Study of the wear process of technological surfaces of saw gin grates

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Abstract. This paper presents the results of the theoretical studies of the process of wear of the technological surfaces of saw gin grates. Mathematical expressions are obtained, with the help of which it is possible to determine the theoretical statistical characteristics of the raw roller and it is indicated that the wear of the grate, in the process of operation from the impact of the raw roller, occurs as a result of the abrasive deposited on it. A rod model of the process of interaction between a raw roller and a grate has also been studied, on the basis of which it is possible to determine the depth of abrasive penetration in the contact surface of the working zone of the grate. The possibility of reducing the wear of grates by increasing the area of their technological surfaces and reducing, due to this, the probability of abrasive grains getting into the same place, is substantiated. A grate with a new convex shape of the technological surface is proposed. Calculations have determined that in this case the service life of the grate increases up to 50%.
Keywords. Saw gin, grate, raw cotton, raw roller, wear, abrasive material, convex grate.

1 Introduction

In the technological process of processing raw cotton, the ginning operation is the basic one, since in this operation raw cotton as a multi-component product ceases to exist and is divided into fibers and seeds. The ginning operation in cotton mills is usually carried out after drying and cleaning of raw cotton. The essence of ginning is the capture and mechanical separation of fibers from seeds [1].

The strength (degree) of attachment of the fiber to the seeds is 2-3 times less than the strength of a single fiber, therefore, the fiber in the process of ginning comes off the seed, retaining its natural properties (length, fineness, degree of maturity, breaking load, etc.) [2].

The technological process of saw ginning is as follows: raw cotton entering the working chamber at the seed comb is captured by the teeth of rotating saws mounted on a shaft with inter-saw spacers, and moves to the workplace of the grate. The cotton flyers captured by the saw teeth are connected with other cotton flyers and inform them of the movement received from the saw teeth. As a result, the entire mass of cotton in the working chamber

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comes into rotation in the direction opposite to the direction of rotation of the saw blades. This is how a rotating raw roller is formed, which provides a continuous supply of cotton to the teeth of the saws, and, consequently, the continuous productive work of the gin [3, 4].

The strands of fibers captured by the teeth of the saws are dragged through the grate in the workplace, torn off from the seeds and transported to a removable device, where they are removed from the teeth of the saws with an air flow and transported along the neck to the battery fiber duct. The gap in the workplace of the grates is 2.8 - 3.2 mm (less than the minimum seed size), so the seeds are held in this place and carried away by the mass of the rotating raw roller until all the fibers come off [5-7].

As a result of the speed difference between the raw roller and the saw cylinder, a gap is formed in the raw roller, as a result of which the seeds do not accumulate, but fall out of the working chamber along the grate [3]. Due to the relatively low quality of the resulting product, it has to be purified at subsequent stages of cotton processing [4].

In this paper, a theoretical study of the process of wear of the technological surfaces of saw gin grates during their interaction with a raw roller to separate the cotton fiber from the seed was carried out in order to determine the influence of factors on the process of grate wear and substantiate a new form of the working technological surface of the grate

2 Materials and methods

Of great importance, for the normal course of the ginning process, is the saw cylinder and the gin grate. To optimize their parameters, a number of research works have been carried out, devoted to the calculation of the operating mode of the saw cylinder and the study of the position of the genie saw in the inter-grate gap of the grate [5-8].

The grate is one of the most important and time-consuming parts of the working chamber and its purpose is to pass saw blades through the gaps between the grates in the working chamber and free removal from it of the fiber torn from the seeds by the teeth of the saw gins.

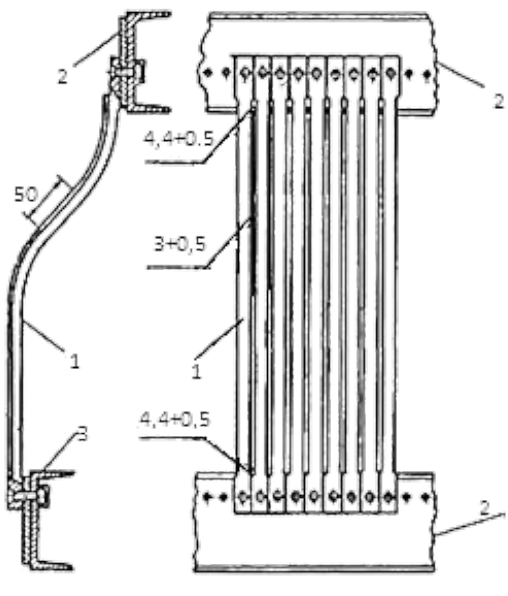

Fig. 1. Grid sieve.

