DETERMINING TENSION OF YARNS WHEN INTERACTING WITH GUIDES AND OPERATIVE PARTS OF TEXTILE MACHINERY HAVING THE TORUS FORM

Volodymyr Shcherban'[1], Oksana Kolysko[1], Gennadiy Melnyk[1], Marijna Sholudko[1], Yuriiy Shcherban'[2] and Ganna Shchutska[2]

[1]Kyiv National University of Technologies and Design, 2 Nemirovicha-Danchenko Str., 01011 Kyiv, Ukraine
[2]Department of Light Industry Technologies State Higher Educational Establishment «Kyiv College of Light Industry», Ivana Kudri str. 29, 01601 Kyiv, Ukraine
melnik2000@ukr.net

Abstract: *The research related to determining of the yarns tension when interacting with guide and operative parts of weaving looms and knitting machines having the form of torus in the area of contact with yarn established the mechanism of yarn tension increase behind the guide having the torus form due to change in geometrical dimensions and friction forces within contact area. It was proved that yarn tension increase behind the guide is effected by ratio of radius of internal circumference of torus to radius of working circumference; contact angle between yarn and working circumference of torus; radial contact angle between the yarn and internal surface of torus; physico-mechanical and structural properties of yarn. For multifilament and spun yarn, the actual contact angle is more than nominal one due to yarn diameter distortion in the contact area with surface of torus. Values of contact angles between yarns and working circumference and values of radial contact angles between yarns and internal torus surface shall be determined according to geometrical dimensions and design of guide and operative parts of weaving looms and knitting machines. The paper includes experimental research of interaction between different by its nature yarns and spun yarn (natural, synthetic, and man-made) and surfaces having the torus form imitating guide and operative parts of weaving looms and knitting machines. Based on experimental research the regression relationships between tension values behind the guide and ratio of radius of internal circumference of torus to working circumference radius, yarn tension prior it goes to guide and nominal value of contact angle were obtained for cotton, woolen, linen spun yarn, and polyamide multifilament. The analysis of the regression relationships made it possible to establish ultimate values of geometrical dimensions for guide having the form of torus when tension has its minimum value. This will enable minimization of the yarn tension during its processing on the weaving looms and knitting machines. 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. These latter are related, in particular, to determining optimal geometric dimensions of guides and operative parts of weaving looms and knitting machines having the form of torus in the area of contact with yarn, 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: *tension, yarn, guide surface having the torus form, contact angle.*

1 INTRODUCTION

Improvement of technological processes for weaving and knitting production shall mean optimization of technological efforts based on minimization of yarn tension in the area of fabric and knit formation [1, 8, 9, 20]. Determining of yarn tension degree in the working area of technological machine when rewinding spun yarn [2-4], of weaving loom [5, 6, 20], knitting machine [7, 9] makes it possible to evaluate intensity of running technological process. Main characteristic property of most technological processes in textile industry is interaction between yarns and guide and operative parts, when guide's surface curvature radius in the area of contact is comparable to the yarn or spun yarn diameter [8, 14, 20]. Figure 1a represents cases of interaction between the yarn and guide and operative parts of knitting machines. Figure 1b represents cases of interaction between the yarn and operative parts of weaving looms. Figure 1c represents designed diagram of interaction between a yarn and guide surface having the form of torus when guide's curve radius and yarn diameter radius are comparable with each other.

