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Study of the Formation of a Dense Structure of OE Yarn

Arabov Jamoliddin Sadriddinovich, Gafurov Jaxongir Kabulovich, Gofurov Kobil Gofurovich, Kamoliddinzoda Nuriddin Ergashova Jamila

Ph.D student, Tashkent Institute of Textile and Light Industry
DSc, Professor, Tashkent Institute of Textile and Light Industry
Professor, Tashkent Institute of Textile and Light Industry
Cabinet manager, Tashkent Institute of Textile and Light Industry
Master, Tashkent Institute of Textile and Light Industry

ABSTRACT: This article is devoted to the formation of a OE yarn uniform in structure, which is examined by studying the features of the formation of a fibrous ribbon from fibers of finite length. For this, the structure of the yarn, depending on the maximum width of the ribbon, is divided into free, dense and overlapping structures. The conditions conducive to the formation in the groove of the rotor of the fibrous ribbon of the maximum width, from which the yarn of a dense structure is obtained, which ensures the best quality of the yarn. The factors affecting the formation of the ultimate width of the fibrous ribbon in the trough of the rotor are studied. These factors are twist, linear and specific density of the yarn, the length of the processed fiber, the diameter of the rotor. The dependences of changes in the limiting width of the fibrous ribbon on these factors in combination with other factors are determined. It has been established that the maximum width of the fibrous ribbon is most influenced by twisting of yarn and the speed of the rotor. The least influence is exerted by the length of the fiber and the diameter of the rotor, which is recommended to take into account when developing OE yarn from fibers of finite length.

I. INTRODUCTION

It is known that OE yarn differs in properties and structure from yarn of other spinning methods [1,2]. The properties of the yarn mainly depend on the parameters of the fiber ribbon and the process of yarn formation in the trough of the rotor. A number of works [3-19] are devoted to the study of the structure and properties of OE yarn. They discuss the conditions for the formation and twisting of yarn, as well as factors affecting the properties of the yarn. The presence of an outer Layer, which wraps around the inner Core layer [1,2], and is not involved in the strength of the yarn, is noted. P.R.Lord considers the structure of OE yarn and notes that it is necessary to more fully understand the structure of yarn. The difference in structure occurs due to the conditions of the formation of yarn [3]. He notes that when folded, the ends of the fibers take the form of hooks, i.e. the straightness of the fibers is lost. This reduces the effective fiber length in the yarn. In addition, the fibers in the yarn are arranged in the form of a spiral with a variable radius and therefore the tension of the fibers is lower. All these factors form a loose, and weaker yarn. The work was one of the first to study the structure and properties of OE yarn. The influence of the structure, i.e. twist and density of the yarn as well as the arrangement (arrangement) of the fibers in it (fiber migration) on the properties of the yarn [4-6]. Migration is studied, i.e. yarn structure using a Hi-scope Questar microscope system [5]. In this case, half step and the maximum height of the arcuate segment along the spatially located labeled fiber were measured. The results show that torsion is unevenly distributed along the radial direction of rotation of the thread. The results can serve as a basis for further study of rotor design and mechanical properties of yarn. Indian scientist A. Bazu analyzes the results of studies of the structure of yarn of various spinning methods, and its influence on the properties of the yarn obtained [6].

The influence of rotor speed, rotor diameter and carding conditions on the properties of yarn was studied [7-10]. In [7], as the rotor speed increases, the tenacity of the yarn decreases and the elongation drops sharply and there is no dependence. With increasing rotor speed or rotor diameter, the number of neps increases markedly, moreover, a higher centrifugal force in the rotor zone causes a change in the properties of the yarn. The reasons for the increase in Neps, which are associated with a high rotor speed and the presence of the outer layer, are noted. Scratching does not provide any significant improvement in yarn quality. It is noted that OE spinning provides the best use of fibrous waste.

