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CALCULATION OF RADIAL AND TANGENTIAL VELOCITIES OF THE RAW COTTON ROLLER IN THE WORKING CHAMBER OF A SAW GIN

РАСЧЕТ РАДИАЛЬНОЙ И ТАНГЕНЦИАЛЬНОЙ СКОРОСТИ СЫРЦОВОГО ВАЛИКА В РАБОЧЕЙ КАМЕРЕ ПИЛЬНОГО ДЖИНА

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This article provides research material on the cotton seed movement inside the working chamber of a saw gin with a huller roll box and a seed removing system. The flow of raw cotton is considered as a continuous medium with a flow rate Q, fed from the plane of an inclined feeder at an angle α to the horizon. Raw cotton entering the working chamber is considered as a continuous medium between two coaxial cylinders R1≤r≤R2, which are components of the raw cotton roller of the working chamber of a gin. The maximum values of kinematic viscosity (up to 0.39 m2/s) and dynamic viscosity (up to 20 kg/(ms)) were determined at cotton productivity of 7 t/h (up to 2 kg/s). Calculations determined that the speed in radial direction at 300° with an increase in the radius R1 from 56 to 69 mm decreases by 24%, and in tangential direction, it increases by 23.5%. It was established that the minimum (30°) and maximum (300°) values of the angular velocity along the circumference of the working chamber differ by 2.24 times. The main changes in the angular velocity occur in the vicinity of the saw (300°) and the cotton input zone (210°) of the working chamber. Near the inner cylinder, the tangential speed is less than the speed of rotation of points on the surface of the outer cylinder (except for points in the vicinity of the saw).

В данной статье приводятся материалы исследования движения семян внутри рабочей камеры пильного джина с шелушильной камерой и семяотводящей системой. Рассмотрен поток хлопка-сырца как сплошная среда, имеющая секундный расход, равный Q, поступающая из плоскости наклонного питателя под углом α к горизонту. Поступивший в рабочую камеру хлопок-сырец рассмотрен как сплошная среда между двумя коаксиальными (соосными) цилиндрами R1≤r≤R2, являющимися составляющими сырцового валика рабочей камеры джина. Определены максимальные значения кинематической (до 0,39 м^2/с) и динамической (до 20 кг/(мс)) вязкости при производительности хлопка 7 т/ч (до 2 кг/с). Расчетами определено, что скорость в радиальном направлении при 300° с увеличением радиуса R1 с 56 до 69 мм снижается на 24%, а в тангенциальном увеличивается на 23,5%. Установлено, что минимальные (30°) и максимальные (300°) значения угловой скорости по окружности рабочей камеры отличаются в 2,24 раза. Ос-

новные изменения угловой скорости происходят в окрестности пилы (300°) и входной зоне хлопка (210°) рабочей камеры. Около внутреннего цилиндра тангенциальная скорость меньше, чем скорость вращения точек поверхности наружного цилиндра (кроме точек в окрестности пилы).

Keywords: saw gin, cotton, cotton seed, working chamber, huller roll box, removing system, coaxial cylinder, angular velocity.

Ключевые слова: пильный джин, хлопок, семена хлопчатника, рабочая камера, очистительная секция, семяотводящая система, коаксиальный цилиндр, угловая скорость.

Introduction

The serial saw gin 5DP-130, being the basic machine, does not meet the requirements of a single-battery production line (7 t/h for cotton) in terms of productivity (passport standard is 2000^{-200} kg of fiber per hour), and there are two of them in the battery [1]. In addition, the second line of cleaning machines UXK, was installed at a typical cotton ginning plant, which makes it possible to increase the cotton production capacity to 14 t/h; these machines are used in the processing of poor varieties of cotton [2–4]. In this regard, for this technology, it is necessary to create a gin that exceeds the performance of a serial gin by 15-20%.

To clarify the directions of further research, an experimental working chamber with a huller roll box was created and installed in a laboratory 30-saw gin with an additional seed-removing device. According to this scheme, it is possible to use only cantilever ribs [5, 6]. Based on the above, the spacing of the saws in the saw cylinder is assumed 18 mm as in a typical saw cylinder [7].