In the working passage of the saw through the gaps between the grates, seeds should not pass along with the fibers and the grates should have a high degree of wear resistance here, over a length of 50 mm, to prevent their rapid development in the gaps during the passage of the fiber. Fig. 1 shows a grate, consisting of grates 1, lower bar 2, and upper bar 3.

Grid-irons are made by casting from cast iron grades Sch15 or Sch12. The wear resistance of the working part of the grate is obtained by bleaching cast iron during casting, installation in the area of the working part of refrigerators.

The wear of the technological surfaces of the grates observed during operation leads to a disruption in the flow of the technological process of ginning of raw cotton and the failure of the grates, which negatively affects the quality of the resulting cotton fiber and metal consumption.

In the previously published materials devoted to the study of the process of wear of the technological surfaces of grates, the conditions for the passage of fibrous mass with trash impurities through the inter-grate gap of the grate were mainly considered, and the wear of the grates was associated with the abrasive effect of such trash impurities [9, 10].

3 Results and discussion

Let us consider a scheme where the raw roller during operation is pressed against the grate by the force P1 from its mass (Fig. 2). Let us assume that the raw roller has the shape of a circle with a radius R0, and in operation, under the action of gravity P1, the roller will be at a distance rv from the center to the point of contact.

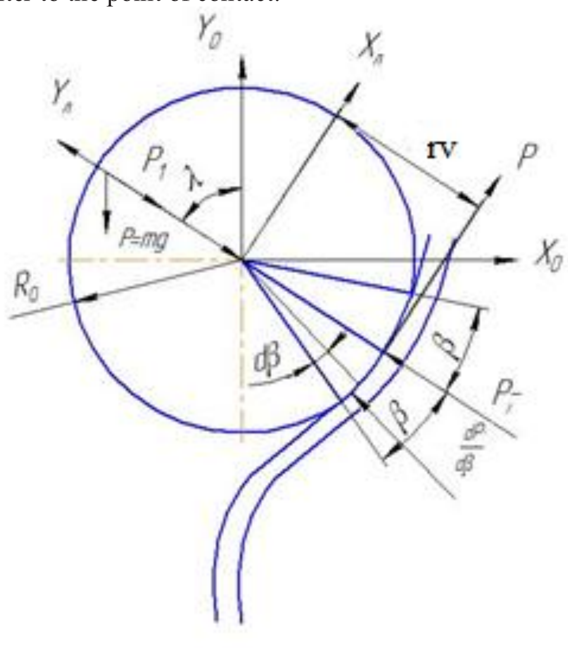

Fig. 2. Scheme of interaction of raw roller with grate.

The static radius of the raw roller depends on the radial stiffness of its material and strength. If we assume that the radial rigidity of a single sector of the raw roller in the place where it touches the grate is divided into small sections with a small angle *dβ* of the sectors and is reduced to a radius, the value is constant for this raw roller, i.e.:

$$C_x = \frac{1}{y}\frac{dP_1}{d\beta} = cont \qquad (1)$$

where y- is the elastic displacement of the raw roller in the direction of the axis; $\frac{dP_1}{d\beta}$ — distributed reaction at the contact area.

Due to the relatively low density of the raw bead and its large radius compared to the working area, we can assume that there is actually contact along the line of contact. In this connection, we can assume that in the contact area, wear will occur evenly, in proportion to the deformation, based on this, we calculate the force P1 using the following formula:

$$P_1 = \int_{-\beta_0}^{\beta_0} C_r \left(R_0 - \frac{r_v}{cos\beta}\right) d\beta \qquad (2)$$

where, β_0- is half the contact angle and $r_v(\beta_0)$- the value of the radius acting on a small area.

Integrating expression (2) we get:

$$P,= \ 2C_r\beta - 2C_r \text{In}(tgp + 1/\cos(\beta))$$

Based on expression (2), it is possible to calculate the reduced value of the raw bead stiffness when deformed by d_y. If the dimensions of the roller are taken smaller than the dimensions of the grate, we get the following:

$$C_r = \frac{P_k cos\varphi_0}{2r_c\left(\varphi_0 - cos\varphi_0 lntg\left(\frac{\pi}{4}+\frac{\varphi_0}{2}\right)\right)} \qquad (3)$$

From expressions (1) and (3) it is possible to determine the theoretical statistical characteristics of the raw roller. The wear of the grate, in the course of operation from the impact of the raw roller, occurs as a result of the abrasive deposited on it, which, adhering to it, is actually an abrasive wheel with a low density of abrasive grains on an elastic base. Charging a raw roller with an abrasive leads to an intensification of the wear process. In this case, micro-cutting will depend on the pressure on the grain and on the micro-geometry of the surface of the grate.

