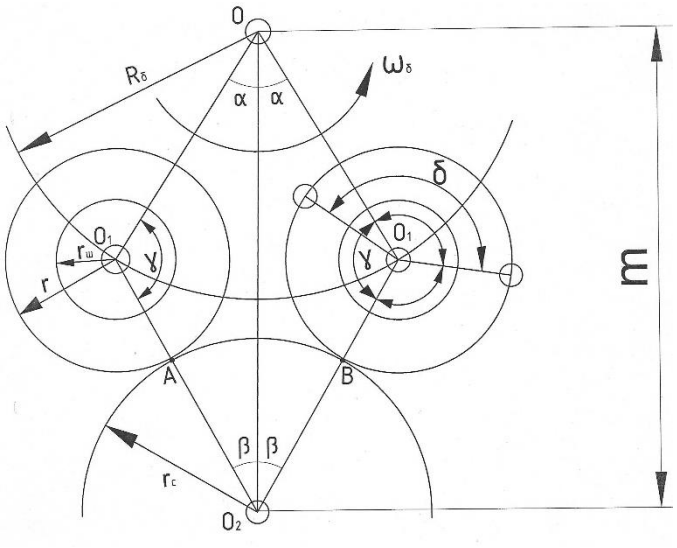


Fig. 2. Schematic representation of the initial A and final B positions of the spindle when the doffer acts on a skein of cotton

Considering the angle of rotation of the spindle around its axis δ during the time the spindle moves from the initial position *A* to the final position *B*, and the angles α and γ obtained as a result of geometric calculations (see Fig. 2), the central angle τ can be determined by the following formula:

$$\tau = 2 \cdot \left(\pi - \arccos \frac{R_б^2 + (r + r_c)^2 - m^2}{2R_б(r + r_c)^2} + \frac{\omega_ш}{\omega_б} \arccos \frac{R_б^2 + m^2 - (r + r_c)}{2mR_б} \right), \qquad (2)$$

where $\cos\gamma = \frac{R_б^2 + (r + r_c)^2 - m^2}{2R_б(r + r_c)^2}$, $\cos\alpha = \frac{R_б^2 + m^2 - (r + r_c)}{2mR_б}$, $\delta = \frac{2\omega_ш}{\omega_б}$,

$r = r_ш + r_м$, $r_м$ is the radius of a skein of cotton, $m = R_б + r_c + r$. By setting different values for the radius of the skein of cotton $r_м$, wound on the spindle, the corresponding values of the central angle τ are calculated. Based on the points found, it is possible to construct the boundaries of the effect of the doffer on cotton.

As a rule, the doffer brushes, interacting with cotton, bend somewhat. In this case, the points located at the ends of the brushes move relative to the doffer. This movement may vary depending on the resistances occurred. However, as studies have shown [10-12], the bending of the doffer brushes when contacting cotton is insignificant and does not have a substantial effect on the shape of the relative path of the ends of the brushes. Therefore, when determining the boundaries of the zone of effect of the doffer on cotton, it is assumed that the points lying at the ends of the brushes are stationary relative to the doffer.

As seen from formula (2), the central angle τ, which determines the boundaries of the zone of effect of the doffer brushes on the skein of cotton wound on the spindle, depends on the angular velocity of the spindle rotation. If the cotton is sufficiently fixed on the spindle and rotates with it, then an increase in the angular velocity of rotation of the spindle significantly brings the boundaries of the processing zone closer to the spindle circle, which ultimately leads to a complete removal of cotton.

4. Conclusion

Based on modeling the process of interaction of the cotton-carrying spindle with the doffer in the removal zone of the harvesting apparatus, a calculation formula was obtained to determine the boundary of the zone of effect of the doffer brushes on a skein of cotton wound on the spindle; numerical calculations were performed in the *MathCAD 15* programming environment. As a result of numerical calculations, graphs of curves showing the path of the center of a circle of the doffer under epi- and hypo-cyclic movements of the spindle in the harvesting apparatus were plotted. Analysis of the graphs showed that with an increase in the angular velocity of rotation of the spindle, the boundary of the zone of effect of the doffer brushes is significantly closer to the circle of the spindle, which leads to a complete removal of cotton.

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