The difference in the tenacity of carded and combed OE yarns from one cotton fiber is very small at high speeds of the rotor, which is associated with an increase in the outer layer of yarn. The dependences of the tenacity of the yarn on the factors influencing it — rotor speed and groove shape for various linear densities of yarn — are determined. It is shown that

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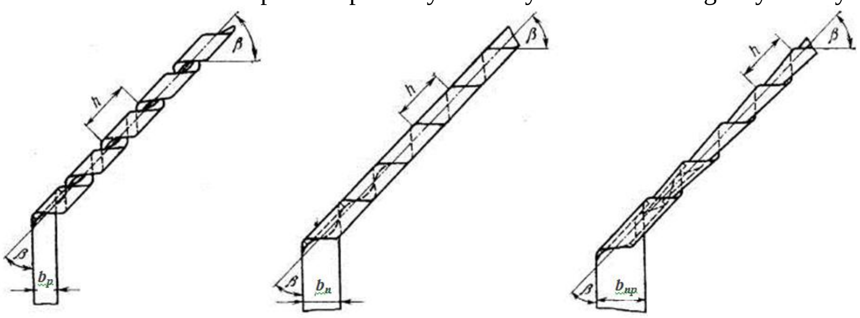
the thinner the rotor channel, the higher the tenacity [8]. The influence of the rotor parameters on the yarn properties is also considered in [9–11]. In all the listed works, standard indicators are evaluated, i.e. tenacity depending on the structure of the yarn. In contrast to this, in a number of works, instead of the tenacity, the stress-strain state of the yarn is studied based on the theory of elasticity [12-16]. To improve the stress-strain state of the OE of the yarn, a movable navel has been proposed, due to which the structural unevenness of the yarn is reduced [17, 18]. It was found that increasing the speed of the rotor on an OE machine leads to an improvement in the stress-strain state of the yarn, i.e. the tensile curve becomes steeper and Young's modulus of elasticity increases. It should be noted that the listed studies do not take into account the conditions for the formation of high-quality yarn. In contrast, Roglena [19] based on [12] gives the condition for obtaining high-quality OE yarn from a fibrous ribbon formed in the trough of a rotor. This condition is to control the limit width of the fibrous ribbon formed in the rotor groove, which provides a dense structure of the resulting yarn. The yarn formed from a narrow ribbon has a free structure, and overlapped yarn is formed from a wider ribbon (Fig. 1). The commonality of these structures is that the axis of the ribbon is directed along the helical line, and the axis of the yarn is considered offset from the axis of the ribbon. The structure of the yarn is helical and uneven compared to perfectly twisted yarn and has a large asymmetry.



a - free **b - dense** **c - overlapped**

Fig. 1. The structure of the OE yarn

As a result of the helical arrangement of the ribbon along the axis of the yarn, a certain void is formed and its cross section is excessively uneven. In addition, it is noted that due to the low density of the fibers along the void, the unevenness in the properties of the yarn can be high. This position, i.e. the formation of yarn from an uneven screw-like arrangement of the ribbon is observed at free and closed positions. Therefore, it is indicated that a uniform helical arrangement can only be with a dense structure. With this in mind, the factors determining the limiting width of the ribbon b_n in the trough of the rotor, which provides a dense yarn structure, i.e., yarns of the best quality, were studied. For one revolution of the rotor, a coil of height h and width b_n is formed from the ribbon. The side of the AB triangle ABC is equal to the width of the ribbon b_n formed in the trough of the rotor and the formula for its determination is given in [19]. To determine the dependences of the maximum width of the ribbon, affecting the formation of a yarn of a dense structure, the conclusion of its formula is given below.

Theoretical part: One round of yarn of height h is formed in one revolution of the rotor (Fig. 2) from the ribbon in its groove. The triangle ABC (Fig. 3) is located in the structure of this turn, from which the width b_n, can be determined as the sine of the acute angle β, i.e.

$$\frac{b_n}{h} = \sin \beta \tag{1}$$

Where , β – the angle of inclination of the coil to the longitudinal axis of the yarn, deg.

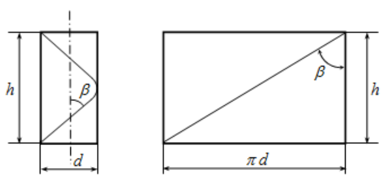


Fig. 2. The development of one turn of torsion

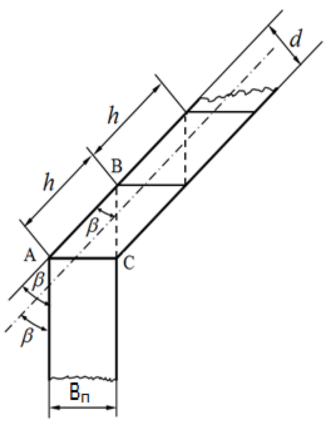


Fig. 3. The scheme of formation of yarn from a fibrous ribbon

A turn of a newly formed yarn is described by its diameter and height of a turn. Helix angle of β, shown in fig. 2 is the torsion angle.