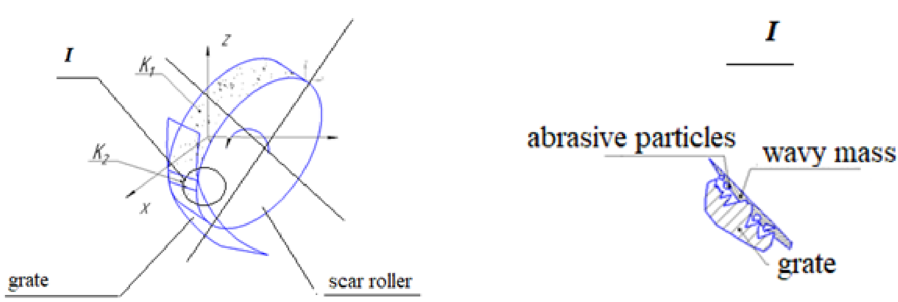

Fig. 3. Surfaces of interaction during wear.

First, let's define the contact surface of abrasive particles with the body K_1, represent its parameters in terms of $\Delta\zeta$, and select from it an elementary area K_2 with a parameter $\Delta\zeta$

(Fig. 3). The actual surface can be calculated through a plane perpendicular to the velocity vector $\eta_n = \Delta\zeta$ [11].

Fig. 4a shows a diagram of the interaction of the real surface of the raw roller with the real surface of the grate, and Fig. 4b shows a rod model of the interaction of a raw roller with a grate.

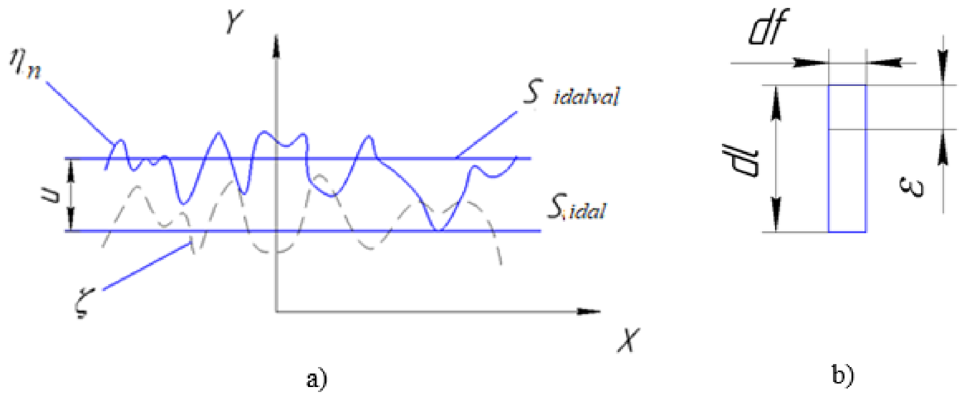

Fig. 4. Simulation of the process of interaction of raw roller with grate.

If we accept the stiffness of the roller C_1 is much less than the stiffness C_2 of the grate, and we express the hardness of the abrasive grain in terms of C_3, then the ratio of the stiffness of the system will look like this:

$$C_3 \gg C_2 \gg C_2 \quad (4)$$

The actual contact surface of the grate is expressed as the sum of the ideal surface and the random surface, recognized in terms of surface roughness and shape deviation, i.e.:

$$S_{fak} = S_{ideal} + S_{sluch} \quad (5)$$

where, S_{fak} - total contact area; S_{ideal} - ideal grate surface; and, S_{sluch} - random surface characterizing the roughness on the surface of the grate.

The description of the contact surface of the raw roller can be expressed as:

$$S_{fakval} = S_{idealval} + S_{sluchval} + u \quad (6)$$

where, $S_{idealval}$ -is the ideal surface of the raw roller outside the contact zone; $S_{sluchval}$ - random function depending on roughness; and, u - displacement of the ideal surfaces of the roller and the grate as a result of contact.

The function u is expressed by the following equation:

$$u = \begin{cases} 0, if, S_{idal} = S_{idalval} \\ \in [0, \infty] if, S_{idal} = S_{idalval} \\ \in [0, -\infty] if, S_{slucn} = S_{idalval} \end{cases} \quad (7)$$

Based on the developed models, we will determine the depth of abrasive penetration in the contact surface of the working area of the grate. In this connection, we resort to the rod model, which will allow us to describe random contact surfaces. The rod model (Fig. 4b) is a microprotrusion of an individual grain with sides *df* in the direction of length. The probability that there is an abrasive grain on it is small. It can be calculated by resorting to the distribution of contamination.