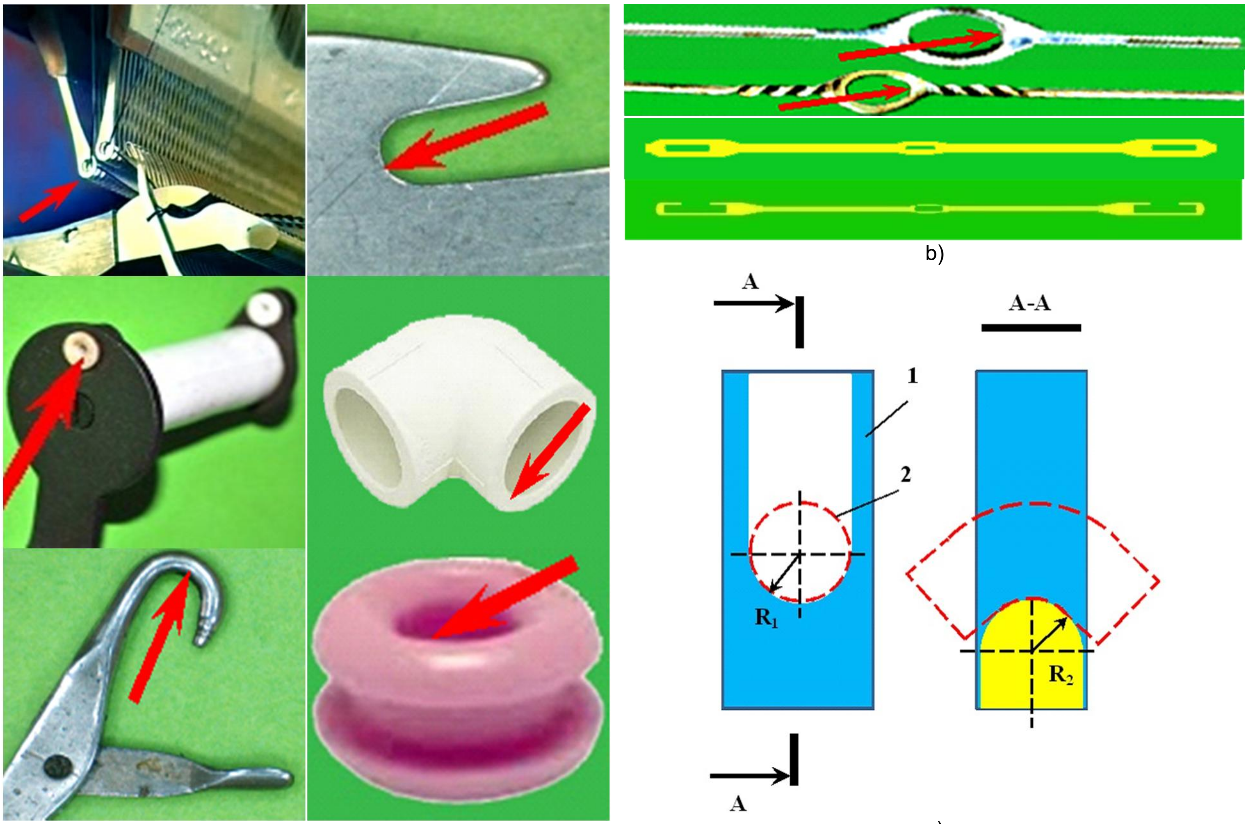

Figure 1 Interaction of yarn with high-curved guides at the textile machinery: a) with guides and operative parts of knitting machines; b) with operative parts of weaving looms; c) designed diagram of interaction between yarn and guide having the form of torus; 1 - fragment of guide surface; 2 - yarn; R_1 - radius of internal circumference of torus; R_2 - radius of working circumference of torus

Analysis of interaction diagram shows that ratio of the radius of internal circumference of torus R_1 to the radius of the working circumference R_2, contact angle between the yarn and the working surface of torus' circumference, radial contact angle between the yarn and internal surface of torus [9] are of great significance. Interaction between the yarn and guide surface, if there exists a radial contact with that surface, occur during fabric element and new course of knitted fabric formation [10]. Such a complex type of interaction requires taking into account the direction of the yarn's friction surfaces and guide surface [11], as well as relative motion of moved material [12]. In our paper [13] we underline the necessity to take into account twists of multifilament and spun yarn and value of its bending modulus. Bending modulus has significant effect on the value of the actual contact angle between the yarn and the guide surface. The above has been proved in our paper [14] during research of conditions of interaction between polyamide multifilament or polyamide monofilament and guide surface. The mentioned papers consider cases of interaction between the yarn and high curved guide surfaces regardless of radial contact with the yarn surface in the contact area. Our papers show the results of experimental determining of the yarn tension with a help of special units [15, 16]. It is impossible to use the obtained results when performing research of interaction between the yarn and high-curved guide, in case there is a radial contact with the yarn surface in the contact area. To contribute to increase accuracy of dimensions and possibilities to ensure metrological self-control in is better to use the redundant measurements method, which makes the measurements result independent of conversion function parameters and their deviation from nominal values [17]. Design of experimental unit determines the accuracy of results receives when determining the yarn tension. The paper [18] shows the diagram for determination of the yarn tension, which uses cylinders with big radii as guides. The mentioned diagram has its disadvantages. Using this diagram, it is impossible to simulate actual conditions of interaction between the yarn and guide and operative parts of weaving looms and knitting machines. The experimental unit with rotating cylinder has similar disadvantages [19]. The paper [20] represents results of determining tension value for wide spectrum of guide surfaces having the form of cylinder. During the experiment, however, there was no radial contact between the yarn and guide surface. Absence of such contact limits the use of obtained results in terms of analysis of conditions pf interaction between the yarn and the actual guide and operative parts of weaving looms and knitting machines.

2 MATERIALS

Four types of yarn have been chosen for experiment.

SN1 series: carded cotton spun yarn 29x2 tex. It is used as warp yarns for production of tartan (spring-autumn twill fabric), and knitted fabric (for outer garments and body linen).

SN2 series: woolen spun yarn 31x2 tex. It is used as warp yarns to produce pure-wool twill suiting (for knitted outer garments, small part also for winter and sports hosiery, as well as hand-wear).

SN3 series: linen wet-spun yarn made of bleached roving 41 tex, obtained from dressed flax. It is used as warp yarns to produce sindon, knitted fabric LN-1 and LN-2 for outer garment.

SSA series: polyamide multifilament 29x2 tex. It is used as warp yarns of outer protective layers of multilayer technical fabrics (MTF) for laying yard-coated pipes, as well as for knitting of outer knitwear and sportswear.

3 EXPERIMENT

For four series SN1, SN2, SN3 and SSA an orthogonal second-order plan for three factors was designed and implemented in the paper [9, 20]. The general view of the regression equation to determine the joint effect of the yarn tension prior it goes to the guide having the form of torus P_0, ratios of radius of internal circumference of torus R_1 to working circumference radius R_2, and the nominal value of the contact angle φ_p on the yarn tension behind the guide having the form of torus P, is as follows:

$$P = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{23}x_2x_3 + \\ + b_{11}x_1^2 + b_{22}x_2^2 + b_{33}x_3^2. \quad (1)$$

The range of factor variation in the equation (1) was determined by the actual yarn processing conditions. In the blinded values: yarn tension before it goes to the guide having the form of torus P_0 was indicated as x_1; ratio of the radius of internal circumference of torus R_1 to working circumference radius R_2 was indicated as x_2; the nominal value of the contact angle φ_p was indicated as x_3.