A full-profile working chamber corresponding in profile to the working chamber of a gin with a huller roll box contains in its central part a driving tubular seed-removing device with holes over the entire surface of the pipe. The holes serve to pass the ginned seeds into the inner cavity of the pipe, from which these seeds are removed by the seed auger.

Determination of tangential and radial components of the velocity vector of the raw cotton roller will make it possible to study the kinematics of cotton and seeds inside the working chamber.

During the operation of the saw gin, cottonenters the working chamber from the feeder in a discrete state, and then is gradually ginned in several cycles due to the action of rotating saws. At that, the cotton coming from the feeder through the throwing drum and saw cylinder into the working chamber, forming a raw cotton roller constantly rotates between the stationary outer cylinder and rotating inner cylinder.

In the process of movement, the seeds are released from the bottom of the working chamber, passing between the saws and the comb, and the rest of the seeds move to the rotating perforated pipe, located in the middle part of the working chamber, pass through its grooves inside the pipe, where they are picked up by the rotating auger and then brought out through the seed removing pipe [5].

Materials and methods

Let us consider an approximate solution to this problem, taking the flow of raw cotton as a continuous medium with a flow rate Q, coming from the plane of an inclined feeder at an angle α to the horizon. The raw cotton that enters the working chamber between two coaxial cylinders $R_1 \le r \le R_2$, which are components of the raw cotton roller of the working chamber of a gin, under the influence of rotation of axial cylinder of radius R_1 moves with angular velocity ω_1 to the saw cylinder (Fig. 1).

In the zone of seeds interaction with the saw cylinder, the fibers are gripped and removed from the cottonthrough the inter-rib slots out into the air chamber, and some of the seeds continue to move inside the working chamber. After several removals of the fibers, part of seeds, under their own weight, rolls down between the saws to the comb, and the other part, located in the zone of perforated pipe, under pressure enters the beveled grooves of the pipe, and then is carried outside by the auger.

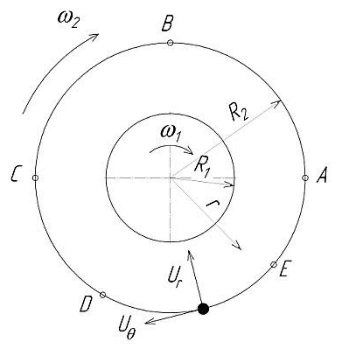

Fig. 1

We solve the problem of the seed movement in working chamber by modeling (Fig. 2) a continuous medium as a viscous liquid with a conditional dynamic viscosity μ_c. To do this, we solve the problem of the flow of a continuous, linearly viscous medium with kinematic viscosity

$\nu_c=\mu_c/\rho_c$ from height $H=L\cdot\sin\alpha$, (1)

where L is the length of the inclined plane of the feeder tilted at an angle α to the horizon (Fig. 2).

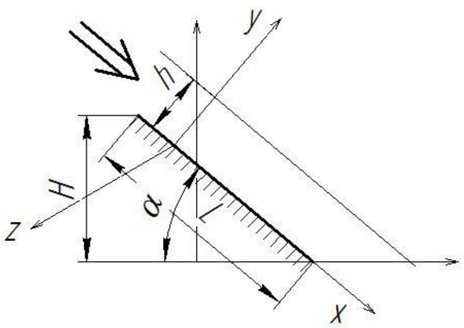

Fig. 2

The equation of motion in a one-dimensional formulation can be written in the following form

$$\mu_c\cdot\frac{\partial^2 V}{\partial y^2}+\rho_c\cdot g\cdot\sin\alpha=0 \quad (2)$$

Integrating over y, we obtain the distribution of velocity and pressure in the considered layer of continuous medium above the plane of the feeder:

$$V=-\frac{\rho_c\cdot g\cdot\sin\alpha}{2\cdot\mu_c}\cdot y(h-y)\ , \quad (3)$$

$$P=P_0+\rho_c\cdot g\cdot\cos\alpha\cdot(h-y), \quad (4)$$

where P_0 =101325 Pa is the atmospheric pressure; ρ_c is the density of continuous medium.

