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Cotton harvesters for one-time cotton-picking

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Abstract. The paper provides the study and substantiation of the parameters of semi-hitched spindle cotton harvesters during one-time cotton-picking. A calculation scheme for the spindle interaction with an open cotton boll in the "cylinder-deformable ball" form was proposed. A mathematical model to change the distance between oppositely located spindle drums in the working chamber and a method to calculate the indentation of the boll contact on the spindle of a vertical-spindle picking apparatus were obtained. The model made it possible to calculate the rational technological parameters of the device and machine. Kinematic functioning parameters of vertical- and horizontal-spindle picking devices were specified, taking into account their installation on a semi-hitched cotton harvester. The obtained data were used to create machines for a one-time cotton-picking.

1. Introduction

In the world experience of mechanized cotton harvesting, a one-time cotton-picking, mainly by spindle cotton harvesters, prevails [1-6]. The technology of one-time picking by machines includes harvesting at a time when more than 90% of cotton bolls are open and at high defoliation resulting in the greatest fall of cotton leaves. The picking quality and the efficiency of the spindle cotton harvesters allow harvesting cotton crop from large areas for a short period of time.

In the 70s-80s of the XX century, scientific research and practical work proved the efficiency of cotton harvesters in cotton yield increase and when picking the crop with the most of the cotton bolls open [6, 7]. The preservation of the natural qualities of cotton fiber and seeds harvested with spindle machines were the main criteria in these works. According to these studies, it was recommended to start harvesting with a vertical-spindle machine at 80% of open cotton bolls of their total amount per 1 ha of the field [7].

Many researchers have studied the fast transient processes (in hundredths of a second) of the cotton and its bolls interaction with the working organs of the picking device using high-speed filming; subsequently, this made it possible to create a theory of spindle activity in the working chamber of the apparatus and to describe the process of cotton picking from the cotton plant by the spindles of the picking device [8, 9].



In subsequent studies of the dynamics of the cotton picking process with spindle harvesters, the fundamental parameters of the spindle, drum, doffer and their operating modes were optimized [10, 11]; however, these studies did not account for the porosity and deformation of the open cotton bolls.

Therefore, an account for the cotton bolls deformation when they interact with the spindle makes it possible to more precisely specify the parameters and operating modes of the picking device and the cotton harvester. This statement is the main reason of our research.

2. Methods

The study was based on the well-known methods of analytical geometry, theoretical and applied mechanics, and the theory and calculation of cotton harvesters. In contrast to the developed research methods, the current paper takes into account the deformation of the porous ball-shaped cotton bolls in interaction with the spindles in the picking device, which made it possible to specify the design and kinematic parameters of cotton harvesters.

3. Results and discussion

Let us dwell on the fundamental features of the currently available design of spindle cotton harvesters. The spatial geometrical shape of a cotton plant with the bolls arrangement along its height - in layers, and along its width - in cones, requires the development and creation of an appropriate design of the picking apparatus. In this respect, the horizontal-spindle apparatus is more adapted to the conditions of cotton picking, due to the spindle penetration into the cotton boll. A drum is a rotor on the shaft of which discs are installed, which are the cassette supports. Fig. 1 shows a diagram of a drum with spindles, a doffer, and a dampening pad.

