EFFECT OF THE YARN STRUCTURE ON THE TENSION DEGREE WHEN INTERACTING WITH HIGH-CURVED GUIDE

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Abstract: *The research of the yarn structure effect on the tension degree when interacting with guides and operative parts of weaving looms and knitting machines, which have a high curve in the area of contact with the yarn, has established the mechanism of the yarn tension increase after it passes the guide due to a change in the guide's curve radius and friction forces in the contact area. It has been proved that the increase in tension is explained by a change in the angle between the yarn and the high-curved guide. At the same time, the actual angle for filament yarn and spun yarn will be higher than the nominal one due to yarn diameter deformation in the contact area, while the angle for monofilament yarns will be less than the nominal one due to the bending modulus. Based on the experimental research, regression relationships between the output tension and the radius of guide surface curve were obtained for polyamide filament yarns of various twists and monofilament yarns. The analysis of the research results made it possible to establish ultimate values of the guide curve radius at which tension will have minimal degree. This will enable minimization of the yarn tension during its processing on the production equipment. This leads to a decrease in yarn breakages, an increase in the production equipment performance by reducing its downtime, improving the quality of the fabric and knitted garments produced. This suggests a practical value of the proposed technology solutions. The latter, in particular, are related to determining optimal geometric dimensions of guides and operative parts of weaving looms and knitting machines, at which the output tension will have the minimal required degree. Therefore, there is a good reason to claim the possibility of guided management of the process of changing the yarn tension in weaving looms and knitting machines by choosing geometrical dimensions of high-curved guide for specific yarn types.*

Keywords: *monofilament yarns, filament yarn, yarn tension, high-curved guides, braid angle, radius of the guide curve.*

1 INTRODUCTION

To date, the range of natural-fiber filter fabric produced by the textile industry does not always meet production requirements. In addition to filter fabrics, many industries use non-ferrous metal mesh as a filter material, which, like natural-fiber fabrics, are non-durable when used. This leads to reduction in the performance of equipment, increase in downtime associated with the replacement of used filters, and this, in turn, leads to an increase in the net cost of the products produced.

Modeling of the yarn processing process in weaving looms and knitting machines is made in order to study the process of yarn interaction with the operative part surfaces in the production equipment [1-3, 7, 10, 13, 14]. The shape of the operative part surfaces is similar to the cylindrical surface [4]. Therefore, when carrying out the experiment, cylindrical rods of different diameters were used as guide way surfaces [4, 5].

Figure 1 shows the diagrams of yarn interaction with a cylindrical guide way. In the first case (Figure 1a), the diameter of the cylindrical guide D substantially exceeds the yarn diameter d:

$$D >> d,\ D = 2R,\ d = 2r \quad (1)$$

where R is the radius of the cylindrical guide and r is the radius of the yarn cross section [2, 5].

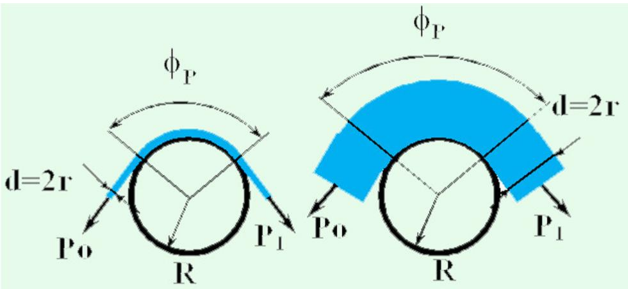


Figure 1 Diagrams of yarn interaction with a cylindrical guide way: a) the case when the diameter of the cylindrical guide way substantially exceeds the yarn diameter; b) the case when the diameter of the cylindrical guide way is comparable to the yarn diameter

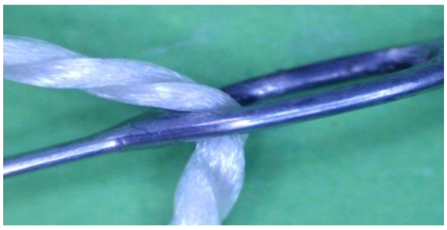
In the second case (Figure 1b), the diameter of the cylindrical guideway is comparable to the yarn diameter [1, 4].

This type of interaction takes place when the yarn comes into contact with the heddle eye surfaces of weaving loom frames (Figure 2a), when it comes into contact with the surfaces of knitting machine needles (Figure 2b - polyamide filament yarn 29 tex; Figure 2c - polyamide filament yarn 29x2 tex).

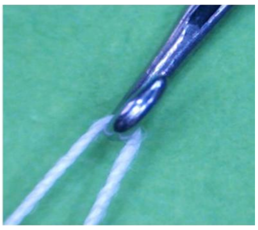
The yarn tension *P* after the cylindrical guide for the case when *D>>d* is determined by the formula [1-3]:

$$P = P_0 e^{\mu \varphi_P} \quad (2)$$

where *P* is the yarn tension behind the cylindrical guide, P_0 is the yarn tension in front of the cylindrical guide [2], μ is the constant of friction [1, 3], φ_P is the nominal value of the angle between the yarn and the guide [4, 5].



a)



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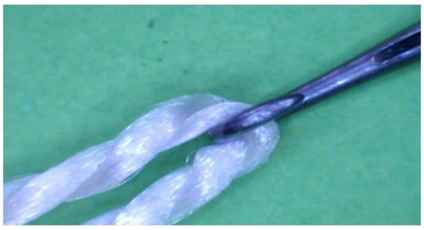

c)

Figure 2 Yarn interaction with operative parts of weaving looms and knitting machines: a) yarn interaction with heddle eye surfaces of weaving loom frames; b) yarn interaction with the surface of knitting machine needles (polyamide filament yarn 29 tex); c) yarn interaction with the surface of knitting machine needles (polyamide filament yarn 29x2 tex)

Figure 3 shows the diagram how the yarn tension behind the cylindrical guide depends on the cylindrical guide radius. The formula (2) does not consider actual conditions of interaction between the yarn and the cylindrical guide when the diameter of the cylindrical guide surface is comparable to the diameter of the yarn $D \approx d$ [1, 4, 5].

