Influence of Belt Transmission Parameters on the Stiffness of the Elastic Elements of the Driven Pulley and Tensioning Roller

Dilrabo Mamatova, Anvar Djuraev

Abstract. The article presents the ways of wide use of belt drives with variable and gear ratios in the drive mechanisms of technological machines. The scheme and principle of operation of the belt drive with composite driven pulleys and a tension roller are given, the necessary variable driving modes of the driven pulley are allowed. Analytical methods for determining the stiffness of the elastic elements of the driven pulley and tensioning roller are given. Based on the analysis of the plotted dependencies, the recommended values of the parameters of the considered belt drive for technological machine drives are substantiated. Production experiments and test results of the 1-CCC (Cotton Cleaning Complex) machine with the recommended belt drive justified the system parameters.

Keywords: belt drive, composite pulley, driven, tensioning pulley, elastic element, bushing.

I. INTRODUCTION

Used in technological machines, belt drives absorb load fluctuations to a certain extent and do not allow transferring these vibrations entirely to the machine's electric drive [1,2,3,4]. Often there is insufficient absorption by the transmission belt in machines, where the fluctuations of loads in the working bodies occur with a large amplitude and frequency. For example, in sewing machines at high speeds, uneven rotation of the main and lower shaft, as well as the motor shaft, can lead not only to a fast drive failure, but also skip stitches, thread breaks, decrease in machine performance, etc.

It should be noted that the development and use of belt drives with a variable gear ratio for efficiency in their use in mechanical engineering is important. In addition, it can be used as an element of drives for various machines in which the rotation of the driven shaft with variable angular speed, especially vibratory machines, machines for processing fibrous and bulk materials, as well as some machines in the light and textile industries that lead to the intensity of technological processes.

At the same time, the service life of the belt drive is to some extent reduced to 5.0~10%, but the efficiency and obtaining quality products with high productivity will increase many times.

Effective belt drive. At the same time, in order to expand the kinematic capability and controllability of changes in the angular velocity of the driven link, the transmission design has been improved, an additional kinematic connection has been created between the output pulley and the tensioning roller. In the proposed belt drive, leading and driven pulleys, covering the belt,
tensioning composite roller with an elastic element located at an eccentric position with respect to the axis of rotation with different thickness around the roller, the output pulley is also made of a composite hub, elastic element and rim. In this case, the elastic element has a shape in the form of a triangular (multifaceted) prism along the outer surface, which is in contact with the same shape of the inner surface of the rim, which ensures the variability of the transmission ratio of the drive gear, thereby changing the angular velocity of the driven pulley. In addition, the output pulley is kinematically connected to the shaft of the tension roller through an additional belt, covering respectively additional pulleys rigidly connected to the shafts of the tension roller and the driven pulley [5].

The belt drive contains the leading *1* and the driven *2* pulleys, covering their belt *3* and the tension roller *4*. The composite tension roller *4* contains the rim *5*, the elastic element *6* and the hub *7*, as well as a pulley *8* rigidly connected to the hub *7* and an additional pulley *9* The hub *10* of the driven pulley *2* which also has a rim *11* and a multifaceted elastic element *12*. Pulleys *9* and *8* are covered by a belt *13* (Fig. 1).

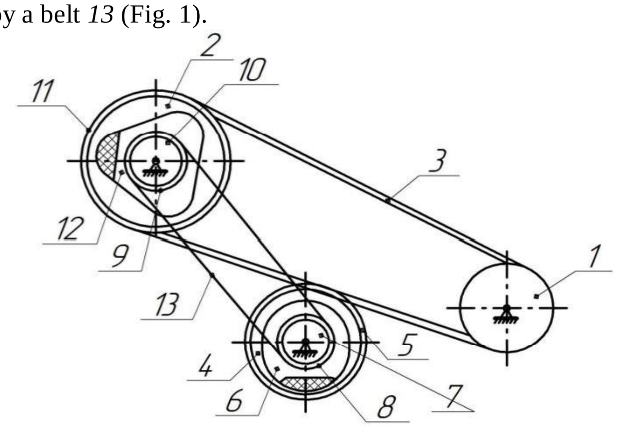

Fig. 1. Belt drive with variable gear ratios

Belt drive works as follows. The drive pulley *1* by means of the belt *3* imparts a rotational movement to the driven pulley *2*, and by means of an additional belt *13* a pulley *8*, which, by rotating the tension roller *4*, causes a cyclic change in the tension of the belt *3*.