While determining ratio of radius of internal circumference of torus R_{1S1} to working circumference radius R_{2S1} the diameter of carded cotton spun yarn 29x2 tex, which is 0.31 mm is taken into account. Therefore, in the middle of the experiment, radius of working circumference of torus R_{2S1} takes on the value of 0.35 mm. Radius of internal circumference of torus R_{1S1} is determined by geometrical dimensions of the operative parts of weaving looms, knitting machines, and textile looms (needles and sinkers of knitting machines, heddles of the textile looms). Radii values were determined using USB Digital microscope Sigeta (Figure 2). In the middle of the experiment, to exclude the yarn jamming the R_{1S1} takes on the value of 0.6 mm. Table 1 shows values of ratio of radius of internal circumference of torus R_{1S1} to radius of working circumference R_{1S1} in the blinded values.

Factor x_3 is a nominal value of contact angle for knitting machines when producing knitted fabric for outer garments and body linen, for needles and sinkers it changes within the range from φ_{pS1} = 60° to φ_{pS1} = 180°. When producing tartan (spring-autumn twill fabric) the maximum nominal value of contact angle (heddle eye) for shuttle looms is φ_{pS1} = 29° in case of open shed. The same for shuttleless looms will be φ_{pS1} = 22°; and pneumatic type rapier looms it will be φ_{pS1} = 41°. Taking into account the above values it takes up in the middle of the experiment the value of nominal contact angle of guide surface having the form of torus 95°.

Table 1 Second-order orthogonal matrix for series SN1 for carded cotton spun yarn 29x2 tex

№	Factors					
	Input tension		Torus radii ratio		Contact angle	
	x_1	P_{0S1} [cN]	x_2	R_{1S1}/R_{2S1}	x_3	φ_{pS1} [°]
1	+1	27	+1	2	+1	105
2	-1	23	+1	2	+1	105
3	+1	27	-1	1.4	+1	105
4	-1	23	-1	1.4	+1	105
5	+1	27	+1	2	-1	85
6	-1	23	+1	2	-1	85
7	+1	27	-1	1.4	-1	85
8	-1	23	-1	1.4	-1	85
9	-1.215	22.6	0	1.7	0	95
10	+1.215	27.4	0	1.7	0	95
11	0	25	-1.215	1.3	0	95
12	0	25	+1.215	2.1	0	95
13	0	25	0	1.7	-1.215	83
14	0	25	0	1.7	+1.215	107
15	0	25	0	1.7	0	95

The correlation between the open-label and blinded values of series SN1 for carded cotton spun yarn 29x2 tex is as follows:

$$x1 = \frac{P_{0S1} - 25}{2}, \quad x2 = \frac{R_{1S1} / R_{2S1} - 1.7}{0.3}, \quad x3 = \frac{\phi_{PS1} - 95}{10} \quad (2)$$

Table 2 shows a second-order orthogonal matrix for series SN2. Factor x_1 is a yarn tension prior the yarn goes to the guide having the form of torus, in the middle of the experiment for woolen spun yarn 31x2 tex it is taken up as relatively equal to filling tension of warp yarns. During production of pure-wool twill suiting, outer knitted garments, hosiery of winter and spots assortment, as well as handwear this value will be P_{0S2} = 22 cN.

When determining ratio of radius of internal circumference of torus R_{1S2} to radius of working circumference R_{2S2} the diameter of woolen spun yarn 31x2 tex, which is 0.34 mm shall be taken into account. Therefore, in the middle of the experiment, the radius of working circumference of torus R_{2S2} is taken up as equal to 0.35 mm. The radius of internal circumference of torus R_{1S2} is determined by geometrical dimensions of operative parts of knitting machines and textile looms. Values of radii were determined using USB Digital microscope Sigeta (Figure 2). In the middle of the experiment, to exclude yarn jamming the value of R_{1S2} was taken up as equal to 0.8 mm. Table 2 shows values of ratio of radius of internal circumference of torus R_{1S2} to the radius of working circumference R_{2S2} in blinded values.

Table 2 Orthogonal matrix for series SN2 for woolen spun yarn 31x2 tex

№	Factors					
	Input tension		Torus radii ratio		Contact angle	
	x_1	P_{0S2} [cN]	x_2	R_{1S2}/R_{2S2}	x_3	φ_{pS2} [°]
1	+1	24	+1	2.9	+1	105
2	-1	20	+1	2.9	+1	105
3	+1	24	-1	1.7	+1	105
4	-1	20	-1	1.7	+1	105
5	+1	24	+1	2.9	-1	85
6	-1	20	+1	2.9	-1	85
7	+1	24	-1	1.7	-1	85
8	-1	20	-1	1.7	-1	85
9	-1.215	19.6	0	2.3	0	95
10	+1.215	24.4	0	2.3	0	95
11	0	22	-1.215	1.6	0	95
12	0	22	+1.215	3	0	95
13	0	22	0	2.3	-1.215	83
14	0	22	0	2.3	+1.215	107
15	0	22	0	2.3	0	95

The correlation between the open-label and blinded values of series SN2 for woolen spun yarn 31x2 tex is as follows:

$$x1 = \frac{P_{0S2} - 22}{2}, \quad x2 = \frac{R_{1S2} / R_{2S2} - 2.3}{0.6}, \quad x3 = \frac{\phi_{PS2} - 95}{10} \qquad (3)$$

Table 3 shows a second-order orthogonal matrix for series SN3. Factor x_1 is yarn tension prior the yarn goes to the guide having the form of torus, in the middle of the experiment for linen wet-spun yarn made of bleached roving 41 tex it is taken up as relatively equal to filling tension of warp yarns. During production of sindon, knitted fabric LN-1 and LN-2 for outer garments this value will be equal to P_{0S3} = 28 cN.