In this case, it is necessary to consider the yarn diameter deformation in the contact area. Furthermore, the tension degree has impact on the bending modulus. It is obvious that the increase in tension is explained by a change in the braid angle between the yarn and the high-curved guide.

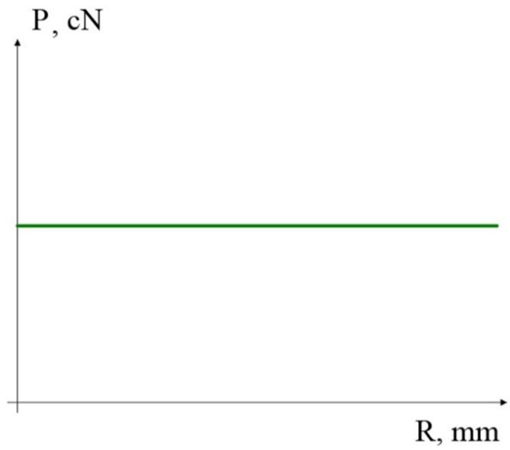

Figure 3 Relationship between the yarn tension behind the cylindrical guideway *P* and the cylindrical guideway radius *R*

At the same time, the actual angle for filament yarn and spun yarn will be higher than the nominal, due to the yarn diameter deformation in the contact area, while the angle for monofilament yarns will be less than the nominal due to the bending modulus. The bending value for filament yarns and spun yarn depends on the degree of their twist [6].

When the yarn twist increases, it's bending modulus increases too. This can be explained by the fact that with an increase in twist, specific pressure between individual filaments increases, which leads to an increase in friction forces that prevent elementary fiber movements during flexure.

Thus, the challenge remains urgent as to determine the effect of the yarn structure on the tension degree behind the guide surface, when the condition is met. When creating a design of the experiment, it is necessary to consider the direction of the relative shift of the friction surfaces [3, 5], the yarn tension before the guide way [8, 11, 12, 15], the structure of the yarn [5, 8, 9], the value of the nominal angle between the yarn and the guide surface [1, 2, 4, 5]. The bending modulus for monofilament yarns and filament yarns, which have different twists, is a crucial factor when determining the degree of tension [1, 3, 6]. Such restrictions required the development of a conceptually new experimental setup pattern, which differs from those designed earlier [2, 3, 16].

2 MATERIALS

Polyamide filaments were selected as raw materials for the experiment. These filaments are the same as those used to produce filter fabric and mesh. Filter fabrics made of polyamide filament yarns and monofilament yarns have a number of advantages over natural-fiber fabrics and non-ferrous mesh. Mesh made with polyamide monofilament yarns, unlike mesh made with non-ferrous metals, has a stronger durability, is resistant to corrosion, can be cut more efficiently and is much cheaper.

For industrial testing, raw materials and equipment were used to carry out experiments in the production environment of "TECHNOFILTER" Mechanical Fabric Factory, Private Joint-Stock Company. Filter mechanical fabrics and meshes of are widely used in mining, sugar, dairy and chemical industries.

For the first set of experiments (variant 1) polyamide monofilament yarn 36.3 tex was chosen, with the diameter of d=2r=0.200 mm, the bending modulus of B=14.0 cN/mm^2. Figure 4a shows a general view.

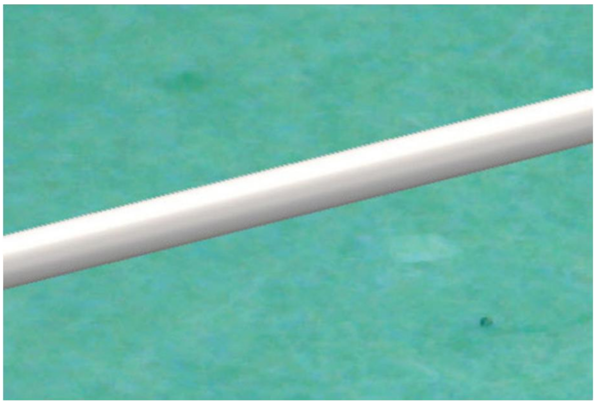

Figure 4 Diagrams of polyamide monofilament yarn 36.3 tex, with the diameter of d=2r=0.200 mm, the bending modulus of B=14.0 cN/mm^2

One of the factors that influences the yarn tension is its twist and specific pressure between individual filaments, which result in an increase in friction. When the yarn twist increases, it's bending modulus increases too. This can be explained by the fact that with an increase in twist, friction forces increase, which prevents elementary fiber movements when bended. So the minimum value of the bending modulus for polyamide filament yarn 29 tex equals to 1.3.10^{-5} cN/mm^2, when the twist tends to zero, and the maximum value equals to 11.2 cN/mm^2, when the twist reaches a critical value and the yarn breaks. The yarn bending modulus value has its impact on the actual value of the angle of the guide surface, the value of which determines the yarn tension. That is why, three series of experiments for polyamide filament yarns of various twist were carried out.