When the protrusions interact, under the action of a force, one body will deform relative to the other (since the grate is considered a solid body compared to a raw roller). In this case, the deformation can be determined from the expression:

$$\lambda = \begin{cases} \alpha(x_0) \text{ by } \alpha(x_0) \\ 0 \text{from } \alpha(x_0)<0 \end{cases} \quad (8)$$

where: $\alpha(x) = S_{fak} - S_{fakval}$

We will not take into account the deformation of the abrasive grains themselves, due to the fact that they are very hard, but we will take into account that their displacement will be equal to the elastic displacement in the material, similarly to the deformation of the rod model, which imitates the protrusion of the surface, the deformation of which is found from the force balance condition:

$$q_1(\varepsilon_0)\Delta x = (q_2(\lambda_0) + q_2(\varepsilon_0))\Delta x \quad (9)$$

Where $q_1(\varepsilon_0)$ and $q_2(\varepsilon_0)$can be chosen from the characteristics of deformable materials. According to expression (9), the real deformation $\varepsilon(x_0)$ at the point $x_0$is obtained from the implicitly given equation:

$$q_1(\varepsilon_0) - q_2(\lambda_0 - \varepsilon_0) = 0 \quad (10)$$

Having obtained the solution (10) in an explicit form, with respect to the real deformation, we determine:

$$\varepsilon(x_0) = F[\lambda] \quad (11)$$

According to the expression obtained, it is possible to find the deformation at any point of contact between the raw roller and the grate, for which the data must be substituted into expression (8) and thus the penetration surface can be determined.

An analysis of the ratio of deformation to the actual contact area makes it possible to determine the dependence of the probabilistic characteristics of the grate profile within the contact zone on the coordinates formed by the microprotrusions.

To determine the specific pressures and components of the wear forces, it is necessary to determine the actual contact area *S(u)* of the raw roller with the grate, which is determined from the expression:

$$S(u) = \int \theta(x)dx \quad (12)$$

where, $\theta(x)$ - are the areas of setting the function, which can be given by the following equation:

$$\theta(x) = \begin{cases} 1 \text{ from } \varepsilon(0)>0 \\ 0 \text{ from } \varepsilon(0)\leq 0 \end{cases} \quad (13)$$

Based on the foregoing, it can be indicated that in order to reduce wear, it is possible to increase their area, thus reducing the likelihood of contact of the grate with the abrasive contact of the grate with a raw roller. In this case, it is necessary to take into account the density of distribution of abrasive particles in the raw roller.

If we assume that the contamination of raw cotton entering the saw gin chamber will be equal to δ %, the relative total contamination of the abrasive material by layers will be λ %, and taking into account the values of the integration areas, we can obtain a generalized formula for the probability of penetration distribution over contact areas from the following expression:

$$P_3 = P_{dop}\delta\lambda \tag{14}$$

To increase the service life of the grates, it is possible to increase the area, this can only be done by increasing the surface area of the working area of the grate, and this can be achieved due to the vicious section - making it convex or concave, then the actual width of the contact of the grate with the raw roller will increase by - in this case, expression (19) will take the following form:

$$P_3 = \frac{P_{dop}\delta\lambda}{\Delta l} \tag{15}$$

That is, the probability that the impact of cartoonized abrasive grains on the surface of the raw roller again in the same place will decrease. Possible grate shapes in cross section are shown in Fig. 5.

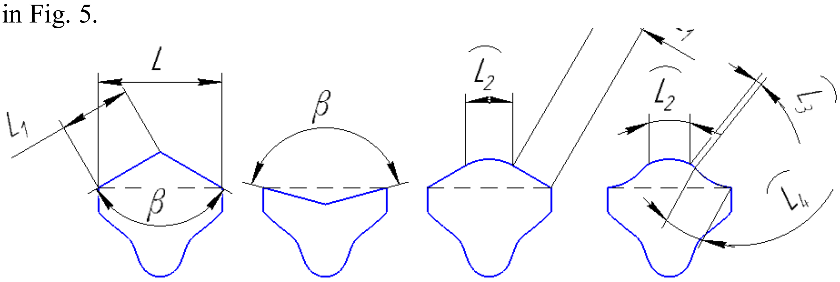

Fig. 5. The proposed varieties of the grate in cross section.

It can be seen from the figure that the actual increase in the surface can be achieved by changing the shape, since the actual width of the contact increases, but the width of the grate itself remains the same. Of the options we proposed, we settled on a grate with a convex surface, as it is technologically simple to manufacture, compared with a concave grate.