When determining the ratio of radius of internal circumference of torus R_{1S3} to radius of working circumference R_{2S3} the diameter of linen wet-spun yarn made of bleached roving 41 tex which equals 0.28 mm is taken into account. Therefore, in the middle of experiment, radius of working circumference of torus R_{2S3} is taken up as 0.35 mm. The radius of internal circumference of torus R_{1S3} is determined due to geometrical dimensions of operative parts of knitting machines and textile looms. In the middle of experiment, to exclude yarn jamming the value of R_{1S3} is taken up as 0.5 mm. Table 3 shows the ratios of radius of internal circumference of torus R_{1S3} to radius of working circumference R_{2S3} in blinded values.

Table 3 Orthogonal matrix for series SN3 for linen wet-spun yarn made of bleached roving 41 tex

№	Factors					
	Input tension		Torus radii ratio		Contact angle	
	x_1	$P_{0S3,}$ [cN]	x_2	R_{1S3}/R_{2S3}	x_3	φ_{pS3} [°]
1	+1	30	+1	1.7	+1	105
2	-1	26	+1	1.7	+1	105
3	+1	30	-1	1.1	+1	105
4	-1	26	-1	1.1	+1	105
5	+1	30	+1	1.7	-1	85
6	-1	26	+1	1.7	-1	85
7	+1	30	-1	1.1	-1	85
8	-1	26	-1	1.1	-1	85
9	-1.215	25.6	0	1.4	0	95
10	+1.215	30.4	0	1.4	0	95
11	0	28	-1.215	1	0	95
12	0	28	+1.215	1.8	0	95
13	0	28	0	1.4	-1.215	83
14	0	28	0	1.4	+1.215	107
15	0	28	0	1.4	0	95

The correlation between the open-label and blinded values of series SN3 for linen wet-spun yarn made of bleached roving 41 tex is as follows:

$$x1 = \frac{P_{0S3} - 28}{2}, \quad x2 = \frac{R_{1S3} / R_{2S3} - 1.4}{0.3}, \quad x3 = \frac{\phi_{PS3} - 95}{10} \qquad (4)$$

Table 4 shows a second-order orthogonal matrix for series SSA. Factor x_1 is yarn tension prior the yarn goes to the guide having the form of torus, in the middle of the experiment for polyamide multifilament 29x2 tex it is taken up as relatively equal to filling tension of warp yarns. When producing multilayer technical fiber MTF for laying yard-coated pipes, knitting outer knitted and sports garments this value will be P_{0SA} = 35 cN.

When determining the ratio of radius of internal circumference of torus R_{1SA} to radius of working circumference R_{2SA} the diameter of polyamide multifilament 29x2 tex, which is 0.29 mm, is taken into account. Therefore, in the middle of experiment, the radius of working circumference R_{2SA} is taken up as 0.35 mm. The radius of internal circumference of torus R_{1SA} shall be determined based on geometrical dimensions of operative parts of knitting machines and textile looms. Values of radii were determined using USB Digital microscope Sigeta (Figure 2). In the middle of the experiment, to exclude yarn jamming, the value R_{1SA} is taken up as 0.55 mm. Table 4 shows values of ratio of radius of internal circumference of torus R_{1SA} to radius of working circumference R_{2SA} in blinded values.

Table 4 Orthogonal matrix for series SSA for polyamide multifilament 29x2 tex

№	Factors					
	Input tension		Torus radii ratio		Contact angle	
	x_1	P_{0SA} [cN]	x_2	R_{1SA}/R_{2SA}	x_3	φ_{pSA} [°]
1	+1	37	+1	1.9	+1	105
2	-1	33	+1	1.9	+1	105
3	+1	37	-1	1.3	+1	105
4	-1	33	-1	1.3	+1	105
5	+1	37	+1	1.9	-1	85
6	-1	33	+1	1.9	-1	85
7	+1	37	-1	1.3	-1	85
8	-1	33	-1	1.3	-1	85
9	-1.215	32.6	0	1.6	0	95
10	+1.215	37.4	0	1.6	0	95
11	0	35	-1.215	1.2	0	95
12	0	35	+1.215	2	0	95
13	0	35	0	1.6	-1.215	83
14	0	35	0	1.6	+1.215	107
15	0	35	0	1.6	0	95

The correlation between the open-label and blinded values of series SSA for polyamide multifilament 29x2 tex is as follows:

$$x1 = \frac{P_{0SA} - 35}{2}, \quad x2 = \frac{R_{1SA} / R_{2SA} - 1.6}{0.3}, \quad x3 = \frac{\phi_{PSA} - 95}{10}. \quad (5)$$

Values of radii of guide having the form of torus were determined using USB Digital microscope Sigeta (Figure 2).