The ratio of the adjacent leg to hypotenuse is the cosine of the acute

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angle β, and taking into account the fact that the square of the hypotenuse is equal to the sum of the squares of the legs gets the following expression

$$\frac{h}{\sqrt{(\pi d)^2 + h^2}} = \cos\beta \tag{2}$$

Considering that the ratio of the opposite leg $\pi d\kappa$ to the adjacent leg h is the tangent of the angle β (Fig. 2), determine the ribbon width b_n (Fig. 3), i.e.

$$\frac{\pi d}{h} = \mathrm{tg}\beta \tag{3}$$

The value of the ribbon width b_n is determined from formula (1), i.e.

$$b_n = h \cdot \sin\beta \tag{4}$$

To obtain the interconnection of the parameters of the two figures, the sine of the acute angle β is replaced by the product of the tangent and cosine of this angle, i.e.

$$\sin\beta = \frac{\sin\beta}{\cos\beta} \cdot \cos\beta = \mathrm{tg}\beta \cdot \cos\beta \tag{5}$$

and get the value of the ribbon width b_n in the form:

$$b_n = h \cdot \sin\beta = h \cdot \mathrm{tg}\beta \cdot \cos\beta \tag{6}$$

By interconnecting (1), (2), (3), then substituting the result in (6), the value of the limiting width of the dense structure b_n is determined

$$b_n = h \cdot \frac{\pi d}{h} \cdot \frac{h}{\sqrt{(\pi d)^2 + h^2}} = \frac{h}{\sqrt{(\pi d)^2 + h^2}} = \frac{h}{\sqrt{1 + \frac{h^2}{(\pi d)^2}}} \tag{7}$$

It can be seen from the formula that the height of the torsion coil and the diameter of the yarn affect the width of the fibrous ribbon. If you analyze the formula, you can see that the width of the ribbon b_n also depends on other factors. One of them is the twist-number of torsions K per one meter of yarn, which is determined by the formula.

$$K = \frac{1000}{h} \tag{8}$$

Hence, the height of the torsion coil h is

$$h = \frac{1000}{K} \tag{9}$$

This is the technological formula of twist, and its kinematic formula is determined by the ratio of the rotor speed n_κ to the linear yarn production speed ϑ_T, i.e.

$$K = \frac{n_\kappa}{\vartheta_T} \tag{10}$$

Taking into account (10), the torsion coil height has the form: $h = \frac{1000 \cdot \vartheta_T}{n_\kappa}$ (11) and the width of the ribbon b_n (7), providing a dense structure of yarn taking into account the value of its diameter, determined through the formula $d = 0{,}0357\sqrt{\frac{T}{\rho}}$ (12) can be written:

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$$b_n == \frac{1000 \cdot \vartheta_T}{n_\kappa \sqrt{1 + \left(\frac{8921 \cdot \sqrt{\rho} \cdot \vartheta_T}{n_\kappa \cdot \sqrt{T}} \right)^2}} \qquad (13)$$

where, n_κ – rotor speed, min $^{-1}$;
ϑ_T– yarn delivery speeds, m / min;
T– linear density of yarn, tex
ρ – yarn density, g/m^3
it is possible to write

$$b_\pi = \frac{1000}{K \sqrt{1 + \left(\frac{8921\sqrt{\rho}}{K \cdot \sqrt{T}} \right)^2}} \qquad (14)$$

taking into account $K = \frac{n_\kappa}{\vartheta_T}$;

where, K– twist of yarn, t/m;

From formulas (13) and (14), it is easy to see that the maximum ribbon width b_n depends on the speed of the rotor, the linear density of the yarn, the release speed, the density of the yarn and its twist.