Integrating expression (3) over y from 0 to h, we find the flow rate of the medium (raw cotton) flowing from the feeder into the working chamber:

$$Q=\rho_c\cdot g\cdot h^3\cdot L\ \frac{\sin\alpha}{12\cdot\mu_c}\ ,\left[\frac{m^3}{s}\right] \text{ or}$$

$$Q=\rho_c^2\cdot g\cdot h^3\cdot L\ \frac{\sin\alpha}{12\cdot\mu_c}\ ,\left[\frac{kg}{s}\right] \quad (5)$$

The average speed of the particles of a continuous medium and its thickness can be obtained from the following equations

$$V_{OH}=Q/(h\cdot L)) \quad (6)$$

$$\text{or}\quad h=Q/(V_{OH}\cdot L)\ . \quad (7)$$

Now let us write the equation of motion ofcottonin the working chamber based on their inflow from the feeder and the rotation of the inner cylinder. We assume that the flow line of particles of a continuous medium is in the plane of the cross section of the working chamber. Then the velocity vector of a particle of continuous medium has velocity components in the radial $U_r$and tangential U_θ directions (Fig. 1), and the axial velocity is zero $U_Z=0$, i.e. $\vec{V}=U_r\cdot\vec{e}_r+U_\theta\cdot\vec{e}_\theta$. We write the equation of motion ofcottonin a vector form [8]

$$\frac{\partial\vec{V}}{\partial t}+2\left[\vec{\omega}\times\vec{V}\right]=-\text{grad}\left[\frac{V^2}{2}+\Pi+P(\rho_c)\right]-2\cdot\nu_c\cdot\text{rot}\vec{\omega} \quad (8)$$

and the continuity equation

$$\frac{\partial\rho_c}{\partial t}+\text{div}\left(\rho_c\cdot\vec{V}\right)=0\ , \quad (9)$$

where $\vec{\omega}=\frac{1}{2}\text{rot}\vec{V}$ is the angular velocity of the particles of the medium; $\vec{V}$ is the velocity vector of the particles of the medium; ρ_c is the density of the medium; Π is the potential energy of external forces.

Here, under the above conditions, angular velocity $\vec{\omega}$ is directed along the axis of symmetry of the working chamber $\vec{\omega} = \omega \cdot \vec{k}$, where $\vec{k}$ is the unit vector of the axis of working chamber, ω=V/r.

From equality (7), we find the conditional kinematic and dynamic viscosity in the following form

$$\nu_c = \frac{g \cdot Q^2}{12 \cdot V_{OH}^3 \cdot L^2} \cdot \sin\alpha \ , \left[\frac{m^2}{s}\right] \quad \text{and}$$

$$\mu_c = \nu_c \cdot \rho_c \ , \ \left[\frac{kg}{m \cdot s}\right] \qquad (10)$$

With the maximum productivity values of the saw gin for cotton: 7 t/h (1.94 kg/s), g=9,806 m/s^2, L=2,358 m, ρ_c=50 kg/m^3, V_{OH}=1 m/s, sinα=0,707, it is possible to construct changes in kinematic and dynamic viscosity depending on the operating efficiency (Fig. 3) [9].

Analysis of Fig. 3 shows an increase in kinematic (up to 0.39 m^2/s) and dynamic (up to 20 kg/(ms)) viscosity of cotton in the feeder tray with an increase in cotton productivity from 0 to 2 kg/s.

Equations (8) and (9) in the projections of a cylindrical system are written in the following form

$$\left.\begin{aligned}
&\frac{\partial U_r}{\partial t} + U_r\frac{\partial U_r}{\partial r} + \cdot\frac{U_\theta}{r}\cdot\frac{\partial U_\theta}{\partial \theta} = -\frac{\partial P}{\partial r} + \nu_c\left[\nabla^2 U_r - \frac{U_r}{r^2} - \frac{2}{r^2}\cdot\frac{\partial U_\theta}{\partial \theta}\right] ,\\
&\frac{\partial U_\theta}{\partial t} + U_r\frac{\partial U_\theta}{\partial \theta} + \frac{U_\theta}{r}\cdot\frac{\partial U_\theta}{\partial \theta} = -\frac{1}{r}\cdot\frac{\partial P}{\partial \theta} + \nu_c\cdot\left[\nabla^2 U_\theta - \frac{U_\theta}{r^2} + \frac{2}{r^2}\cdot\frac{\partial U_\theta}{\partial \theta}\right] ,\\
&\frac{\partial \rho_c}{\partial t} + \frac{\partial\left(r\cdot\rho_c\cdot U_r\right)}{\partial r} + \frac{\partial \rho_c\cdot U_\theta}{\partial \theta} = O \ .
\end{aligned}\right\} \qquad (11)$$