Since the gear ratio of the belt drive is a function of the relative slip of the belt *3*, and the relative slip is a function of the tension of the belt *3*, a change in the tension leads to a change in the gear ratio of the transmission, i.e. to the corresponding change in the angular velocity of the driven pulley *2*.

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In addition, during operation, the position of the rim *5* of the tension roller *4* changes relative to the hub *7* due to the deformation of the annular elastic element *6*, depending on the width of the latter. This leads to a cyclic change in the force of the rim *5* on the belt *3*, which provides a change in the gear ratio of the transmission.

Similarly, the position of the rim *11* of the driven pulley *2* relative to the hub *10* due to the deformation of the multifaceted (in the drawing of the triangular) annular elastic element *12* also changes.

This actually will change the position of the rim *11* relative to the axis of rotation of the driven pulley *2*, also leading to an additional change in the tension of the belt *3*. Thus, the driven pulley *2* will perform a rotational movement according to the complex law of change in angular velocity.

For additional coordination and control of this law of change in the angular velocity of the pulley *2*, it is additionally associated with a composite belt pulley *4*, consisting of a belt *13*, pulleys *9* and *8*, rigidly connected with the respective shafts of the pulley *2* and the tension roller *4*. In the process, through this the transfer of virtually all changes in the angular velocity of the driven pulley *2* are transmitted to the tension roller *4*, and this in turn, and the tension of the belt *3*. In this case, the output link *2* receives the necessary laws of change in angular velocity, allowing inte classify any processes.

The angular velocity of the driven pulley *2* is a complex function, i.e.

$$\dot{\varphi}_2 = f(\dot{\varphi}_1, \dot{\varphi}_4,)$$

where, $\dot{\varphi}_1, \dot{\varphi}_2, \dot{\varphi}_4$- the angular velocities of the corresponding pulleys;

u_{12}, u_{24} - the gear ratio of the belt transmission.

We have developed a number of designs of belt transmission with variable parameters [6,7,8,9].

There are methods for calculating belt transmissions with constant parameters [10,11,12,13,14]. But, there are no methods for calculating belt gears with variable parameters.

II. METHOD. ANALYSIS OF THE INFLUENCE OF BELT TRANSMISSION PARAMETERS ON THE DEFORMATION CHARACTERISTICS OF THE ELASTIC ELEMENT OF THE COMPOSITE DRIVEN PULLEY

We have developed a belt drive design, driven pulley, which is made as an integral part including a hub, a rim and an elastic element between them. The elastic element will sufficiently absorb the load oscillations on the driven pulley shaft, which is directly connected with the working body of the technological machine. The design provides tensioning roller with an elastic sleeve. Due to the deformation of the elastic sleeve of the tensioning roller, the belt tension will be changed cyclically. This leads to a cyclical change in the resultant force deforming the elastic element of the composite driven pulley in the axial direction. From this it is important to choose the stiffness of the elastic element of the driven pulley transmission. Significant oscillations of the rim of the driven pulley in the axial direction can lead to a change not only in the center distance of the transmission, but also reduce the durability of the belt.

Therefore, the analysis of the influence of the belt transmission parameters on the deformation characteristics of the elastic element of the composite driven pulley is necessary when calculating the drives of technological machines. When the belt interacts with the driven pulley, the following forces arise: tension forces in the belt drive branches $\bar{F}_1$ and $\bar{F}_2$; centrifugal force of the belt in the zone of interaction with the rim of the driven pulley $\bar{F}_c$; generalized deforming force from the rim of the driven pulley on the elastic element of the pulley $\bar{Q}$ (see. Fig. 2).