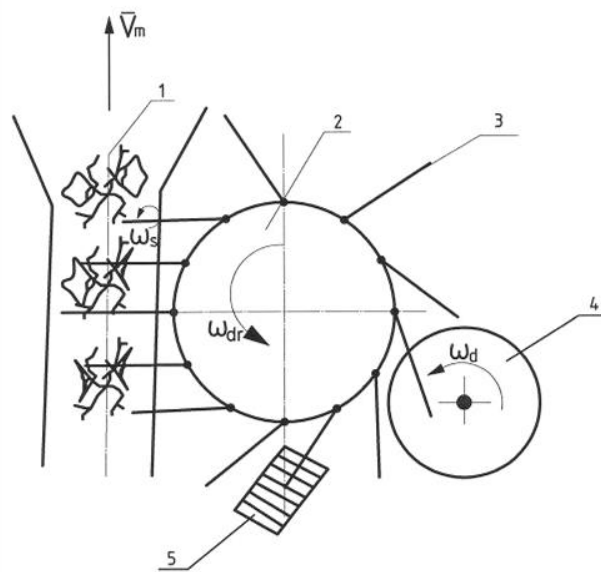


Figure 1. Principal diagram of a drum with horizontal spindles and doffers: 1-working chamber of the device, 2-drum, 3-spindle, 4- doffer, 5- dampening pad

The horizontal-spindle picking device with sequentially located drums according to this scheme operates in the following sequence when interacting with the cotton plant: by one-sided double effect and two-sided single effect on the cotton bolls.

In contrast to this design of the device, the process of cotton picking with a vertical-spindle picking apparatus proceeds according to the principle of a cotton plant adaptation to cylindrical toothed surfaces of paired vertical drums with spindles rotating about vertical axes. The plants are compressed by drums to a width of 36 ... 24 mm of the working chamber of the apparatus and are rolled in with spindles, the teeth of which pick off cotton from the open bolls from the cotton plant sides without

penetrating into it. Fig. 2 shows the design diagram of the front pairs of drums with spindles and the doffer of the apparatus [8, 9].

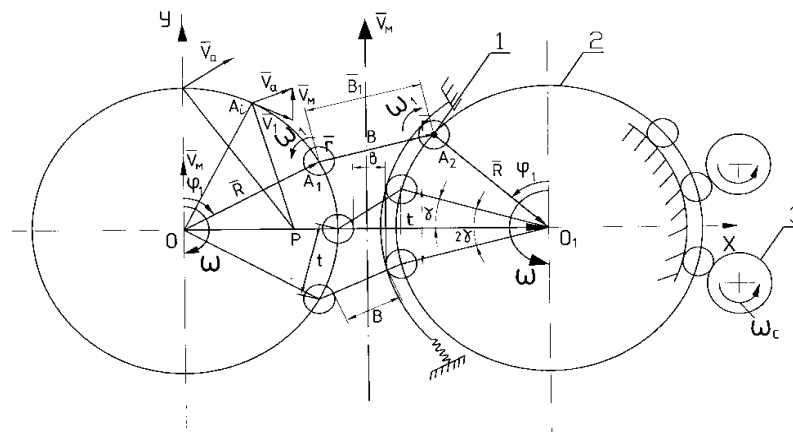


Figure 2. Design scheme for determining the distance between the centers of the spindles (1) arranged pair wise in drums (2) and a doffer (3)

Based on the analysis of known published sources and materials of Internet sites, we have summarized the results of the schematic diagrams development, the creation and testing of various designs of spindle cotton harvesters [13].

In Uzbekistan, since 1997, Case-2022 machines have been assembled at the Uz Casemash JV; at present, the semi-hitched JX-220 cotton harvesters with horizontal spindle picking devices and an ejection system to transport cotton to a hopper are being manufactured at the Tashkent Agricultural Machinery Plant JSC. The semi-hitched MX harvesters, equipped with picking devices with horizontal spindles will expand the range of their operation.

When harvesting cotton crop, modern MX-type semi-hitched machines operate at two operating speeds: $V_m = 4.13 \text{ km/h}$ ($V_m = 1.147 \text{ m/s}$) in the first pass and $V_m = 5.32 \text{ km/h}$ ($V_m = 1.48 \text{ m/s}$) in the second pass. These speeds are the initial data for further refined calculations. As is well-known, the speeds of the machine (V_m) and the spindle drum (V_{dr}) in the picking device of horizontal spindle harvesters are mutually synchronized, i.e. $\overline{V_{dr}} = \overline{V_m}$. Under the leadership of Academician A.D. Glushchenko, the authors carried out detailed studies in this direction, reflected in monograph [12].