It is known [1] that OE yarn has a two-layer structure consisting of inner and outer layers. The inner layer determines the mechanical properties, i.e. resists stretching. The outer layer is involved in the formation of the linear density of the yarn, but does not resist stretching, i.e. not involved in the formation of the mechanical properties of yarn. This explains the reduced tenasity of the OE yarn. Therefore, when determining the maximum width of the ribbon, it is recommended to take into account the capture coefficient, determined by the ratio of half the length of the fiber to the perimeter of the rotor,

i.e. $К_3 = \frac{l}{2\pi D}$ (15). Given this coefficient, the linear density of the inner layer $T_{ст}$ differs from the linear density of the produced yarn, i.e.

or $T_{ст} = T(1 - К_3)$ или $T_{ст} = T\left(1 - (0{,}159 \cdot l/D)\right)$ (16)

Thus, the maximum ribbon width for the formation of a dense structure yarn is determined by the formula

$$b_n = \frac{1000}{K \cdot \sqrt{1 + \left(\frac{8921 \cdot \sqrt{\rho}}{K \cdot \sqrt{T \cdot (1 - (0{,}159 \cdot \frac{l}{D}))}} \right)^2}}$$

or

(17)

$$b_n == \frac{1000 \cdot \vartheta_T}{n_\kappa \sqrt{1 + \left(\frac{8921 \cdot \vartheta_T \sqrt{\rho}}{n_\kappa \cdot \sqrt{T} \cdot (1 - (0{,}159 \frac{l}{D}))} \right)^2}}$$

The practical part. In order to control the spinning parameters of a yarn of a dense structure, the dependences of the marginal ribbon width b_n on the factors influencing it were determined.

Moreover, the values of the factors varied within the limits of their practical application, i.e., the linear density of the yarn from 20 tex to 50 tex, the rotor speed from 7500 sec^{-1} to 15000 sec^{-1}, the number of torsions from 950 t/m to 1150 t/m, fiber length from 24 mm to 38 mm, rotor diameter from 24 mm to 66 mm, yarn density from 0.9g/m^3 - up to 1.3 g/m^3. Formulas (17) were solved with respect to the factors affecting the maximum ribbon width b_n using the Maple computer program, and the corresponding dependencies were obtained, shown in Figures 4-8.

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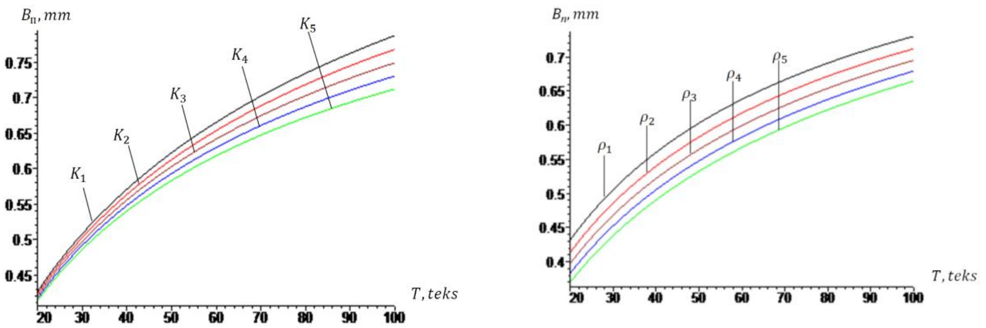

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Fig. 4. Dependence of the limiting width of the $b_{п}$ ribbon on the linear density of yarn T for various values of its twist K (a) and density (b). *K_1=950;, K_2=1000; K_3=1050; K_4=1100; K_5=1150 t/m,*

$\rho_{1=}0{,}9; \rho_{2=}1{,}0; \rho_{3=}1{,}1; \rho_{4=}1{,}2; \rho_{5=}1{,}3$ g/m^3.

As it can be seen from the Figure 4a, with an increase in the linear density of the yarn, the limiting width of the ribbon, providing a dense structure of the yarn, increases. The ribbon width for small values of linear density and twist is smaller, and with an increase in linear density, the width of the ribbon increases regardless of the twist values. The maximum width of the ribbon with increasing linear density of the yarn at different densities increases along the corresponding curves. It should be noted that the values of b_n below the limit width of the ribbon contribute to the production of yarn of a free structure, and above the limit width correspond to the overlapped structure of the yarn.

The rotor speed is one of the dominant factors affecting the limit width of the ribbon formed in the rotor groove. The dependence of the maximum ribbon width on the rotor speed is shown in Fig. 5.