For the second series of experiments (variant 2), polyamide filament yarn 29 tex was chosen, which consisted of 80 filaments, flat twist Kr=100 twists/meter, the nominal diameter d=2r=0.199 mm, the bending modulus B=2.6.10^{-5} cN/mm^2. Figure 5 shows a general view of the yarn.

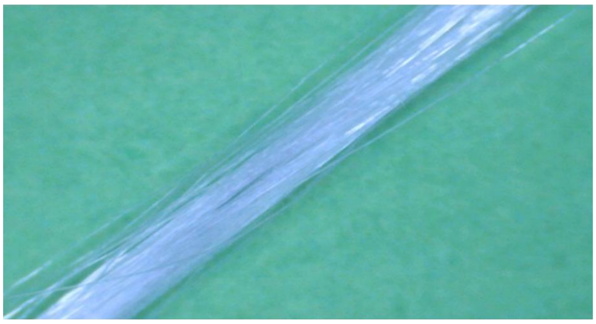

Figure 5 Diagram of polyamide filament yarn 29 tex consisting of 80 filaments, flat twist Kr=100 twists/meter, the nominal diameter d=2r=0.199 mm, the bending modulus B=2.6.10^{-5} cN/mm^2

For the third series of experiments (variant 3), polyamide filament yarn 29 tex was chosen, which consisted of 80 filaments, flat twist Kr=400 twists/meter, the nominal diameter d=2r=0.200 mm, the bending modulus B=4.0.10^{-2} cN/mm^2. Figure 6 shows a general view of the yarn. The value of the bending modulus for the polyamide yarn of medium twist is 1,000 times higher than that of the flat-twisted polyamide yarn [6].

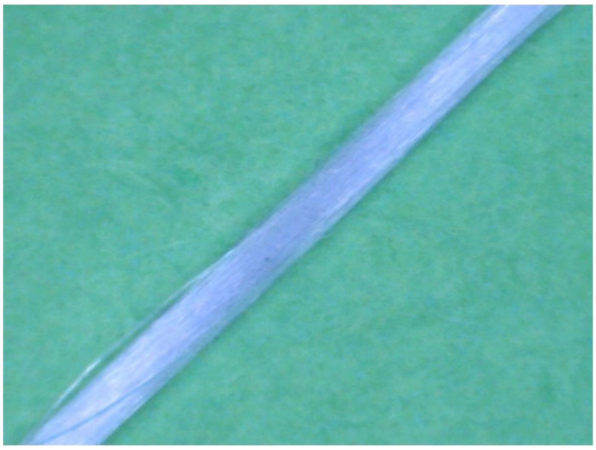

Figure 6 Diagram of polyamide filament yarn 29 tex consisting of 80 filaments, flat twist Kr=400 twists/meter, the nominal diameter d=2r=0.200 mm, the bending modulus B=4.0.10^{-2} cN/mm^2

For the fourth series of experiments (variant 4), polyamide filament yarn 29 tex was chosen, which consisted of 80 filaments, flat twist Kr=800 twists/meter, the nominal diameter d=2r=0.208 mm, the bending modulus B=0.22 cN/mm^2. Figure 7 shows a general view of the yarn.

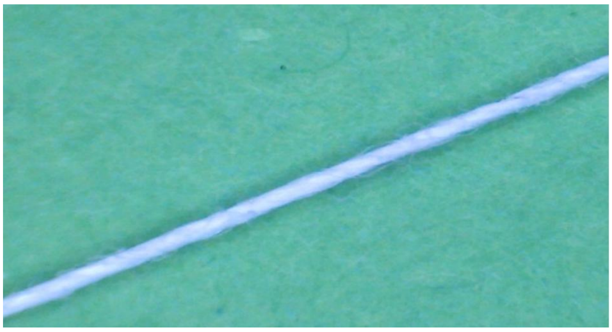

Figure 7 Diagram of polyamide filament yarn 29 tex consisting of 80 filaments, flat twist *Kr*=800 twists/meter, the nominal diameter *d*=2*r*=0.208 mm, the bending modulus *B*=0.22 cN/mm^2

The four variants used yarns with almost equal diameter made of the same material (polyamide), but with a different structure: monofilament yarn; filament yarn.

3 METHODS

For each of the 4 yarn variants, an orthogonal second-order plan for three factors was designed and implemented in the paper [4, 5]. The general view of the regression equation to determine the joint effect of the yarn tension prior it goes to the cylindrical guide P_0, the radius of the cylindrical guide R and the nominal value of the angle φ_P on the yarn tension behind the cylindrical guide P, is as follows:

$$P = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{23}x_2x_3 + \\ + b_{11}x_1^2 + b_{22}x_2^2 + b_{33}x_3^2. \quad (3)$$

The range of factor variation in the equation (3) was determined by the actual yarn processing conditions. In the blinded values: the yarn tension before it goes to the cylindrical guide P_0 was indicated as x_1; the cylindrical guide radius R was indicated as x_2; the nominal value of the braid angle between yarn and guide φ_P was indicated as x_3.