Based on [12], the rotation frequencies of the spindles and doffer shafts were specified under condition $V_{dr} = V_m = 1.48 \text{ m/s}$ and rotation frequency of the drum shaft equal to $n_6 = n_4 = 150 \text{ rpm}$ using the scheme shown in Fig. 3, and $Z_1 = Z_5 = 104$; $Z_2 = 13$; $Z_6 = 94$; $Z_7 = 95$; $Z_{10} = 38$; $Z_{11} = 160$; $Z_{12} = 55$; $Z_{13} = 42$, gear coupling moduli are $Z_1 \dots Z_{13}; m_1 = 2, 117$; $Z_3 = 21$ and $Z_4 = 18$ $m_2 = 1, 27 \text{ mm}$; $R_1 = \frac{m_1}{2} \cdot Z_5$.

Determine the frequency of rotation of the sun gear with the number of teeth Z_1

$$n_1 = n_{dr} \frac{Z_{11}}{Z_{10}} \cdot \frac{Z_6}{Z_5} = 150 \cdot \frac{160}{38} \cdot \frac{94}{104} = 570,85 \text{ rpm} \tag{1}$$

and the peripheral speed of a point on the diameter of its pitch circle

$$V_1 = \frac{\pi}{30} \cdot n_1 \cdot \frac{M_1}{2} \cdot Z_5 = \frac{\pi}{30} \cdot 570,85 \cdot 0,11 = 6,572 \text{ m/s} \tag{2}$$

Determine the peripheral speed of a point on the rotation axis of the shafts of 14 cassettes:

$$V_6 = \frac{\pi}{30} \cdot n_6 \cdot \rho_6 = \frac{\pi}{30} \cdot 150 \cdot 0,12382 = 1,944 \text{ m/s} \quad (3)$$

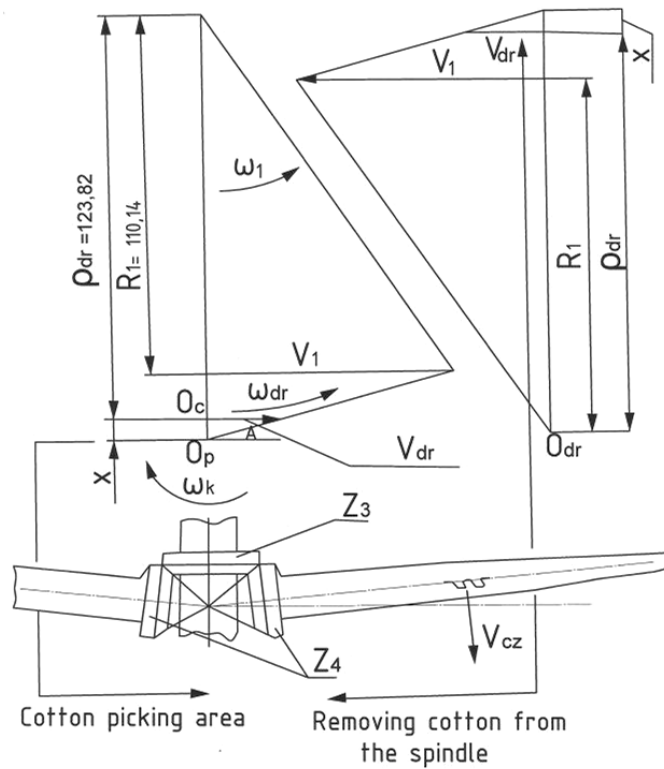


Figure 3. Speed diagrams for the right-hand spindle drum of a horizontal-spindle device at $n_6=158$ rpm