here r andθ are the cylindrical coordinates; U_r, U_θ are the components of the velocity vector in the radial and tangential directions; $P(\rho_c)=\int dP/\rho_c$ is the pressure function; $\nabla^2 U = \frac{1}{r}\cdot\frac{\partial}{\partial r}(r\cdot\frac{\partial U}{\partial r}) + \frac{1}{r^2}\cdot\frac{\partial^2 U}{\partial \theta^2}$ is the Laplacian [10].

We assume that the continuous medium of the raw cotton roller is homogeneous, i.e. the density of the medium is constant ρ_c=const. Then the pressure function is defined by equality $P(\rho_c)=P/\rho_c$.

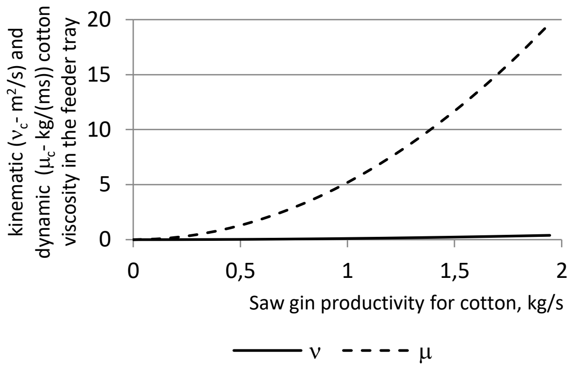

Fig. 3

The continuity equation is reduced to the following equation

$$\frac{\partial\left(rU_r\right)}{\partial r} + \frac{\partial U_\theta}{\partial \theta} = O \ . \qquad (12)$$

Let the movement of particles of the medium in the working chamber be stationary, since the amount of raw cotton coming from the feeder in a discrete flow into the working chamber is uniform in time, the perforated pipe rotates with angular velocity ω_1, and the saw rotates with a speed of 730 rpm. Then the equations of motion (8) at ω_1 =const is written in a vector form as

$$2\left[\vec{\omega}\times\vec{V}\right] = -\mathrm{grad}\left[\frac{V^2}{2} + \Pi + \frac{P}{\rho}\right] - \nu_c\cdot \mathrm{rot}(\mathrm{rot}\vec{V}) , \qquad (13)$$

$$\frac{\partial\left(r\cdot U_r\right)}{dr} + \frac{dU_\theta}{d\theta} = 0, \ \ \mathrm{div}\vec{V} = 0 \ \cdot \qquad (14)$$

The angular velocity of the raw cotton roller is determined by the following equation

$$\omega = \frac{1}{2}\left(\frac{\partial U_\theta}{\partial r} - \frac{1}{r}\cdot\frac{\partial U_r}{\partial \theta}\right) . \qquad (15)$$

The solution to the system of equations (11) is sought by the method of separation of variables

$$\left.\begin{aligned} U_r' &= F_1(r)\cdot\Phi_1(\theta) \\ U_\theta' &= F_2(r)\cdot\Phi_2(\theta) \end{aligned}\right\} . \qquad (16)$$

Thus, the following equations are obtained for the sought-for functions $F_к(r)$ and $\Phi_к(\theta)$:

$$F_к\left(r\right) = A_1^{(K)}\cdot r + B_1^{(K)}\cdot\frac{1}{r} ; \quad \Phi(\theta) = \sum_{n=1}^{N}\left[a_0 + a_n\theta_n^n\right] \qquad (17)$$

To determine coefficients $A_к$, $B_к$ (at points A, B, C, D, and E - Fig. 1), we have the following boundary conditions:

$$U_\theta(R_2,\theta)=\Phi(\theta);\ U_\theta(R_1,\theta)=\omega_1\cdot R_1;$$
$$U_r(R_1,\theta)=-U_{HC};$$
$$U_r(R_2,\theta)=-V_{H0}\cdot\cos\alpha\ \text{ for } \theta\in\left[\frac{4\cdot\pi}{9};\frac{5\cdot\pi}{9}\right];$$
$$U_r(R_2,\theta)=0\ \text{ for } \theta\ \bar{\in}\left[\frac{4\cdot\pi}{9};\frac{5\cdot\pi}{9}\right],$$

where U_{HC} is the velocity of particles flowing through the slots of the inner cylinder, R_1 is the radius of the pipe.