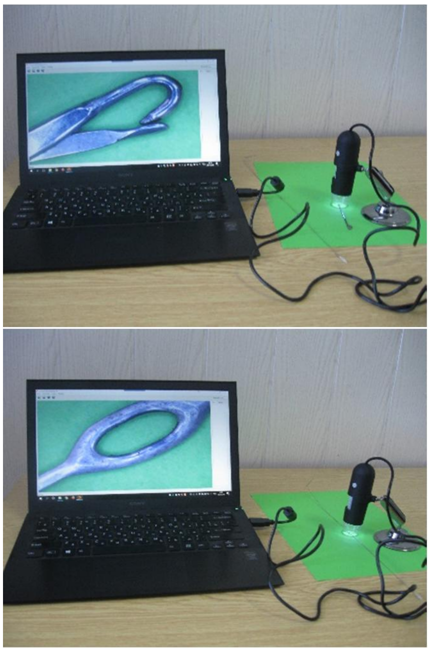

Figure 2 Installation to determine radii of guide having the form of torus yarns/decimetre); 5 - MTF - 9 (density of weft yarns 140 yarns/decimetre)

Figure 3 shows the diagram of experimental unit. Its set-up is described in detail in the paper [9, 20]. The distinction is that unit 4 of modelling the conditions of interaction between guides and operative parts of textile looms and knitting machines, which have the form of torus in the contact area with a yarn, includes a set of needles and sinkers, and heddles of knitting loom. The diameter of the working surface of torus is commensurate with diameter of the processed yarns.

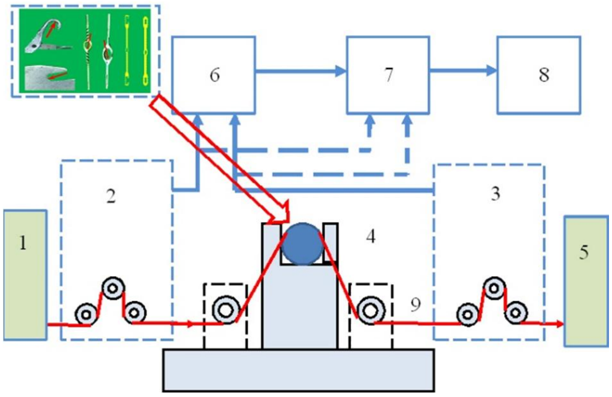

Figure 3 Installation to determine radii of guide having the form of torus yarns/decimetre); 5 - MTF - 9 (density of weft yarns 140 yarns/decimetre). The diagram of the experimental unit: 1 - yarn feeder unit; 2 - unit for measuring the yarn tension's slack side; 3 - unit for measuring the yarn tension's slack side; 4 - unit for modelling 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

4 RESULTS AND DISCUSSION

As a result of implementation of second-order orthogonal designs for three factors (Tables 1-4) for series SN1-SN3 and SSA about 10 parallel measurements were performed. Its mean values are shown in Table 5.

Table 5 Results of the series of the experimental research to determine the joint effect of the yarn tension prior it goes to the guide having the form of torus P_0, the ratios of radius of internal circumference of torus R_1 to the radius of working circumference R_2, and nominal values of the contact angle φ_P to the yarn tension P behind the guide having the form of torus (series SN1-SN3 and SSA)

№	Factors			P_1 [cN]	P_2 [cN]	P_3 [cN]	P_{SA} [cN]
	x_1	x_2	x_3				
1	+1	+1	+1	49.6	36.3	31.9	70.5
2	-1	+1	+1	40.5	29.4	27.7	60.8
3	+1	-1	+1	50.3	36.8	32.1	71.7
4	-1	-1	+1	41.1	29.8	27.8	61.8
5	+1	+1	-1	44.8	33.8	31.6	63.6
6	-1	+1	-1	36.9	27.4	27.4	55.1
7	+1	-1	-1	45.4	34.2	31.7	64.5
8	-1	-1	-1	37.3	27.8	27.4	55.9
9	-1.215	0	0	38.1	27.9	27.1	57.5
10	+1.215	0	0	48.3	35.9	32.2	68.4
11	0	-1.215	0	43.6	32.1	29.9	63.7
12	0	+1.215	0	42.8	31.6	29.6	62.3
13	0	0	-1.215	40.6	30.5	29.5	59.1
14	0	0	+1.215	45.7	33.2	29.9	66.8
15	0	0	0	43.1	31.8	29.7	62.9

Using the known method of determining the coefficients in the regression equation (1) for the second-order orthogonal plan [10, 14], taking into account the relationships (2-5), the following regression relationships were determined.

Table 6 shows the values of the coefficients and the range of error in the regression equation (1) for the coded values of the factors, the error of the values of which, using the Student's test, with 95% probability allows to determine their value.

Table 6 Coefficient values and range of error in the regression equation

Series SN1		Series SN2	
	value		value
b0	43.1054+/-0.359364	b0	31.8135+/-0.347293
b1	8.3844+/-0.368791	b1	6.46958+/-0.356404
b2	-0.588622+/-0.368791	b2	-0.343582+/-0.356404
b3	4.18336+/-0.368791	b3	2,29375+/-0,356404
b11	0.109283+/-0.529399	b11	0.0923636+/-0.511618
b12	-0.075+/-0.438569	b12	0.075+/-0.423839
b13	0.575+/-0.438569	b13	0.375+/-0.423839
b22	0.109283+/-0.529399	b22	0.0320084+/-0.511618
b23	-0.075+/-0.438569	b23	-0.125+/-0.423839
b33	0.0489278+/-0.529399	b33	0.0320084+/-0.511618
Series SN3		Series SNA	
	value		value
b0	29.7+/-0.339485	b0	62.9135+/-0.36778
b1	4.16568+/-0.348391	b1	8.96794+/-0.377428
b2	-0.138974+/-0.348391	b2	-1.00799+/-0.377428
b3	0.338505+/-0.348391	b3	6.29525+/-0.377428
b11	-0.0603552+/-0.50011	b11	0.0320084+/-0.541797
b12	-0.05+/-0.414309	b12	-0.075+/-0.44884
b13	0.0+/-0.414309	b13	0.625+/-0.44884
b22	0.0603552+/-0.500114	b22	0.0923636+/-0.541797
b23	-0.05+/-0.414309	b23	-0.125+/-0.44884
b33	0.0+/-0.500114	b33	0.0320084+/-0.541797