Considering the diagram in Fig. 3, the distance X , where the instantaneous center O_p of cassette shaft rotation is located, is determined from:

$$\frac{X}{V_{dr}} = \frac{\rho_{dr} - R_1}{V_1 - V_{dr}}, \quad (4)$$

Hence, based on the known distance $\rho_{dr} = 123,82 \text{ mm}$, $R_1 = 110,14 \text{ mm}$ [12], we define

$$X = \frac{V_{dr}(\rho_{dr} - R_1)}{V_1 - V_{dr}} = \frac{1,944(123,82 - 110,14)}{6,572 - 1,944} = 5,746 \text{ mm}. \quad (5)$$

Next, we determine the angular speed of the cassette shaft

$$\omega_c = \frac{V_{dr}}{X} = \frac{1,944 \cdot 10^3}{5,746} = 338,3 \frac{1}{s}, \text{ or } n_k = n_{14} = \frac{30}{\pi} \omega_c = 3232,4 \text{ rpm}, \quad (6)$$

And the spindles peed

$$n_{uu} = \frac{Z_3}{Z_4} n_k = \frac{21}{18} \cdot 3232,4 = 3771 \text{ rpm}. \quad (7)$$

Determine the estimated speed of the doffer shaft

$$n_c = n_{20} = n_1 \cdot \frac{Z_5}{Z_{13}} = 570,85 \cdot \frac{104}{42} = 1413,5rpm. \tag{8}$$

At the lower part of Fig. 3 the directions of the speeds V_1 and V_{dr} of the teeth of cotton harvester and the cotton doffing from the spindles (from the side of the doffer shaft to which these spindles fit) are shown. The Table was compiled based on the calculations performed.

Table 1. Calculated values of the kinematic parameters of the picking device and semi-hitched cotton harvester with horizontal spindles at given V_m

Vehicle speed V_m , m/s (km/h)	1.147 (4.13)	1.305 (4.7)	1.48 (5.32)
Drum shaft rotation frequency n_{dr} , rpm(s^{-1})	116.5 (12.19)	132.5 (13.89)	150 (15.7)
Maximum spindle speed n_s in the working area, rpm (s^{-1})	2896 (303.1)	3332 (348.7)	3771 (395.5)
Doffer shaft rotation frequency n_d , rpm (s^{-1})	1089 (114)	1249 (130.7)	1413.5 (148)

These kinematic modes were implemented on an MX harvester with horizontal-spindle picking device during 2019 cotton harvesting period.

The selective cotton harvester of the MX type was equipped with vertical-spindle picking devices. Below, improved methods for calculating the parameters of the picking device and the operating modes of the harvester are given.

In the studies conducted by D.M. Shpolyansky [15], and T. Abdazizov [16], the deformation of a porous cotton boll was determined by experimental measurements and calculations; the boll was taken in the form of a circle of 25% - 30% of the diameter of a conditional ball (the boll model) when its cotton was gripped by a solid spindle.

Taking into account this condition, a design scheme was proposed for their traction of a ball (conventionally, an open boll) of an initial radius r_b with a cylinder (a spindle on a drum of a picking device), of radius r , shown in Fig. 3.

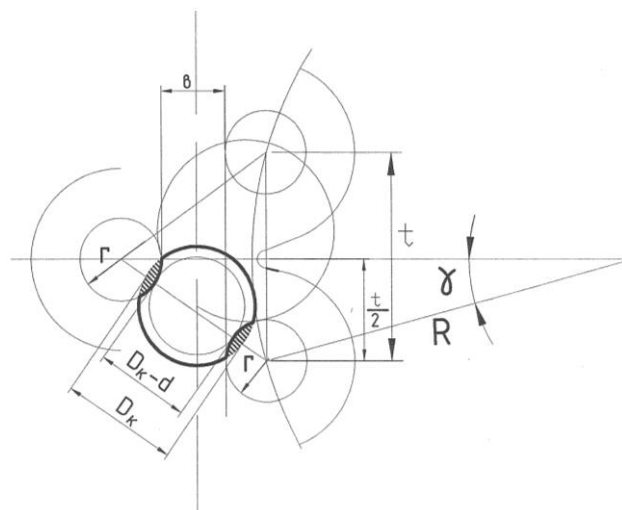


Figure 4. Scheme for calculating the geometrical deformation of the cotton boll between the spindles of the picking device drums

A porous ball interacting with a rigid cylinder receives a deformation equal to d and leaves an indentation on the cylinder surface in the form of a spatial ellipsoid with large h_1 and minor h_2 semi-axes shown in Fig. 4.