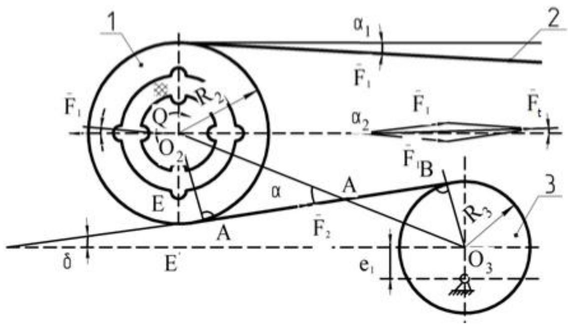


Fig. 2. The design scheme of a belt drive with a composite driven pulley and an eccentric tensioning roller

Provided the system is balanced:

$$\bar{F}_1 + \bar{F}_2 + \bar{F}_C + \bar{Q} = 0 \qquad (1)$$

where, F_t - total, $\bar{F}_1$, $\bar{F}_2$- tension force of the leading and driven branches; $\bar{F}_C$- centrifugal force of the belt in the zone of the grasp of the belts of the rim of the driven pulley; $\bar{Q}$- generalized deforming elastic element force.

Projecting (1) on the horizontal axis we have:

$$F_C \cdot cos\gamma - F_1 \cdot cos\alpha_1 - F_2 \cdot cos\theta = Q \cdot cos\xi \qquad (2)$$

where, ξ, α_1, Q, γ are the angles between the corresponding force vectors and the horizontal axis.

Considering that the tension roller has eccentricity:

$$\theta = \theta_{ave} \pm \Delta\theta = \theta_1 + 2\Delta\theta \qquad (3)$$

where, θ_{ave}- the average angle θ ; θ_1 the minimum value of the angle θ

$\Delta\theta$ - angle deviation θ .

The maximum deformation of the elastic element of the driven pulley in axial direction occurs at the maximum value of the angle θ, at the location of the tension roller eccentricity in the vertical axis above the axis of rotation:

$$\theta = \alpha - \frac{\pi}{2} + arccos\frac{O_2E^{/}}{O_2O_3} \tag{4}$$

To determine the angle α, consider ΔO_2CA a similar one ΔO_3BC:

$$\frac{R_3}{R_2} = \frac{O_3C}{O_2C} = \frac{O_2O_3 - O_2C}{O_2C};$$

$$O_2C = \frac{R_2 \cdot O_2O_3}{R_3 + R_2}$$

From ΔACO_2 we have:

$$\alpha = arcsin \cdot \frac{R_2 + R_3}{O_2O_3} \tag{5}$$

where, R_2, R_3 - the radius of the driven pulley and tensioning pulley.
Received (5) delivering in (4) we have:

$$\theta = arcsin\frac{R_2 + R_3}{O_2O_3} - \frac{\pi}{2} + arccos\frac{O_2E^{/}}{O_2O_3} \tag{6}$$

When the circumferential force P_0 in the transmission (load), the tension of the belt legs are determined according to [6] of;

$$F_i = P_0\frac{e^{f\alpha p}}{e^{f\alpha p} - 1}; F_i = P_0\frac{P_0}{e^{f\alpha p} - 1};\ F_1 + F_2 \leq 2S_0 \tag{7}$$

where, $f -$ the coefficient of the belt friction on the surface of pulley; $\alpha -$ the belt angle of small pulley.
With alternating tension of the belt, taking into account the received by us, we can write down

$$F_1 = \frac{P_0}{2} + \frac{EF}{e^{f\alpha p} - 1}[1 - \frac{e_1\cos\varphi'_3 + \sqrt{R^2{}_3 - e_1^2\sin^2\varphi'_3}}{e_1\cos\varphi_3 + \sqrt{R^2{}_3 - e_1^2\sin^2\varphi_3}}]$$

$$F_2 = -\frac{P_0}{2} + [1 - \frac{e_1\cos\varphi'_3 + \sqrt{R^2{}_3 - e_1^2\sin^2\varphi'_3}}{e_1\cos\varphi_3 + \sqrt{R^2{}_3 - e_1^2\sin^2\varphi_3}}] \tag{8}$$