Values and interval of variation of the yarn tension before the yarn goes to the cylindrical guide way P_0 and the cylindrical guide way radius R are determined based on the conditions of interaction with the cylindrical guide surface. Two main criteria may be distinguished here. Let's analyze them in detail.

The first criterion refers to the choice of such an acceptable degree of the tension P_0 of bending resistance of the yarn before it reaches the guide surface, which will ensure the necessary angle for the cylindrical guide. Figure 8 shows the designed diagram.

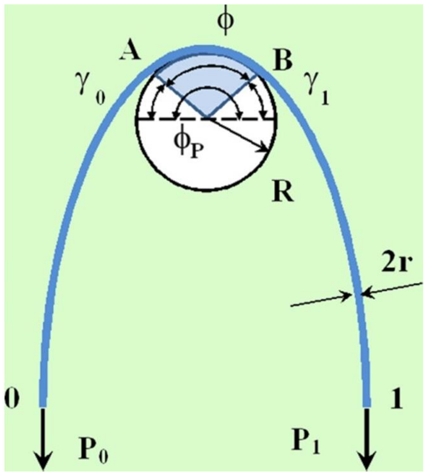

Figure 8 Design diagram to determine an acceptable degree of the tension P_0 of bending-resistant yarn before the guide surface

The equation below shows the relation between the tension P_0 of the yarn before the cylindrical guide surface, the bending modulus B, the radii of the cylindrical guide surface R and the yarn r, the angle γ_0 by which the actual braid angle φ is reduced due to the flexural resistance of the yarn, is reduced due to the bending resistance of the yarn [3].

$$\cos\gamma_0 = 1 - \frac{B}{2P_0(R+r)^2} \quad (4)$$

Let's find the bottom limit of the degree of the tension P_0 of the yarn before the cylindrical guide surface. It is obvious that at the degree of $\gamma_0=\pi/2$, the nominal angle φ will equal to 0 (Figure 8). Then using the equation (4), the following inequality is obtained:

$$P_0 > \frac{B}{2(R+r)^2} \quad (5)$$

It is quite obvious that the degree of the tension P_0 of the yarn before the cylindrical guide should be selected with the equation (5) in mind. Figure 9 shows graphic relationship between the value of P_0 and R for polyamide monofilament yarn (variant 1), for polyamide filament yarn (variants 3 and 4). The highlighted area in Figure 9 corresponds to the range of radius variation R of the cylindrical guide, under which the condition $D \approx d$ is met. The analysis of these relationships shows that to get into this interval, the tension degree P_0 should be higher than 20 cN for monofilament yarn (variant 1). For polyamide yarns (variants 3 and 4) the tension should be higher than 5 cN. For variant 2, the value of the nominal angle will be ensured by the tension less than 5 cN.

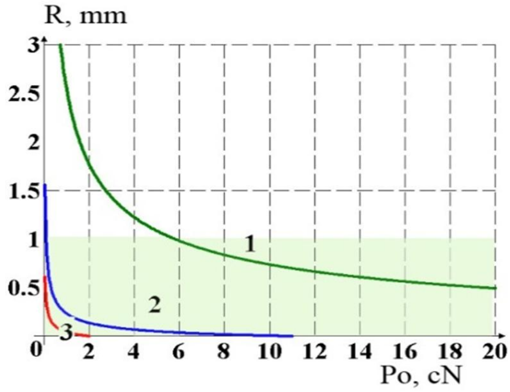

Figure 9 Relationship between the radius of the guide curve *R* on the tension P_0 of the yarn: 1) polyamide monofilament yarn; 2) hard-twisted polyamide filament yarn; 3) medium-twisted polyamide filament yarn

In view of the above, two series of experimental research were implemented. In the first series, for variants 1-4, the degree of tension P_0 of the yarn before the cylindrical guide in the middle of the experiment corresponded to 30 cN. In the second series, for variants 2-4, the degree of tension P_0 of the yarn before the cylindrical guide in the middle of the experiment corresponded to 10 cN. In the middle of the experiment, the radius of the cylindrical guide curve for the first and second series was equal to 1 mm. In the middle of the experiment, the nominal value for the angle φ_P for the first and second series equalled to 135°. Table 1 shows a second-order orthogonal matrix for the first series of the experiments for polyamide yarns (variants 1-4).

Table 1 Second-order orthogonal matrix for the first series of the experiments for polyamide yarns (variants 1-4)

№	Factors					
	Input tension		Radius of the guide curve		Braid angle	
	x_1	P_0 [cN]	x_2	*R* [mm]	x_3	φ [°]
1	+1	32	+1	1.3	+1	145
2	-1	28	+1	1.3	+1	145
3	+1	32	-1	0.7	+1	145
4	-1	28	-1	0.7	+1	145
5	+1	32	+1	1.3	-1	125
6	-1	28	+1	1.3	-1	125
7	+1	32	-1	0.7	-1	125
8	-1	28	-1	0.7	-1	125
9	-1.215	27.6	0	1.0	0	135
10	+1.215	32.4	0	1.0	0	135
11	0	30	-1.215	0.6	0	135
12	0	30	+1.215	1.4	0	135
13	0	30	0	1.0	-1.215	123
14	0	30	0	1.0	+1.215	147
15	0	30	0	1.0	0	135

The correlation between the open-label and blinded values for the first series of experiments for polyamide yarns (variants 1-4) is as follows:

$$x1 = \frac{P_0 - 30}{2}, \quad x2 = \frac{R - 1.0}{0.3}, \quad x3 = \frac{\phi - 135}{10}. \tag{6}$$

Table 2 shows a second-order orthogonal matrix for the second series of the experiments for polyamide yarns (variants 2-4).