First, we find function $\Phi(\theta)$ from the boundary conditions at the swirl rate U_θ for $r=R_2$, $U_\theta(R_2,\theta)=U_{\theta o}\cdot\Phi(\theta)$ where

$$U_{\theta o}=U_\theta(R_2,\pi/2) \quad (18)$$

To determine coefficients $A_к$, $B_к$ at points A, B, C, D, and E, we use the distribution of the tangential velocity of a particle of the medium along the inner surface of the outer cylinder. Here R_2- is the radius of the working chamber, obtained experimentally [7]:

At point A - $U_\theta(R_2,0°)=0.926$ m/s, $\omega(R_2,0)=5.51\ s^{-1}$;
At point B - $U_\theta(R_2,90°)=0.944$ m/s, $\omega(R_2,90°)=4.19\ s^{-1}$;
At point C - $U_\theta(R_2,180°)=1.0$ m/s, $\omega(R_2,180°)=4.34\ s^{1}$; (19)
At point D - $U_\theta(R_2,240°)=1.481$ m/s, $\omega(R_2,240°)=6.61\ s^{-1}$;
At point E - $U_\theta(R_2,320°)=2.037$ m/s, $\omega(R_2,320°)=15.67\ s^{-1}$.

From the values given in (19), we find the unknown parameters of formula (17) at points A, B, C, D and E (Fig. 1), so that the sought-for function is determined by the following equality:

$$\Phi(\theta)=-0{,}006\cdot\theta^5+0{,}0717\cdot\theta^4-0{,}2747\cdot\theta^3+ +0{,}4119\cdot\theta^2-0{,}1988\cdot\theta+0{,}9259 \quad (20)$$

Now we define the sought-for functions $U_r(r,\theta)$ and $U_\theta(r,\theta)$ and angular velocity $\omega(r,\theta)$:

$$\left.\begin{aligned}F_1(\hat r)&=\frac{1}{1-\hat R_1^2}\cdot\left[U_{H0}\cdot\left(\frac{\hat R_1^2}{\hat r}-\hat r\right)-U_{HC}\cdot\left(\frac{\hat R_1}{\hat r}-\hat R_1\cdot\hat r\right)\right]\\ F_2(\hat r)&=\frac{1}{1-\hat R_1^2}\cdot\left[U_{\theta 0}\cdot\left(\hat r-\frac{\hat R_1^2}{\hat r}\right)+\omega_1\cdot R_1\cdot\left(\frac{\hat R_1}{\hat r}-\hat R_1\cdot\hat r\right)\right]\end{aligned}\right\},\ (21)$$

where $\hat R_1=R_1/R_2$; $\hat r=r/R_2$. We obtain the solution to the problem in the form

$$\left.\begin{aligned}&U_r(\hat r,\theta)=F_1(\hat r)\cdot\Phi(\theta),\quad U_\theta(\hat r,\theta)=F_2(\hat r)\cdot\Phi(\theta)\\ &\omega(\hat r,\theta)=\frac{1}{2}\cdot\left[F_2(\hat r)\cdot\Phi(\theta)-\frac{1}{\hat r}\Phi(\theta)\cdot F_1(\hat r)\right]\end{aligned}\right\}.(22)$$

Equations (21 and 22) were calculated for this experimental setup with the following values: R_2=200 mm, n_2=90 rpm, $\omega_2=90\cdot\pi/30=9{,}425\ s^{-1}$. If we assume that $V_{HC}=0{,}3\cdot V_{\theta 0}$, $V_{ro}=V_{OH}\cdot\sin\alpha$, $\alpha=45^o$, $U_{\theta o}=V_{OH}\cdot\cos\alpha$, $U_{\theta o}=1$ m/s, $V_{HC}=0{,}3$ m/s, then we obtain the following values of the sought-for functions $F_1(\hat r)$ and $F_2(\hat r)$ for different radii of the seed-removing device R_1 (table 1).