The centrifugal force of the belt according to [6] is determined from the expression:

$$F_c = \frac{\rho_p \cdot h_p \cdot b_p}{g}\alpha'\vartheta_p^2 \tag{9}$$

where, ρ_p - the specific belt; b_p, h_p - width and thickness of the belt; α' - the angle of grasp in the driven pulley; φ_3, φ'_3 - components of the angle of girth of the belt tension roller; E, F - modulus of elasticity and the cross-sectional area of the belt; α_p - wrap angle of the drive belt pulley; ϑ_p - linear belt speed; g - acceleration of gravity.

Considering that the angular speed of the driven pulley is variable due to the eccentricity of the tensioning roller, according to [6] we have:

$$\omega_2 = \frac{\omega_1 R_1}{R_2} \cdot \frac{e_1\cos\varphi'_3 + \sqrt{R_3^2 - e_1^2\sin^2\varphi'_3}}{e_1\cos\varphi_3 + \sqrt{R_3^2 - e_1^2\sin^2\varphi_3}} \tag{10}$$

The obtained expressions (6), (8), (9), (10) substituting in (12) we finally obtain the formula for calculating the force that deforms the elastic element of the driven pulley:

$$Q = \frac{\omega_1^2\rho_p \cdot h_p \cdot b_p \cdot \alpha' \cdot R_1^2\cos\gamma}{g\cos\xi}\left(\frac{e_1\cos\phi'_3 + \sqrt{R^2{}_3 - e_1^2\sin^2\phi'_3}}{e_1\cos\phi_3 + \sqrt{R^2{}_3 - e_1^2\sin^2\phi_3}}\right) -$$

$$-\frac{P_0}{2\cos\xi}\left[\cos\alpha_1 - \cos\left(\arcsin\frac{R_2 + R_3}{O_2O_3} - \frac{\pi}{2} + \arccos\frac{O_2E'}{O_2O_3}\right)_1\right] - \frac{EF}{(e^{f\alpha p} - 1)}[1 -$$
$$-\frac{e_1\cos\phi'_3 + \sqrt{R^2{}_3 - e_1^2\sin^2\phi'_3}}{e_1\cos\phi_3 + \sqrt{R^2{}_3 - e_1^2\sin^2\phi_3}}] \cdot \left[\cos\alpha_1 + \cos\left(\arcsin\frac{R_2 + R_3}{O_2O_3} - \frac{\pi}{2} + \arccos\frac{O_2E'}{O_2O_3}\right)\right] \tag{11}$$

The stiffness coefficient of the elastic element of the composite driven pulley of the belt drive is determined by:

$$C_p = \frac{1}{\delta_в}\left\{\frac{\omega_1^2\rho_p \cdot h_p \cdot b_p \cdot \alpha' \cdot R_1^2\cos\gamma}{g\cos\xi}\left(\frac{e_1\cos\phi'_3 + \sqrt{R^2{}_3 - e_1^2\sin^2\phi'_3}}{e_1\cos\phi_3 + \sqrt{R^2{}_3 - e_1^2\sin^2\phi_3}}\right) -\right.$$

$$-\frac{P_0}{2\cos\xi}\left[\cos\alpha_1 - \cos\left(\arcsin\frac{R_2 + R_3}{O_2O_3} - \frac{\pi}{2} + \arccos\frac{O_2E'}{O_2O_3}\right)_1\right] - \frac{EF}{(e^{f\alpha p} - 1)}[1 -$$
$$\left.-\frac{e_1\cos\phi'_3 + \sqrt{R^2{}_3 - e_1^2\sin^2\phi'_3}}{e_1\cos\phi_3 + \sqrt{R^2{}_3 - e_1^2\sin^2\phi_3}}] \cdot \left[\cos\alpha_1 + \cos\left(\arcsin\frac{R_2 + R_3}{O_2O_3} - \frac{\pi}{2} + \arccos\frac{O_2E'}{O_2O_3}\right)\right]\right\} \tag{12}$$