Table 2 Second-order orthogonal matrix for the second series of the experiments for polyamide yarns (variants 2-4)

№	Factors					
	Input tension		Radius of the guide curve		Braid angle	
	x_1	P_0 [cN]	x_2	*R* [mm]	x_3	φ [°]
1	+1	12	+1	1.3	+1	145
2	-1	8	+1	1.3	+1	145
3	+1	12	-1	0.7	+1	145
4	-1	8	-1	0.7	+1	145
5	+1	12	+1	1.3	-1	125
6	-1	8	+1	1.3	-1	125
7	+1	12	-1	0.7	-1	125
8	-1	8	-1	0.7	-1	125
9	-1.215	7.6	0	1.0	0	135
10	+1.215	12.4	0	1.0	0	135
11	0	10	-1.215	0.6	0	135
12	0	10	+1.215	1.4	0	135
13	0	10	0	1.0	-1.215	123
14	0	10	0	1.0	+1.215	147
15	0	10	0	1.0	0	135

The correlation between the open-label and blinded values for polyamide yarns (variants 2-4) is as follows:

$$x1 = \frac{P_0 - 10}{2}, \quad x2 = \frac{R - 1.0}{0.3}, \quad x3 = \frac{\phi - 135}{10}. \tag{7}$$

Figure 10 shows the diagram of the experimental unit. Its set-up is described in detail in the paper [4, 5]. The distinction is that unit 4 of modeling the conditions of interaction with guides and operative parts of textile machines includes a set of cylindrical rods, the diameter of which equals to the diameter of the guides and operative parts of textile machines.

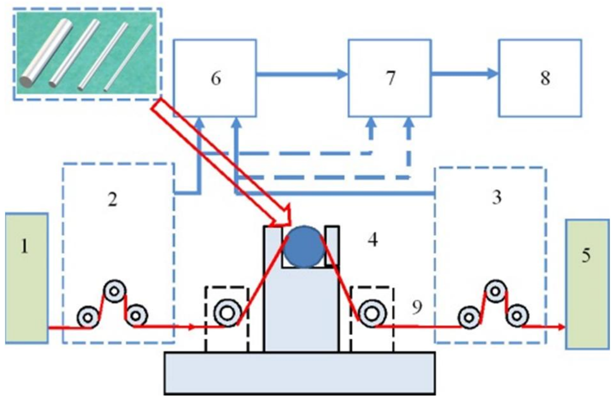

Figure 10 Diagram of the experimental unit: 1) filament feeder unit; 2) unit for measuring the yarn tension's slack side; 3) unit for measuring the yarn tension's slack side; 4) unit for modeling the conditions of interaction with guides and operative parts of textile machines; 5) yarn receiver unit; 6) driver; 7) analog-to-digital converter ADC; 8) personal computer; 9) yarn.

The value of the radii of the guides and polyamide filament yarns, their structure was determined using USB Digital microscope Sigeta (Figure 11).

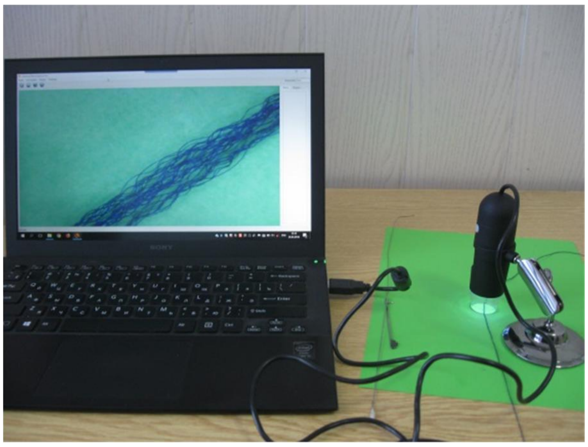

Figure 11 Set-up to determine the radii of the guide way and polyamide filament yarns

4 RESULTS AND DISCUSSION

As a result of implementation of second-order orthogonal designs for three factors (Tables 1-2) for the first series (variants 1-4) and the second series (variants 2-4), about 10 parallel measurements were performed. Its mean values are shown in Tables 3 and 4.

Using the known method of determining the coefficients in the regression equation (3) for the second-order orthogonal plan [4, 5], taking into account the relationships (6), the following regression relationships were determined:

The first series for *27.6 cN ≤ P_0 ≤ 32.4 cN*:

for polyamide monofilament yarn 36.3 tex (variant1):

$$P_1 = 3.27 + 0.72P_0 - 9.29R - 0.14\varphi + 0.53P_0R + \\ +0.01P_0\varphi + 0.16R\varphi - 0.02P_0^2 - 6.44R^2 - 0.001\varphi^2, \quad (8)$$

for polyamide filament yarn 29 tex, medium twist *Kr*=100 twists/meter (variant 2):

$$P_2 = 112.35 - 2.13P_0 - 19.77R - 0.63\varphi - 0.88P_0R + \\ +0.02P_0\varphi - 0.21R\varphi + 0.05P_0^2 + 24.67R^2 + 0.003\varphi^2, \quad (9)$$

for polyamide filament yarn 29 tex, medium twist *Kr*=400 twists/meter (variant 3):

$$P_3 = 101.06 - 1.83P_0 - 15.98R - 0.59\varphi - 0.85P_0R + \\ +0.02P_0\varphi - 0.19R\varphi + 0.05P_0^2 + 22.33R^2 + 0.003\varphi^2, \quad (10)$$

for polyamide filament yarn 29 tex, hard twist *Kr*=800 twists/meter (variant 4):

$$P_4 = 91.14 - 1.62P_0 - 10.12R - 0.57\varphi - 0.80P_0R + \\ +0.02P_0\varphi - 0.18R\varphi + 0.04P_0^2 + 19.0R^2 + 0.003\varphi^2. \quad (11)$$