The magnitude of geometrical deformation of a ball (a cotton boll) is determined as (Fig. 4)

$$d = D_b - B \tag{9}$$

where B is the distance between the surfaces of the opposite spindles (cylinder) of pair wise located drums, mm, D_b —is the initial diameter of the boll in the form of a conventional ball, mm.

Fig. 2 shows a design scheme for determining the distance between the centers of the spindles B_1 on pair wise located drums. The distances B_1 , B ($B_1 = B + 2r$) between the surfaces on the drums interacting with the cotton are determined based on the design of the vector polygon $OA_1A_2O_1$ on the OX axis (Fig. 2) according to the well-known methods of analytical geometry in the form [16]

$$B = \left\{ \left[R(\sin \phi + \sin \phi_1) - a \right]^2 + \left[R(\cos \phi - \cos \phi_1) \right]^2 \right\}^{1/2} - 2r \tag{10}$$

where ϕ is the angle of rotation of a drum with spindles, measured from the longitudinal axis passing through the center O of the left drum; and it is parallel to the cotton sowing axis, rad.; ϕ_1 - idem, for the right drum shifted by an angle $\gamma = \pi/z$, i.e. $\phi_1 = \phi - \pi/z$, rad; a is the center-to-center distance between the spindle drums, $a = R(1 + \cos \pi/z) + 2r + \epsilon$, mm; ϵ is the gap between the opposite spindles of pairwise operating drums (a working gap), mm.

Based on expression (12) at $B_{min} = D_b - d$ (Figs. 2-4) and the angle of rotation $\phi = 90^\circ$ of the left drum, $\phi_1 = 90^\circ - \gamma$ ($\gamma = \pi/z$, z is the number of spindles on the drum), a formula could be obtained to determine the working gap accounting for the deformation of the open cotton boll of the least diameter:

$$\epsilon = \sqrt{[(D_{kmin} - d) + 2r]^2 - R^2 \sin^2 \gamma} - 2r. \tag{11}$$

An account for the boll deformation (Figs. 3-4) in the working area of the picking device due to the change in distance B between the opposite spindles according to the law described by expression (10), the previously known formulas [16] for determining the pitch of the spindles on the drum (Fig. 2) and their number (Fig. 5), are specified in the form

$$t = 2\sqrt{(2r + 2r_k - d) - (b + 2r)}, \tag{12}$$

$$z = \frac{2\pi R}{\kappa \cdot \ell_\kappa} = \frac{2\pi R}{\kappa \cdot (D_\kappa - d)}, \tag{13}$$

where $D_b - d = \ell_b$ is the radius of the deformed boll, mm; κ is the drum advance coefficient ($\kappa = V_\sigma / V_M$).

In [9, 15], experimental studies have determined the least diameter of the open boll, equal to $D_b = 46.5$ mm with a porosity of 92% at a given $R = 146$ mm, $r = 14$ mm and $d = 0.1744D_b$ (the authors have determined this empirical dependence based on summarizing the results of the above studies). Substituting these data into formulas (12) and (13), we get $t = 65 \dots 66$ mm, $z = 14$ pcs.