From the obtained (12) it is possible to calculate the stiffness coefficient of the elastic element of the driven pulley, based on the results of which you can choose the necessary material (rubber brand), providing the required working conditions of the working body of the technological machine. With the initial calculated values of the parameters of a belt drive in a 97 grade brand sewing machine. The calculated value of the torsional stiffness of the elastic sleeve of the driven pulley is (3.5–4.0)·10^2 Nm/rad, while the corresponding tires are 3820MBCS [15].

III. STUDY OF THE EFFECT OF BELT TRANSMISSION PARAMETERS ON THE STIFFNESS OF THE ELASTIC ELEMENT OF THE COMPOSITE TENSIONING ROLLER

It is known that the traction ability of a belt drive with a tensioning device is greater than in gears without tensioning devices [7]. Usually in belt drives with constant belt tension, the gear ratio is constant.

While the tension of the leading and driven branches are also constant. In technological machines, the load in the belt drive will be variable [8, 6]. In this case, the tension of the branches of the belt will also be changed.

To withstand the belt tension within certain limits and increase its durability, we recommend a belt drive, a tension roller, which is made integral with an elastic element.

At the same time, the outer sleeve of the tensioning roller is made of rubber with certain stiffness. It is important to determine the stiffness of the elastic sleeve of the composite tensioning roller depending on the parameters of the belt drive. (Fig.3, *a*) diagram of the recommended belt drive is shown, from which it can be seen that the elastic sleeve *5* somewhat quenches the oscillations of the driven belt branch. The degree of interaction of the belt *3* with the sleeve *5* depends on the transmission parameters, especially the stiffness of the sleeve *5* of the tension roller *4*. It is known from [8] that the initial tension of the belt is determined from the expression:

$$S_0 = \frac{\gamma_p \cdot \text{в}_p \cdot h_p}{g} \vartheta^2 \qquad (13)$$

where, γ_p - the specific belt, в_p - the belt width, h_p - the belt thickness, ϑ - the peripheral speed.

According to the design scheme (see Fig.3, *b*), we determine the strength of the roller interaction with the belts, taking into account (13):

$$Q_p = \frac{\omega_3^2 R_3^2 \cdot \gamma_p \cdot \text{в}_p \cdot h_p}{g \cos\Delta_p} \cdot \left(\sin\alpha_3' + \sin\alpha_3''\right)$$

where, Δ - the deformation of the elastic sleeve in the vertical direction.