For the nominal value of the angle in the middle of the experiment φ_P=135°, with the change in the yarn tension before the cylindrical guide *27.6 cN ≤ P_0 ≤ 32.4 cN*:, the equations (8-11) are converted as follows:

for polyamide monofilament yarn 36.3 tex (variant 1):

$$P_1 = 1.94P_0 + 12.75R - 0.02P_0^2 - 6.44R^2 + 0.53P_0R - 24.65 \quad (12)$$

for polyamide filament yarn 29 tex, flat twist *Kr*=100 twists/meter (variant 2):

$$P_2 = 79.67 + 0.23P_0 - 48.12R - 0.88P_0R + 0.05P_0^2 + 24.67R^2 \quad (13)$$

for polyamide filament yarn 29 tex, medium twist *Kr*=400 twists/meter (variant 3):

$$P_3 = 70.62 + 0.47P_0 - 42.44R - 0.85P_0R + 0.05P_0^2 + 22.33R^2 \quad (14)$$

for polyamide filament yarn 29 tex, hard twist *Kr*=800 twists/meter (variant 4):

$$P_4 = 59.48 + 0.68P_0 - 33.96R - 0.80P_0R + 0.04P_0^2 + 19.0R^2 \quad (15)$$

Table 3 Results of the first series of the experimental research to determine the joint effect of the yarn tension prior it goes to the cylindrical guide P_0, the radius of the cylindrical guide *R* and the nominal value of the angle φ_P on the yarn tension behind the cylindrical guide *P* (variants 1-4)

№	Factors			P_2 [cN]	P_3 [cN]	P_4 [cN]	P_1 [cN]
	Input tension x_1	Radius of the guide curve x_2	Braid angle x_3				
1	+1	+1	+1	88.53	87.10	85.13	50.35
2	-1	+1	+1	77.51	76.18	74.33	42.94
3	+1	-1	+1	107.17	104.11	99.81	38.26
4	-1	-1	+1	93.85	90.98	86.94	32.21
5	+1	+1	-1	78.57	77.31	75.55	45.47
6	-1	+1	-1	68.79	67.61	65.96	38.83
7	+1	-1	-1	54.48	91.77	87.97	35.41
8	-1	-1	-1	82.73	80.19	76.69	29.99
9	-1.215	0	0	76.80	75.09	72.72	36.06
10	+1.215	0	0	90.09	88.24	85.67	43.95
11	0	-1.215	0	101.21	97.77	92.92	31.65
12	0	+1.215	0	77.03	75.84	74.18	45.47
13	0	0	-1.215	77.57	75.91	73.61	37.79
14	0	0	+1.215	89.76	87.86	85.19	42.31
15	0	0	0	83.45	81.67	79.19	39.98

Table 4 Results of the second series of the experimental research to determine the joint effect of the yarn tension prior it goes to the cylindrical guide P_0, the radius of the cylindrical guide R and the nominal value of the angle φ_P on the yarn tension behind the cylindrical guide P (variants 2-4)

№	Factors			P_2 [cN]	P_3 [cN]	P_4 [cN]
	Input tension x_1	Radius of the guide curve x_2	Braid angle x_3			
1	+1	+1	+1	33.93	33.03	31.78
2	-1	+1	+1	21.56	20.86	19.89
3	+1	-1	+1	48.44	46.11	42.86
4	-1	-1	+1	28.58	26.91	24.56
5	+1	+1	-1	30.07	29.28	28.16
6	-1	+1	-1	19.15	18.53	17.67
7	+1	-1	-1	42.38	40.32	37.43
8	-1	-1	-1	25.11	23.64	21.57
9	-1.215	0	0	20.91	20.02	18.77
10	+1.215	0	0	37.15	35.89	34.14
11	0	-1.215	0	40.64	38.17	34.72
12	0	+1.215	0	25.46	24.77	23.82
13	0	0	-1.215	26.71	25.71	24.31
14	0	0	+1.215	30.98	29.83	28.20
15	0	0	0	28.77	27.69	26.19

Figure 12 shows the response surfaces for the first series of experiments for variants 1-4. The relevance of the regression relationships obtained was checked with the SPSS program for statistical processing of experimental data [5].