All other things being equal, an account for the required 30% of a cotton boll (a ball) deformation volume in the working area of the picking device increases the calculation accuracy by 1.17-1.25 times for the operating modes of the MX-1.8 (and MX-2.4) cotton harvesters. This is especially important at a given advance of the drum κ , and the staggered arrangement of spindles (Fig. 2) in the working chamber of the picking device. The deformed cotton boll leaves an ellipsoidal contact indentation on a spindle, shown in Fig. 5. Determination of the contact indentation parameters is of practical importance when calculating the spindle dimensions [17]. Based on the accepted designations (Fig. 5, a, b), using triangles ΔO_kKB_1 , ΔO_1AE and ΔO_kAE , where $OK = r_b$, $D_b = 2r_b$, $O_1A = r$,

$O_bB = r_b - \Delta$, $B_1K = h_1$, $AE = h_2$, the formulas to calculate the values of ellipse semi-axis radii

h_1 and h_2 were obtained in the form [17]

$$h_1 = \sqrt{\Delta(D_k - \Delta)}, \tag{14}$$

$$h_2 = \sqrt{r^2 - \frac{(l^2 + r^2 - r_k^2)^2}{4l^2}}, \tag{15}$$

where Δ is the cotton boll deformation ($\Delta = 0,5d$) mm; l is the distance between the centers of the boll and the spindle, mm.

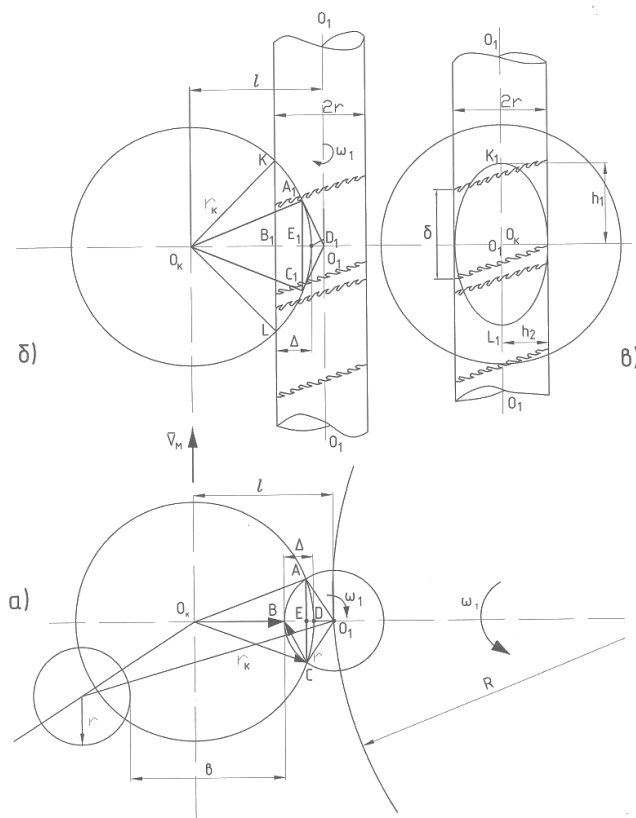


Figure 5. Projections of "spindle-cotton boll" spatial interaction

Considering the deformation, the length of the arcOABC, being the minor axis of the ellipse with the central angle of contact between the ball and the cylinder equal to 2α , is determined by the formula

$$h'_2 = h_2 \cdot 2\alpha, \text{ where } \alpha = \arcsin\left(\frac{h_2}{r}\right). \tag{16}$$

Calculation formulas (14), (15) and (16) with given values of r , D_b , d , allow determining the parameters of the ball-cylinder contact: the width δ of one turn of the gripping element, the number of spindle teeth involved in the interaction with the open cotton bolls.