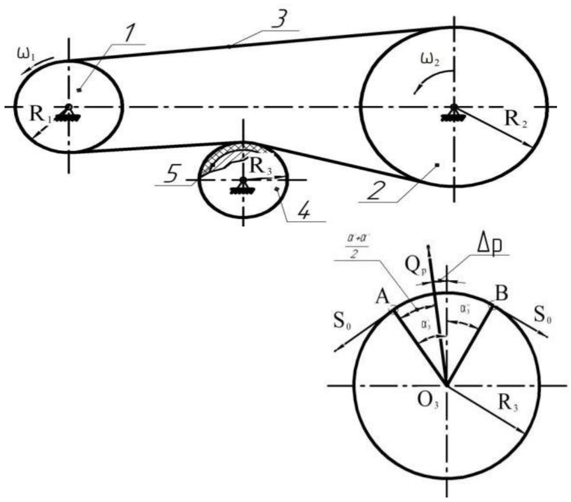


Fig. 3. Calcualated scheme of belt drive

a - belt drive with a composite tension roller

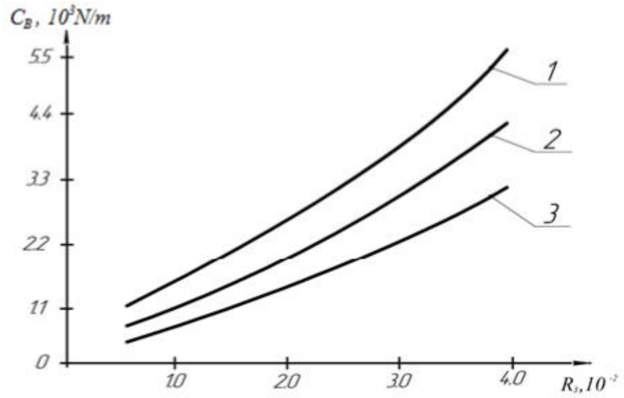
where, 1-driving pulley, 2 - driven pulley,
3 - belt, 4 - composite tension roller, 5 - elastic sleeve.

b - design diagram of the interaction of the belt with the tensioning roller.

where, α_3', α_3'' - the components of the angle of the girth of the belt elastic sleeve tensioning roller; Δ_p - the angle between the force Q_p and the vertical axis of the belt.

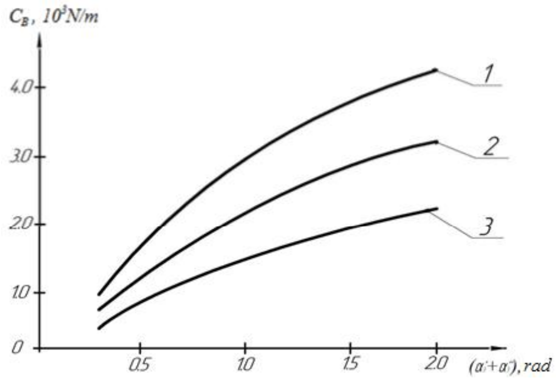
When the belt interacts with the elastic sleeve of the tension roller, the elastic sleeve deforms in the vertical direction. On this basis, it is possible to determine the stiffness coefficient of the elastic sleeve when the belt is acting on the sleeve by force $Q_p' = -Q_p$ In the process of belt drive, as can be seen from the expression (14), the stiffness coefficient of the elastic sleeve of the composite tension roller depends mainly on the radius and speed of rotation of the roller and the parameters of the belt, the angle of wrap and e.t. (Fig.4) and (Fig.5) presents the obtained graphical dependences of the change in the stiffness coefficient of the elastic sleeve on the change in the radius of the tensioning roller and the angle of girth of the tensioning roller of the transmission belt.

$$C_{\text{в}} = \frac{\omega_3^2 R_3^2 \cdot \gamma_p \cdot \text{в}_p \cdot h_p}{\Delta g \cos\Delta_p} \cdot \left(\sin\alpha_3' + \sin\alpha_3''\right) \qquad (14)$$



where, 1-($\alpha_3' + \alpha_3''$)=1,65; 2-($\alpha_3' + \alpha_3''$)=1,23;
3-($\alpha_3' + \alpha_3''$)=0,568

Fig. 4. Dependences of the change in the stiffness coefficient of the elastic bushing of the tensioning roller on the variation of its radius and the belt wrap angle of the surface of the elastic bushing



1-Δ=0,5·10^{-3} m; 2-Δ=1,0·10^{-3} m; 3-Δ=1,4·10^{-3} m.

Fig. 5. Dependences of the change in the stiffness coefficient of the elastic bushing of the tensioning roller on the variation of the wrap angle of the belt surface of the elastic bushing

Analysis of the graphs obtained shows that with an increase in the tension roller radius, the increase in the stiffness coefficient is non-linear.

Thus, with an increase in the radius of the tensioning roller from $1.0 \cdot 10^{-2}$ m to $3.85 \cdot 10^{-2}$ m, the rigidity of the elastic bushing of the tensioning roller increases from $0.85 \cdot 10^{3}$ N/m to $5.65 \cdot 10^{3}$ N/m.