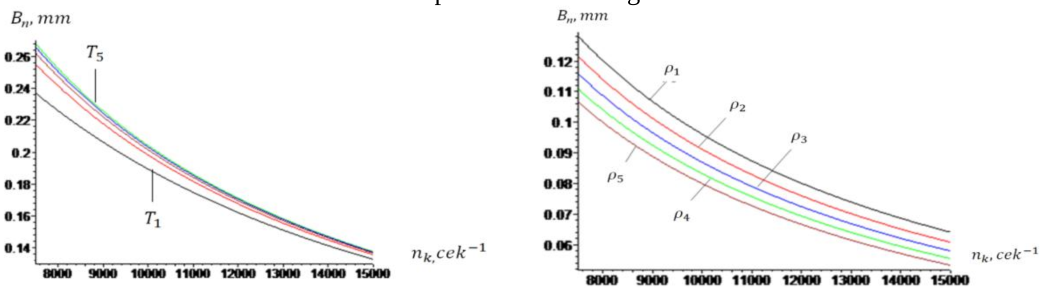

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Fig. 5. The dependence of the maximum width of the $b_{п}$ribbon on the rotor speed

n_k at different values of the linear density of the yarn T (a) and the density of the yarn ρ_i(b)

T_1=20; T_2=40; T_3=60; T_4=80; T_5=100tex, $\rho_{1=}0{,}9; \rho_{2=}1{,}0; \rho_{3=}1{,}1; \rho_{4=}1{,}2; \rho_{5=}1{,}3$g/m^3.

It is noticeable that with a twofold increase in the rotor speed ($7500 \div 15000$ cek^{-1}) and an increase in linear density from 20 tex to 100 tex and the density of the yarn being produced from 0.9 g/m^3 to 1.3 g/m^3, the maximum width of the fibrous ribbon b_n to obtain a dense yarn structure in the trough of the rotor is reduced. Moreover, with an increase in the linear density of the yarn, the marginal width of the ribbon narrows.

Similarly, the effect of twist on the marginal width of the ribbon is studied to obtain a dense yarn. With an increase in the number of torsions from 950 t/m to 1150 t/m, i.e. with a 1.25-fold increase, the limiting ribbon width b_n decreases proportionally by 1.25 times for all yarn densities, as can be seen in Fig.6a. With an increase in the number of torsions, the limiting width of the ribbon at all linear densities of yarn partially narrows (Fig. 6b).

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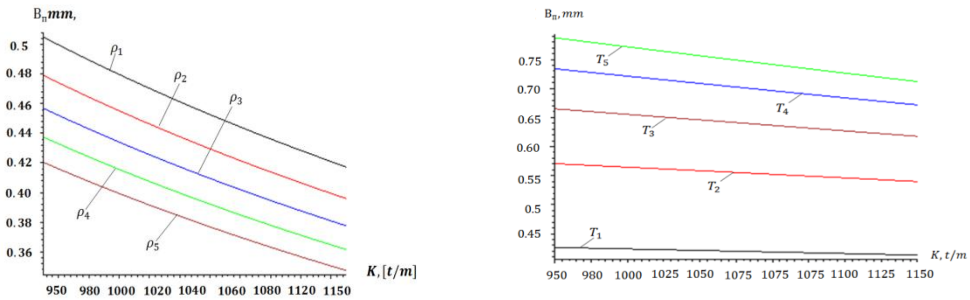

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Fig. 6. Dependence of the maximum width of the ribbon $b_п$ on the twist K for various yarn densities and linear yarn densities (b) T_1=20; T_2=40; T_3=60; T_4=80; T_5=100 tex.

The figure shows that in the study range, the maximum ribbon width b_n with a minimum twist (950t/m) varies from 0.42 mm to 0.52 mm. With increasing yarn twist, the maximum width of the ribbon at all yarn densities decreases in a straight line. As a result of the twist increase, the ribbon width decreases as a result of fiber compaction in the trough of the rotor, which contributes to an increase in the density of the formed yarn ρ (Fig. 6.a). On the other hand, reducing the width of the ribbon helps to improve the conditions for the distribution of torsion at the open end of the yarn formed in the trough of the rotor. It should be noted that as a result of increasing the length of the twisted open end of the yarn, there is a decrease in the proportion of fibers in the inner layer and an increase in the proportion of fibers in the outer layer of yarn. Thus, the structure of the yarn is likely to change. To achieve dense yarn production, it is necessary to comprehensively use the above dependencies.