Based on the design formulas (14), (15) and (16) with given values of r , D_k , $d = 2\Delta$, it is possible to calculate the width δ of one turn of the gripping element of the spindle. At that, condition $\delta < 2h_1$ should be met, and the teeth pitch of the notch on the tape (Fig. 5) of a composite spindle should be less than $2h_2$. Calculations have shown that at $D_{k\min} = 46,5\text{mm}$, $\Delta = 4\text{mm}$ (or $d = 8\text{mm}$) and

$2h_1 = 26\text{mm}$, $2h_2 = 16,14\text{mm}$. The greatest and the least diameters of the ellipse are $r = 14\text{mm}$, $R = 16,14\text{mm}$ respectively. Hence it follows, that the tape width δ can be elongated to 20 ... 22mm and the teeth pitch of the notch can be set at 10mm. Then, accounting for their density and uniformity of arrangement on the spindle, and considering the experiments results [18], the teeth number on the serial composite spindle can be reduced from 810 + 20 pcs. to 620 + 20 pcs.

Calculations of the kinematic modes of a selective machine with vertical-spindle picking devices, based on the known kinematic machine diagram [18], are conducted in the following sequence.

According to the experimental data of a number of researchers [9, 15], the limiting speed of cotton sliver rupture from an open boll varies from 1.6 m/s to 2.1 m/s for different varieties of cotton. Equating it to the speed of sliver winding on the spindle during the cotton-picking process, we can determine the spindle speed V_w

$$\omega_a = V_w / r, \quad (17)$$

where ω_a is the frequency of rotation of the spindle axis at cotton sliver winding, s^{-1} ;

V_w is the speed of sliver winding on a spindle, m/s ($V_w = 1,65...2,1\text{m/s}$);

As is well-known [11], a drive roller with rolling radius r_r of the spindle is a satellite of the planetary gear mechanism, and for a given drum radius R (Fig. 2) the gear ratio is $i = R / r_r$. The drum shaft rotation frequency is determined by i

$$\omega = \omega_a / i = \frac{\omega_a \cdot r_r}{R}, \quad (18)$$

and its linear speed of the drum in the center of the spindle is

$$V_{dr} = \omega \cdot R \text{ or } V_{dr} = \omega_a \cdot r_r. \quad (19)$$

As mentioned above, the speeds of the drum V_{dr} and machine V_m are related through the advance coefficient (kinematic coefficient) of the drum $k = V_{dr} / V_m$ [19].

At a given value of k the machine speed is determined as

$$V_m = \frac{\omega_a \cdot r_r}{k}. \quad (20)$$

Experimental data are taken as known [9, 11, 15], i.e., if $V_{dr} = 1,65...2,1\text{m/s}$, and $r_r = 13\text{m/s}$ and $k = 1,3...1,5$, then $V_m = 1,03...1,5\text{m/c}$ or $V_m = 3,7...5,4\text{km/h}$, $V_{dr} = 1,65...2,1\text{m/c}$, то есть $r_r = 13\text{mm}$ and $k = 1,3...1,5$,

So, at $\omega_a = 118...150\text{s}^{-1}$ the rotation frequency of the drum shaft changes in the range of 10.5 ... 13.35 s^{-1} (100 ... 127.5 rpm) and machine speed in the range of 3.7 ... 5.4 km/h. For the production kinematic diagram of the picking device, the frequency of rotation of the doffer shaft is in the range of 1540 ... 1963 rpm. Note that the working speeds of the MX harvesters are within the calculated ones. But the frequency of drum rotation at the 1st speed is 20% ... 30% higher; this requires correction to reduce it to the calculated values.

4. Conclusions

1. The methods for calculating the operating modes of a semi-hitched cotton harvester for selective one-time cotton-picking were developed equipped with:
 - horizontal-spindle picking devices;
 - vertical-spindle picking devices.
2. The improved methods of calculating the parameters of the vertical-spindle picking device of the production technological scheme based on the proposed "deformable ball-cylinder" model allow increasing the accuracy of calculations by 1.17 ... 1.25 times and determining the optimal parameters of the spindle, drum, and working gap of the picking device.

3. The design parameters were recommended for the drafting, manufacture and testing of the selective semi-hitched harvester for one-time cotton-picking.

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