Results and discussion

Table 2 shows the indices of the change in tangential velocity (18) along the inner surface, obtained from experimental data; Fig. 4 shows the distribution of radial velocity $U_r(\hat r,\theta)$ (22), and Fig. 6 shows the distribution of tangential velocity $U_\theta(\hat r,\theta)$ (22) of the particles of the medium in the working chamber of the setup.

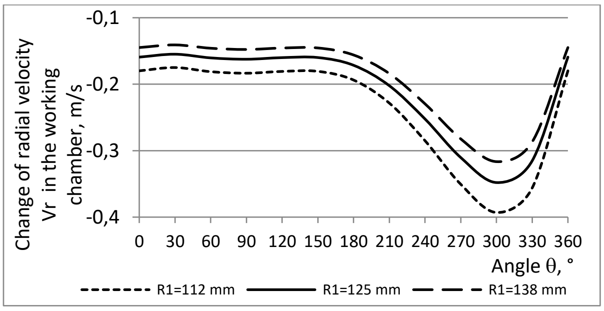

Fig. 4

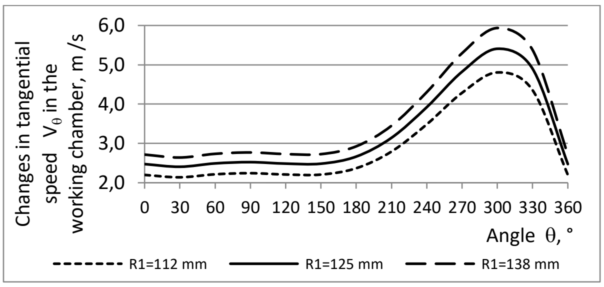

Fig. 5

Changes in angular velocity of the raw cotton roller in the working chamber are shown in Fig. 6.

Table 1

The frequency of rotation of the seed-removing pipe, rpm	R_1=56 mm	R_1=62.5 mm	R_1=69 mm
	$F_1(\hat{r})$=0.061260053/$\hat{r}$ - 1.47526005·$\hat{r}$, $F_2(\hat{r})$=	$F_1(\hat{r})$=0.093460865/$\hat{r}$ - 1.50746087·$\hat{r}$, $F_2(\hat{r})$=	$F_1(\hat{r})$=0.129765943/$\hat{r}$ - 1.54376594·$\hat{r}$, $F_2(\hat{r})$=
0	-0.12170185/$\hat{r}$ +1.121550837·$\hat{r}$	-0.15626547/$\hat{r}$ +1.156114459·$\hat{r}$	-0.19380328/$\hat{r}$ +1.193652271·$\hat{r}$
100	0.094988867/$\hat{r}$ +0.904860122·$\hat{r}$	0.121965937/$\hat{r}$ +0.877883052·$\hat{r}$	0.151264376/$\hat{r}$ +0.848584613·$\hat{r}$
150	0.203334224/$\hat{r}$ +0.796514765·$\hat{r}$	0.26108164/$\hat{r}$ +0.738767348·$\hat{r}$	0.323798205/$\hat{r}$ +0.676050784·$\hat{r}$
200	0.311679582/$\hat{r}$ +0.688169407·$\hat{r}$	0.400197344/$\hat{r}$ +0.599651645·$\hat{r}$	0.496332034/$\hat{r}$ +0.503516955·$\hat{r}$
250	0.420024939/$\hat{r}$ +0.579824049·$\hat{r}$	0.539313048/$\hat{r}$ +0.460535941·$\hat{r}$	0.668865863/$\hat{r}$ +0.330983125·$\hat{r}$
300	0.528370297/$\hat{r}$ +0.471478692·$\hat{r}$	0.678428751/$\hat{r}$ +0.321420237·$\hat{r}$	0.841399692/$\hat{r}$ +0.158449296·$\hat{r}$
350	0.636715654/$\hat{r}$ +0.363133334·$\hat{r}$	0.817544455/$\hat{r}$ +0.182304534·$\hat{r}$	1.013933522/$\hat{r}$ -0.01408453·$\hat{r}$
400	0.745061012/$\hat{r}$ +0.254787977·$\hat{r}$	0.956660159/$\hat{r}$ +0.04318883·$\hat{r}$	1.186467351/$\hat{r}$ +-0.18661836·$\hat{r}$