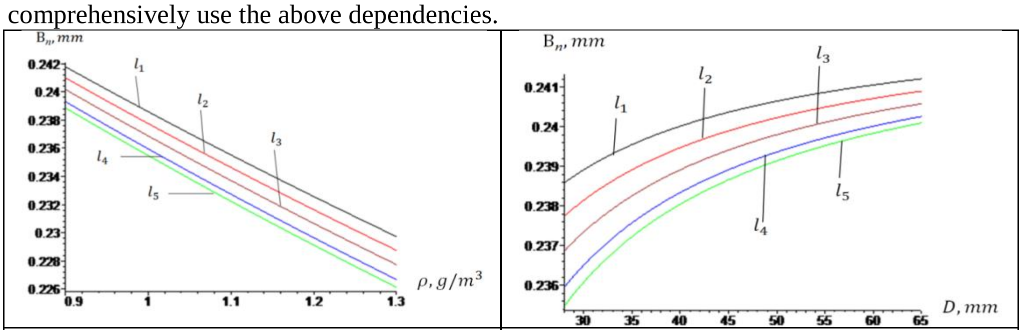

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Fig. 7. Dependence of the limiting width of the ribbon $b_п$ on the density of the yarn ρ (a) and the diameter of the rotor D (b) for various fiber lengths l·

$l_1=24; l_2=28; l_3=32; l_4=36; l_5=40mm$;

It is seen that with increasing density of the yarn, the limiting width of the ribbon for forming yarn from different fiber lengths decreases in a straight line (Fig. 7, a). With an increase in the rotor diameter, the ribbon width increases along the curve (Fig. 7, b). Based on the analysis of the patterns, it can be said that below the limit width of the ribbon, a free yarn structure is formed, and above, a yarn of an overlapped structure is formed. This position must also be taken into account in the complex for the production of high quality yarn.

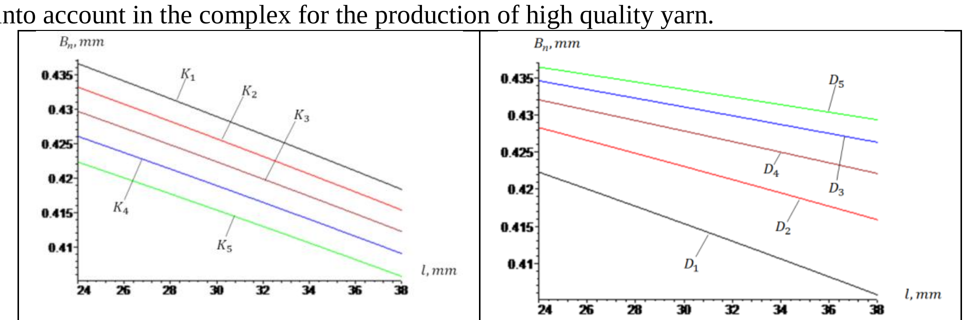

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Fig. 8. Dependence of the maximum ribbon $b_n$width on the fiber length l at different twist of the yarn K (a) and the diameter of the rotor D (b).

K_1=950; K_2=1000; K_3=1050; K_4=1100; K_5=1150t/m, D=28;36;44;52;60mm

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The effect of fiber length on the limiting width of the ribbon at different twists (Fig. 8a) and rotor diameter (Fig. 8b) was studied.

With an increase in fiber length from 24 mm to 38 mm, i.e. 1.6 times the width of the ribbon b_n in the trough of the rotor for all twist values increases only 1.06 times. In other words, we can say that an increase in length by 60% leads to an increase in the marginal width of the ribbon by only 6%, i.e. 10 times less. This suggests that the fiber length affects the width of the ribbon slightly. Below the graph l_5, it turns out to be free, and above l_1, an overlapping yarn structure is obtained.

Finally, according to the formula (15), the rotor diameter also affects the ribbon width, with an increase from 24 mm to 60 mm (2.5 times), b_n expands only 1.04 times (4%) (Fig. 8b) , then this factor has a minimal impact.

Conclusion. The factors influencing the marginal width of the ribbon, which ensures the formation of a tight mechanical structure OE yarn, which provides high quality indicators, are investigated. The dependences of the maximum ribbon width b_n of the linear density of yarn T, the rotor speed $n_к$, the twist of the yarn K, the density of the yarn ρ,, the diameter of the rotor D_k and the fiber length l are determined for various combinations of factors. It has been established that the maximum influence on the limiting width of the ribbon has the rotor speed and twist of the yarn, and the fiber length and the diameter of the rotor have a minimal effect. The linear density of the yarn affects the ultimate width of the ribbon non-linearly. To obtain high-quality OE yarn in practice, it is recommended to use the dependences of the marginal width of the ribbon on the factors influencing it, taking into account their mutual combinations.

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