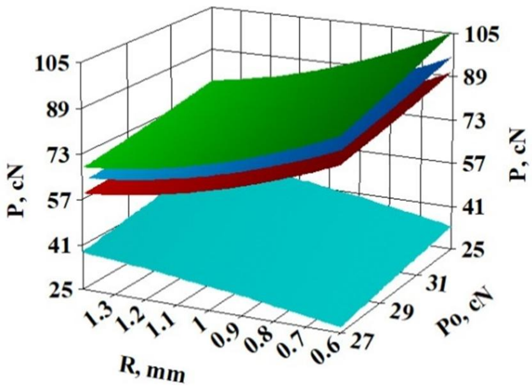

Figure 12 Response surfaces for the first series of experiments for variants 1-4:
- ■ - for polyamide filament yarn 29 tex, flat twist;
- ■ - for polyamide filament yarn 29 tex, medium twist;
- ■ - for polyamide filament yarn 29 tex, hard twist;
- ■ - for polyamide monofilament yarn 36.3 tex

For the nominal value of the angle in the middle of the experiment φ_P=135°, with the change in the yarn tension before the cylindrical guide P_0=30 cN, the equations (12-15) are converted as follows:

for polyamide monofilament yarn 36.3 tex (variant 1):

$$P_1 = 15.55 + 28.65R - 6.44R^2 \quad (16)$$

for polyamide filament yarn 29 tex, flat twist (variant 2):

$$P_2 = 133.89 - 74.52R + 24.67R^2 \quad (17)$$

for polyamide filament yarn 29 tex, medium twist (variant 3):

$$P_3 = 127.47 - 67.94R + 22.33R^2 \quad (18)$$

for polyamide filament yarn 29 tex, hard twist (variant 4):

$$P_4 = 118.13 - 57.96R + 19.0R^2 \quad (19)$$

Figure 13 shows graphic relationships of the change in the yarn tension after the cylindrical guide (the first series of experiments), which were obtained using the equations (16-19).

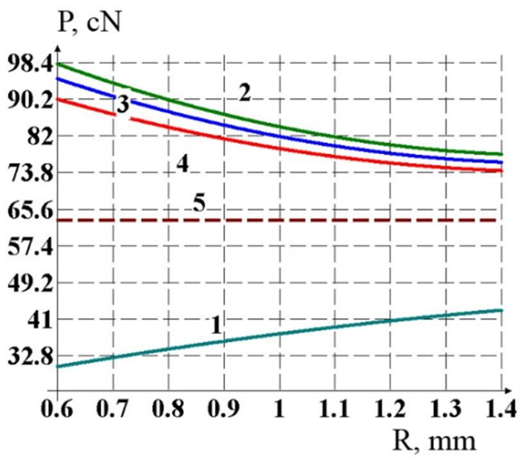

Figure 13 Graphic relationships between the change in the yarn tension after the cylindrical guide (the first series of experiments):
1 - for polyamide filament yarn 36.3 tex;
2 - for polyamide filament yarn 29 tex, flat twist;
3 - for polyamide filament yarn 29 tex, medium twist;
4 - for polyamide filament yarn 29 tex, hard twist;
5 - the relationship for polyamide yarn *D>>d, D=2R, d=2r*

For variants 2-4, for polyamide filament yarns, the tension P decreases when the radius R of the cylindrical guide is increased. This is explained by the fact that the yarn surface deformation is decreased in the contact area and, therefore, the value of the braid angle for the cylindrical guide also decreases. For variant 1, for monofilament yarns, the tension P increases as the radius R of the cylindrical guide increases, which is explained by an increase in the braid angle. The line 5 is an asymptote for relationships 2-6, which corresponds to the case when D>>d, equation (2).

The second series for $7.6\ cN \le P_0 \le 12.4\ cN$:

for polyamide filament yarn 29 tex, flat twist *Kr*=100 twists/meter (variant 2):

$$P_2 = 38.96 + 1.3P_0 - 6.21R - 0.49\varphi - 2.88P_0R + \\ +0.03P_0\varphi - 0.14R\varphi + 0.07P_0^2 + 18.77R^2 + 0.002\varphi^2, \quad (20)$$

for polyamide filament yarn 29 tex, medium twist *Kr*=400 twists/meter (variant 3):

$$P_3 = 35.41 + 1.27P_0 - 3.56R - 0.47\varphi - 2.7P_0R + \\ +0.02P_0\varphi - 0.12R\varphi + 0.06P_0^2 + 16.55R^2 + 0.002\varphi^2, \quad (21)$$

for polyamide filament yarn 29 tex, hard twist *Kr*=800 twists/meter (variant 4):

$$P_4 = 29.07 + 1.08P_0 + 0.03R - 0.41\varphi - 2.45P_0R + \\ +0.02P_0\varphi - 0.11R\varphi + 0.06P_0^2 + 13.66R^2 + 0.002\varphi^2. \quad (22)$$

For the nominal value of the angle in the middle of the experiment φ_P=135°, with the change in the yarn tension before the cylindrical guide $7.6\ cN \le P_0 \le 12.4\ cN$, the equations (20-22) are converted as follows:

$$P_2 = 9.22 + 4.74P_0 - 24.65R + 0.07P_0^2 + 18.77R^2 - 2.88P_0R \quad (23)$$

$$P_3 = 6.23 + 4.58P_0 - 20.21R + 0.06P_0^2 + 16.55R^2 - 2.7P_0R \quad (24)$$

$$P_4 = -2.48 + 4.32P_0 - 14.28R + 0.06P_0^2 + 13.66R^2 - 2.45P_0R \quad (25)$$

Figure 14 shows the response surfaces for the second series of experiments for variants 2-4. Relationships between the yarn tension after the cylindrical guide and the tension P_0 and the radius of the cylinder R were established at the fixed value of nominal angle for the cylinder φ. This value corresponded to the focus point of the experiment (Table 2). The relevance of the regression relationships obtained was checked with the SPSS program for statistical processing of experimental data [5].