Table 2

Points	θ,°	Experimental values for R_1=0 m	Calculated values for R_1=0 m	Difference, %	Calculated values for R_1, m		
					0.056	0.625	0.069
A	0	0.926	0.9259	0.01	2.1996	2.4750	2.7166
B	90	0.944	0.9444	-0.04	2.2436	2.5245	2.7710
C	180	1	0.9973	0.27	2.3693	2.6660	2.9262
D	240	1.481	1.4671	0.94	3.4854	3.9218	4.3047
E	320	2.037	1.9657	3.50	4.6698	5.2545	5.7675
	0	0.926	0.9259	0.01	2.1996	2.4750	2.7167

Cotton gets to the saw through the throwing drum, located at the maximum distance from the center of rotation of the raw cotton roller, under the action of the rotational movement of the raw cotton roller and the resulting centrifugal force.

Comparison of the values (Table 2) of tangential velocity $U_\theta(R_2,\theta)$along the inner surface, obtained on the basis of experimental studies and as a result of modeling according to equation (20), showed a difference of up to 3.5%, which confirms the reliability of the results up to 96.5%.

Changes in angular velocity of the raw cotton roller in the working chamber are shown in Fig. 6.

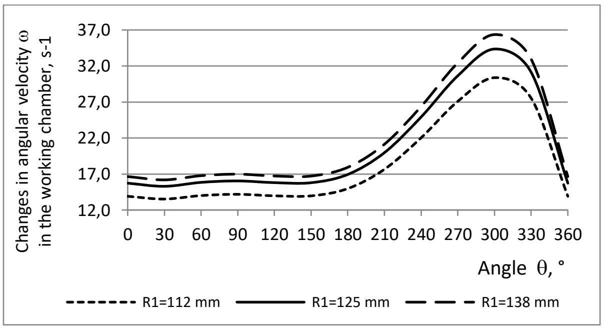

Fig. 6

Cotton gets to the saw through the throwing drum, located at the maximum distance from the center of rotation of the raw cotton roller, under the action of the rotational movement of the raw cotton roller and the resulting centrifugal force.

Therefore, it is necessary to select the parameters in such a way that the husked seeds are removed from the inside of the working chamber through the combs and seed-removing pipe using an auger.

The calculation results show that the speed in radial direction at 300° with an increase in the radius R_1 from 56 to 69 mm decreases by 24%, and in tangential direction, it increases by 23.5%.

It was stated that the minimum (30°) and maximum (300°) values of angular velocity along the circumference of the working chamber differ by 2.24 times. The main changes in angular velocity occur in the vicinity of the saw (300°) and the cotton input zone (210°) of the working chamber (Fig. 6). Near the inner cylinder, the tangential speed is less than the speed of rotation of points on the surface of the outer cylinder (except for points in the vicinity of the saw, see Fig. 5).

C O N C L U S I O N S

Mathematical modeling of the movement of cottonand seeds inside the working chamber of the saw gin made it possible to determine the radial, tangential and angular speeds of the raw cotton roller along the surface of the seed-removing pipe and the working chamber.

The pattern of change of kinematic viscosity (up to 0.39 m^2/s) and dynamic viscosity (up to 20 kg/(ms)) of cotton in the feeder tray depending on the productivity of cotton (up to 2 kg/s) was determined.

The reliability of the calculated values of tangential velocity $U_\theta(R_2,\theta)$along the inner surface relative to the experimental values is 96.5%.

Calculations determined that the speed in radial direction at 300° with an increase in the radius R_1 from 56 to 69 mm decreased by 24%, and in tangential direction increased by 23.5%. At that, the minimum (30°) and maximum (300°) values of angular velocity along the circumference of the working chamber differ by 2.24 times.

Л И Т Е Р А Т У Р А

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