Series SN1, for carded cotton spun yarn 29x2 tex, the range of change in input tension *22.6 cN* ≤ P_{0S1} ≤ *27.4:*

$$P_{S1} = 15.07 + 0.081P_{0S1} - 0.3Z1 - 0.17\varphi_{PS1} + 0.02P_{0S1}\varphi_{PS1} - 0.07P_{0S1}Z1 - \\ -0.01Z1\varphi_{PS1} + 0.02P_{0S1}^2 + 0.7Z1^2 + 0.0002\varphi_{PS1}^2, \quad Z1 = R_{1S1} / R_{2S1}. \quad (6)$$

Series SN2, for woolen spun yarn 31x2 tex, the range of change in input tension *19.6 cN* ≤ P_{0S2} ≤ *24.4 cN*:

$$P_{S2} = 12.6 + 0.22P_{0S2} - 0.52Z2 - 0.12\varphi_{PS2} + 0.007P_{0S2}\varphi_{PS2} - 0.01P_{0S2}Z2 - \\ -0.002Z2\varphi_{PS2} + 0.02P_{0S2}^2 + 0.1Z2^2 - 0.0004\varphi_{PS2}^2, \quad Z2 = R_{1S2} / R_{2S2}. \quad (7)$$

Series SN3, for linen wet-spun yarn made of bleached roving 41 tex, the range of change in input tension *25.6 cN* ≤ P_{0S3} ≤ *30.4 cN*:

$$P_{S3} = 1.52P_{0S3} + 0.79Z3 + 0.029\varphi_{PS3} - 0.04P_{0S3}Z3 - \\ -0.008Z3\varphi_{PS3} - 0.007P_{0S3}^2 + 0.3Z3^2 - 8.68, \quad Z3 = R_{1S3} / R_{2S3} \quad (8)$$

Series SSA, for polyamide multifilament 29x2 tex, the range of change in input tension *32.6 cN* ≤ P_{0SA} ≤ *37.4 cN*:

$$P_{SA} = 9.69 + 0.57P_{0SA} + 0.79Z_{SA} - 0.22\varphi_{PSA} + 0.015P_{0SA}\varphi_{PSA} - 0.07P_{0S2}Z_{SA} - \\ -0.02Z_{SA}\varphi_{PSA} + 0.01P_{0SA}^2 + 0.56Z_{SA}{}^2 + 0.0002\varphi_{PSA}^2, \quad Z_{SA} = R_{1SA} / R_{2SA}. \quad (9)$$

For nominal value of contact angle in the middle of experiment φ_P = 95°, when determining changes in yarn tension behind the guide surface having the form of torus, the equations (6-9) are converted as follows:

- series SN1, for carded cotton spun yarn 29x2 tex, the range of change in input tension *22.6 cN* ≤ P_{0S1} ≤ *27.4*:

$$P_{S1} = 0.73 + 1.98P_{0S1} - 1.25Z1 - 0.07P_{0S1}Z1 + 0.02P_{0S1}^2 + 0.7Z1^2 \\ Z1 = R_{1S1} / R_{2S1}, \quad (10)$$

- series SN2, for woolen spun yarn 31x2 tex, the range of change in input tension *19.6 cN* ≤ P_{0S2} ≤ *24.4*:

$$P_{S2} = 4.81 + 0.89P_{0S2} - 0.71Z2 - 0.01P_{0S2}Z2 + 0.02P_{0S2}^2 + 0.1Z2^2 \\ Z2 = R_{1S2} / R_{2S2}, \quad (11)$$

- series SN3, for linen wet-spun yarn made of bleached roving 41 tex, the range of change in input tension *25.6 cN* ≤ P_{0S3} ≤ *30.4*:

$$P_{S3} = 1.52P_{0S3} + 0.03Z3 - 0.04P_{0S3}Z3 - 0.0075P_{0S3}^2 + 0.3Z3^2 - 5.93 \\ Z3 = R_{1S3} / R_{2S3}, \quad (12)$$

- series SSA, for polyamide multifilament 29x2 tex, the range of change in input tension *32.6 cN* ≤ P_{0SA} ≤ *37.4*:

$$P_{SA} = 1.99P_{0SA} - 1.11Z_{SA} - 0.067P_{0S2}Z_{SA} + 0.005P_{0SA}^2 + 0.56Z_{SA}{}^2 - 9.03 \\ Z_{SA} = R_{1SA} / R_{2SA}. \quad (13)$$

Figure 4 shows the response surfaces for series SN1-SN3 and SSA. Yarn tension behind the guide surface having the form of torus is represented by functions, which take into account joint effect of yarn tension before the yarn goes to the guide having the form of torus P_0, ratios *Z* of radius of internal circumference of torus R_1 to radius of working circumference R_2. Nominal value of the contact angle φ_p was fixed value. Such value corresponded to the middle of the experiment (Tables 1-4). Adequacy of the obtained regression relationships was tested using SPSS program for statistical processing of experimental data [8, 9, 14, 20].