For the nominal value of the angle in the middle of the experiment φ_P=135°, with the change in the yarn tension before the cylindrical guide P_0=10 cN, the equations (23-25) are converted as follows:

for polyamide filament yarn 29 tex, flat twist (variant 2):

$$P_2 = 63.62 - 53.45R + 18.77R^2 \quad (26)$$

for polyamide filament yarn 29 tex, medium twist (variant 3):

$$P_3 = 58.03 - 47.21R + 16.55R^2 \quad (27)$$

for polyamide filament yarn 29 tex, hard twist (variant 4):

$$P_4 = 46.72 - 38.78R + 13.66R^2 \quad (28)$$

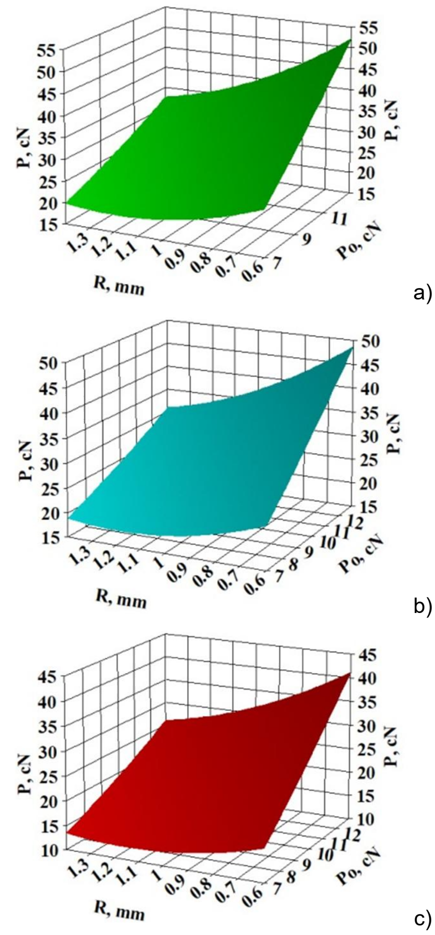

Figure 14 Response surfaces for the second series of experiments for variants 2-4:

a) for polyamide filament yarn 29 tex, flat twist *Kr*=100 twists/meter (variant 2);
b) for polyamide filament yarn 29 tex, middle twist *Kr*=400 twists/meter (variant 3);
c) for polyamide filament yarn 29 tex, hard twist *Kr*=800 twists/meter (variant 4)

Figure 15 shows graphic relationships of the change in the yarn tension after the cylindrical guide (the second series of experiments), which were obtained using the equations (26-28). For variants 2-4, for polyamide filament yarns, the tension P decreases when the radius R of the cylindrical guide is increased.

This is explained by the fact that the yarn surface deformation is decreased in the contact area and, therefore, the value of the braid angle for the cylindrical guide also decreases.

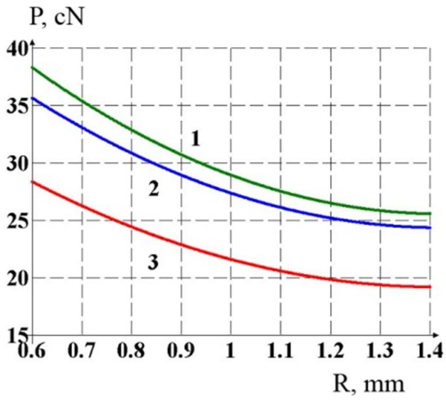

Figure 15 Graphic relationship of the change in the yarn tension after the cylindrical guide (the second series of experiments, variants 2-4)

The results obtained can be used to optimize the technological process of manufacturing filter fabrics from polyamide filament yarns and monofilament yarns, when it is possible, at the initial stage, to determine the intensity of the fabric formation process.

3 CONCLUSIONS

As a result of the comprehensive experimental research to determine the effect of the yarn structure on the tension degree when interacting with high-curved guides, regression relationships were obtained for polyamide monofilament yarns and filament yarns that made it possible to determine the effect of their structure, tension before the guide surface, radius of the high-curved cylindrical guide and the nominal angle for the guide on the tension degree after the guide.

In view of the above, two series of experimental research were implemented: for the change in the yarn tension P_0 before the cylindrical guide in the range from $27.6\ cN \leq P_0 \leq 32.4\ cN$ (the first series); for the change in the yarn tension P_0 before the cylindrical guide in the range from $7.6\ cN \leq P_0 \leq 12.4\ cN$ (the second series).

In the first series, for four types of polyamide yarns (variant 1 - polyamide monofilament yarn 36.3 tex, variant 2 - polyamide filament yarn 29 tex of flat twist, variant 3 - polyamide filament yarn 29 tex of medium twist, variant 4 - polyamide filament yarn 29 tex of hard twist) patterns in the change of the output tension were determined depending on the radius of the cylindrical guide way curve. In the second series, for variants 2-4, regression relationships were obtained to determine the joint effect of the yarn tension before the cylindrical guide P_0, the radius of the cylindrical guide R and the nominal value of the angle φ_P on the yarn tension behind the cylindrical guide P.

The results obtained enable optimization of yarn processing using production equipment, to reduce yarn breakage and to improve performance.

The results obtained can be used to improve technological processes in the textile and knitwear production.

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