This is because with an increase in the radius of the tensioning roller, the force of interaction of the elastic sleeve with the belt increases, and therefore the stiffness of the sleeve increases accordingly. Increasing the angle of the belt around the surface of the elastic transmission sleeve also leads to an increase in the stiffness of the elastic sleeve according to a nonlinear pattern.

The nonlinearity of the graphs is also due to the fact that with a change in ($\alpha_3' + \alpha_3''$) the angle of force effect changes accordingly. When ($\alpha_3' + \alpha_3''$) =1.65 is happy and ω_3 = 44.3 s^{-1} the stiffness coefficient reaches $3.92 \cdot 10^{3}$ N/m. Important are the choice of values of the stiffness coefficient of the elastic sleeve for small values of the radius of the roller and the largest values of the angle of wrap. At the same time, for the considered belt drive, the recommended parameters are: ($\alpha_3' + \alpha_3''$) = 1.1÷ 1.3 rad, R_3 = (2.5÷ 3.5) $\cdot 10^{-2}$ m; C_B = (4.1÷ 5.3) $\cdot 10^{2}$ N/m [16, 17, 18, 19].

IV. RESULTS AND DISCUSSION

Analysis and results of production tests of a fiber material cleaner with a recommended belt drive

On the basis of theoretical sound parameters, a prototype belt was manufactured and installed in the drive of the cotton cleaner from small litter. Production tests were carried out in the 1st and 2nd production lines of raw cotton purification in 1-CCC cleaners.

The initial contamination of raw cotton has a significant effect on the cleaning effect. During the tests, the humidity and initial contamination of the compared sections of the cleaning of production lines were maintained in the same range. Analyzes were carried out at the factory laboratory.

Table I

Indicator, %	After upgraded section of the unit in the 1st line 1-CCC	After the serial unit in the 2 nd line 1-CCC
Humidity, %	10,1/8,1	10,1/8,1
	9,5/8,5	9,5/8,5
	9,8/8,4	9,8/8,4
Debris, %	4,6/2,75	4,6/3,3
	4,6/2,65	4,6/3,07
	4,3/2,55	4,3/2,8
After cleaning, cleaning effect, %	40,7	34,3
	38,8	33,2
	40,4	36,5

Note: the experiments were carried out in triplicate. The table shows the average values of indicators.

During the tests, the recommended design of the belt drive of the drum drive in the raw cotton cleaner from small litter of the 1-CCC brand showed high reliability and stability of operation. The results of comparative technological tests on the flow lines of cleaning with serial and experienced designs of the cleaning sections of the 1-CCC units are shown in Table I.

The results of the comparative technological production tests on the 1st and 2nd lines of cleaning 1-CCC Pskent cotton factory of the Tashkent region. The test results showed that the cleaning effect compared with the existing version of the drum drive increases by an average of 7.2%. When using the recommended drive belt drive, additional torsional vibrations of the drum barrel occur, effective removal of trash is ensured, and the process of inhibition of cotton is eliminated.

The summary of defects decreased by 1.18%, mechanical damage by 1.37%, and free fiber by 0.42%.

V. CONCLUSION

An efficient belt drive for variable transmission ratios is recommended. Formulas are obtained for determining the stiffness of the elastic elements of the pulley and tensioning roller. Dependences of the change in the stiffness coefficient of the elastic bushing of the tension roller on the variation of its radius and the belt wrap angle of the surface of the elastic bushing In this case, with an increase in the radius of the tensioning roller, the force of interaction of the elastic sleeve with the belt increases, and therefore the stiffness of the sleeve increases accordingly. Increasing the angle of the belt around the surface of the elastic transmission sleeve also leads to an increase in the stiffness of the elastic sleeve according to a nonlinear pattern. Production tests obtained positive results in the purification of fibrous material. Recommendations have been developed for the wide use of belt drives with composite pulleys and elastic elements in drives of technological machines.

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