For nominal value of contact angle φ_P = 95°, having fixed value of the input tension, the equations (10-13) are converted as follows:

- series SN1, for carded cotton spun yarn 29x2 tex, with the value of input tension in the middle of experiment P_{0S1} = 25 cN:

$$P_{S1} = 62.75 - 3Z1 + 0.7Z1^2, \quad Z1 = R_{1S1} / R_{2S1} \quad (14)$$

- series SN2, for woolen spun yarn 31x2 tex, with the value of input tension in the middle of experiment P_{0S2} = 22 cN:

$$P_{S2} = 33.96 - 0.93Z2 + 0.1Z2^2, \quad Z2 = R_{1S2} / R_{2S2} \quad (15)$$

- series SN3, for linen wet-spun yarn made of bleached roving 41 tex, with the value of input tension in the middle of experiment P_{0S3} = 28 cN:

$$P_{S3} = 30.76 - 1.09Z3 + 0.3Z3^2, \quad Z3 = R_{1S3} / R_{2S3} \quad (16)$$

- series SSA, for polyamide multifilament 29x2 tex, with the value of input tension in the middle of experiment P_{0SA} = 35 cN:

$$P_{SA} = 66.93 - 3.46Z_{SA} + 0.56Z_{SA}^{2}, \quad Z_{SA} = R_{1SA} / R_{2SA}. \quad (17)$$

Equations (14-17) were used to obtain values for yarn tension behind guide surface having the form of torus depending upon ratio *Z* of radius of internal circumference of torus R_1 to radius of working circumference R_2, which are represented in Table 7. Figure 5 shows curves reflecting the changes in yarn tension behind guide surface having the form of torus depending on ratio *Z* of radius of internal circumference of torus R_1 to radius of working circumference R_2. These curves were fitted according to the data from Table 6. Analysis of the curves on Figures 5a and 5b shows that value of tension behind the guide surface having the form of torus decreases with the value of ratio *Z* of radius of internal circumference of torus R_1 to radius of working circumference R_2 (Figure 1c) increase. It can be explained by decrease of value of contact angle of the lateral surface of yarn in the contact are with guide surface having the form of.

Obtained results may be used for optimization of technological processes in weaving and knitting productions with relation to minimization of the yarn tension in the working area, where knitted fabric and fabric are formed.

Table 7 Values of yarn tension behind the guide surface having the form of torus depending on ratio *Z* of radius of internal circumference of torus R_1 to radius of working circumference R_2

Z	Yarn tension values behind the guide surface having the form of torus			
	SN1	SN2	SN3	SSA
1	60.45	33.13	29.97	64.03
1.1	60.29	33.05	29.92	63.80
1.2	60.15	32.98	29.88	63.58
1.3	60.03	32.92	29.85	63.37
1.4	59.92	32.85	29.82	63.18
1.5	59.82	32.79	29.80	63.00
1.6	59.74	32.72	29.78	62.82
1.7	59.67	32.66	29.79	62.67
1.8	59.61	32.61	29.75	62.51
1.9	59.57	32.55	29.76	62.37
2.0	59.55	32.50	29.78	62.25