At the same time, we stopped at a convex grate, where at the top there is a radius connecting the side surfaces, which are exponential generators. Thus the actual contact width will be the maximum and the actual contact width can be calculated using the following formula:

$$H = \frac{\pi R\alpha}{180} + 2\int\sqrt{1-(f'(y))^2}\,dy = c + 2\sqrt{1-e^{2y}}dy = \frac{\pi R\alpha}{180} + ln\sqrt{\frac{\sqrt{e^{2y}+1}-1}{\sqrt{\sqrt{e^{2y}+1}+1}}} + \sqrt{e^{2y}+1} \tag{16}$$

Based on expression (16), it is possible to calculate the area of contact between the raw roller and the grate using the following formula

$$\Delta S = S\left(\frac{H}{L} - 1\right) \tag{17}$$

On average, the area increases by 13%. At the same time, with an increase in the area, the pressure on the grate from the raw roller decreases, therefore, the incoming load on the rod model, which we considered above, will decrease, in addition, the penetration force will change due to a change in the angle of the component with this surface (Fig. 6). Although the rod model is essentially a point, it is still an abrasive particle: it has a geometric parameter and, in fact, it can be represented as a body lying on an inclined plane, where the angle of inclination of the plane is tangent to the generatrix, and this is essentially the derivative of the generatrix function and therefore Let's take the angle of inclination equal to 45^0, so the generatrix is exponential.

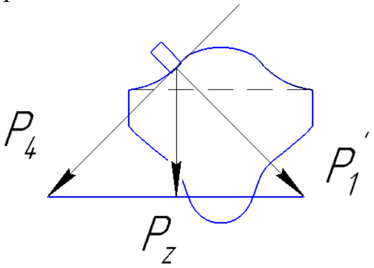

Fig. 6. Calculation scheme for the action of forces on an abrasive particle with an exponentially forming inclined surface of the working area of the grate.

It can be seen from the diagram that P_1 the force can be calculated using the following formula:

$$P_1 = P_z cos\alpha \approx 0.71P_z \tag{18}$$

And this means that the force of pressing the abrasive particle to the grate will decrease by 30%, the probability of wear of the grate surface will also decrease, and taking into account the increase in area by 13%, it turns out that the load will decrease by 34%.

Let's consider the nature of the grate wear caused by the grinding of abrasive particles into the raw roller (Fig. 7). Let us assume that the abrasive particle is held by the fibers, it has a size slightly larger than the surface roughness of the grate, once in the working area, the particle touches the top of the surface roughness of the grate, held by the fiber, it is carried along by it further, while it bends the top of the roughness, bending the top releases the particle further, and itself under the action of elastic forces returns back, thus, with repeated impact on the top, the latter experiences multiple cyclic loading and breaks off.

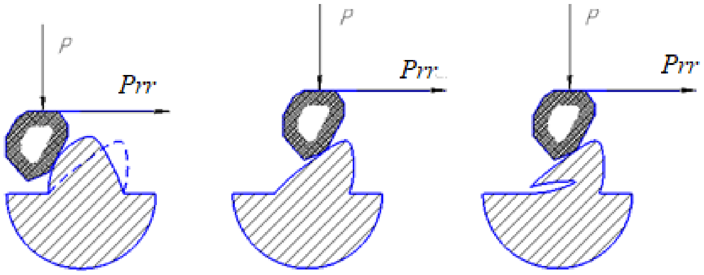

Fig. 7. Scheme of abrasive wear.

Given the parameters of the roughness Rm and the particle retention force in the raw roller (rr) P, to simplify the calculations, we assume that it has the shape of a cone with a diameter at the base:

$$\sigma = \frac{M}{W_x} = \frac{32PRm}{\pi d^3} \tag{19}$$

where, M - bending moment and Wx - moment of resistance; σ-stress.

Let's determine the amount that the top can withstand using the formula:

$$N = N_0 \left(\frac{\sigma_{max}}{\sigma}\right)^m = N_0 \left(\frac{\sigma_{max}\pi d^3}{32Ph}\right)^m \tag{20}$$

Taking into account the expression (15) for the probability of a repeated hit of a particle in the same place and (17) for the pressing force of the model, and also, knowing the frequency of rotation of the raw roller, the calculation method can determine the time spent on the demolition of one vertex using the following formula:

$$t = \frac{\pi dn}{1000} kN_0 \left(\frac{32Ph}{\sigma_{max}\pi d^3}\right)^m \tag{21}$$

4 Conclusion

Substituting the numerical values into formula (21), we obtained that the service life of a grate with a convex surface is 42% longer than that of a conventional grate. Based on the results obtained as a result of a theoretical study of the process of wear of the technological surfaces of saw gin grates, the use of grates with a new convex shape of their technological surfaces is proposed.

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