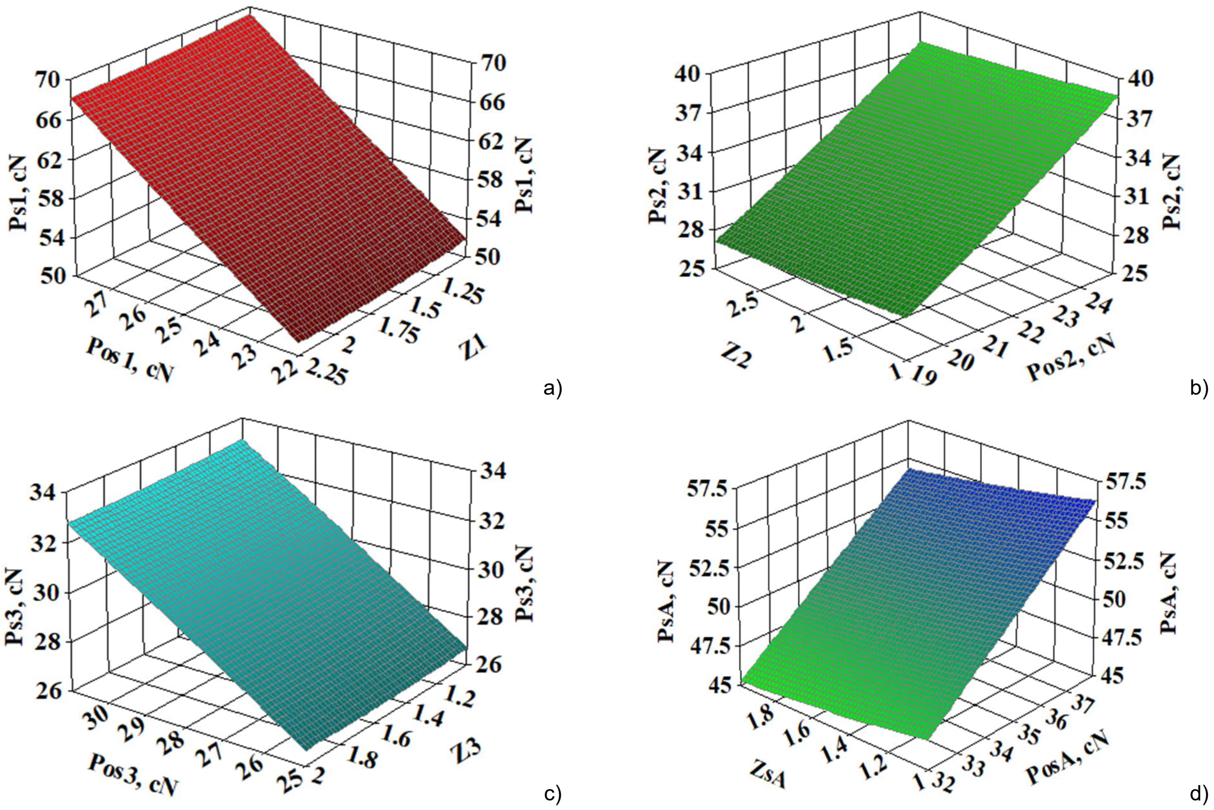

Figure 4 response surfaces for series SN1-SN3 and SSA: a) for cotton carded spun 29x2 tex (series SN1); b) for woolen spun yarn 31x2 tex (series SN2); c) for linen wet-spun yarn made of bleached roving 41 tex (series SN3); d) for polyamide multifilament 29x2 tex (series SSA)

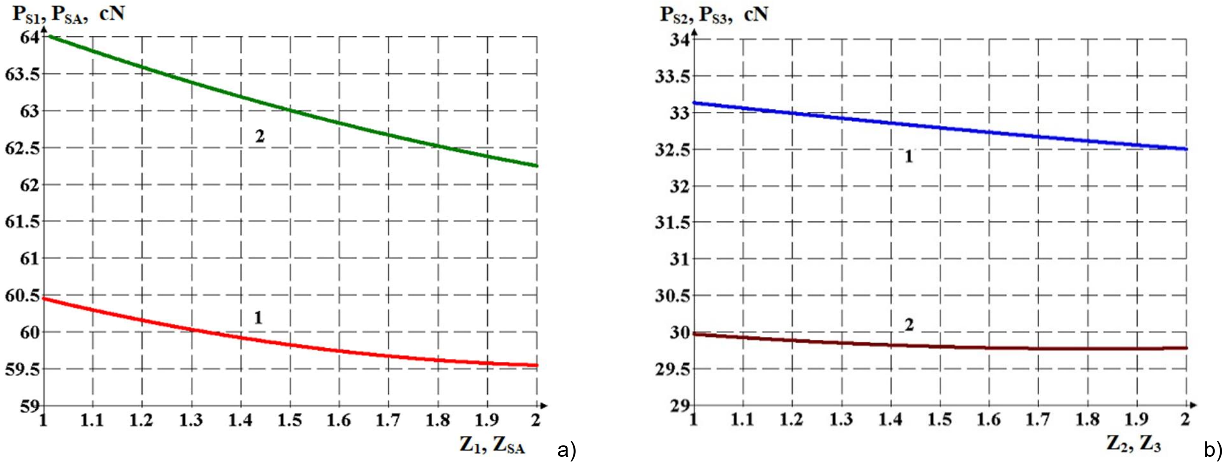

Figure 5 curves reflecting the changes in yarn tension behind guide surface having the form of torus depending on ratio of radius of internal circumference of torus to radius of working circumference: a) series SN1(1), series SSA(2); b) series SN2(1), series SN3(2)

5 CONCLUSIONS

Improvement of a technological process in weaving and knitting production means optimization of technological efforts based on minimizing of yarn tension in the fabric and knitted fabric formation area. The research related to determining of the yarns tension when interacting with guide and operative parts of weaving looms and knitting machines having the form of torus in the area of contact with yarn established the mechanism of yarn tension increase behind the guide having the torus form due to change in geometrical dimensions and friction forces within contact area.

The regression relationships were obtained resulting from delivery of series of experimental researches to determine joint effect of yarn tension prior it goes to guide having the form of torus P_0, ratio of radius of internal circumference of torus R_1 to radius of working circumference R_2, and nominal value of contact angle φ_P on yarn tension P behind the guide having the form of torus for carded cotton spun yarn 29x2 tex (input tension variation range $22.6\ cN \leq P_{0S1} \leq 27.4$ - series SN1), for woolen spun yarn 31x2 tex (input tension variation range $19.6\ cN \leq P_{0S2} \leq 24.4\ cN$ - series SN2), for linen wet-spun yarn made of bleached roving 41 tex (input tension variation range $25.6\ cN \leq P_{0S3} \leq 30.4\ cN$ - series SN3), for polyamide multifilament 29x2 tex (input tension variation range $32.6\ cN \leq P_{0SA} \leq 37.4$ - series SSA). It was established that tension degree behind the guide surface having the form of torus becomes less while value of ratio Z of radius of internal circumference of torus R_1 to radius of working circumference R_2 increases. It can be explained by decrease of contact angle value for lateral surface of yarn in the area of contact with guide surface having the form of torus.

Obtained results and their usage make it possible to optimize yarn manufacturing process at the technological equipment in view of minimization of yarn tension in the working area, where fabric and knitted fabric are formed, to reduce yarn breakage, and to improve performance of weaving and knitting machines.

Obtained results can be used to improve technological processes in the fabric and knitted fabric production.

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