WARP YARN TENSION DURING FABRIC FORMATION

Volodymyr Shcherban', Gennadiy Melnyk, Marijna Sholudko and Valerij Kalashnyk

Kyiv National University of Technologies and Design, 2 Nemirovicha-Danchenko Str. Kyiv, 01011, Ukraine
melnik2000@ukr.net

Abstract: *Tension of warp yarn, before it enters the weaving area, is the value which determines intensity of the weaving process and cloth structure. Increased value of warp yarn tension, before entering the fabric formation area, causes a spiralling number of breaks, and decreased value does not allow to ensure shed cleanliness. Tension of warp yarns, before they enter the fabric formation area, includes input tension and additional tension, arising by virtue of frictional forces between warp yarns and surfaces of guiding and working components of cylinder form or one close to it.*
This work represents experimental research in interaction between different in itself natural warp yarns and cylindrical surfaces imitating separating rod of yarn break detector as well as heddle eye for automatic shuttleless pneumatic rapier looms. As a result of the experiment regression dependences were obtained between warp yarns and value of the cylinder radius, as well as between contact angle and warp yarn tension just before the guide. Consistent application of the data of regression dependences allows to determine warp yarns tension before they enter the fabric formation area for different kinds of natural raw material of warp yarns for wide range of looms.

Keywords: *tension, warp yarns, weaving area, contact angle, curvature radius.*

1 INTRODUCTION

Tension of warp yarn, before it enters fabric weaving area, is a value determining intensity of the weaving process and cloth structure [1, 3-4, 7-8]. Tension of warp yarns, before they enter fabric weaving area, comprises both input tension and additional tension, which arises by virtue of frictional forces between warp yarns and surfaces of guiding and working components having cylinder form or one close to it [2, 4, 8]. Figures 1a and 1b represent guiding and working components of the loom the warp yarn interacts with when entering the weaving area.

Figure 1 Guides and working components of the loom: a - tension rail; b - heddle eyes

Curvature radius of the provided surfaces, which have cylinder form or one close to it, both significantly longer as compared to radius of the cross-section a warp yarn and commensurate with it [2, 4]. Such type of interaction also occurs in implementation of similar technological processes [5, 6]. Simulation of the warp yarn processing using a loom involves study of interaction between warp yarns and cylindrical surfaces. These surfaces are dummies for surface of separating rods, which are components of the yarn break detector, as well as heddle eyes for automatic shuttleless pneumatic rapier looms [1-3, 7]. When drafting the plan of the experiment, the direction connected to slip of rubbing surfaces [9], speed of yarn or guiding surface [10, 14] and radius of the curvature of cylindrical surface [11, 13] should be taken into account. Keeping in mind that spun yarn and multi-filaments are used as warp yarns, flexural rigidity can be ignored [3-4, 7-8, 12].

Figure 2 shows warp yarn threading system for a loom. It is divided into three areas for our purpose: I area – between warp beam and separating warp stop motion; II area – between tension rail and heddle frames; III area – between separating warp stop motion and fell of the cloth. Increase in intensity of warp yarn tension divided into areas represented by green, blue and red color. These colors have been used during modelling of response surfaces and plotting of warp yarn tension. Indexes for designation warp yarn tension, contact angles, curvature radius of the cylindrical surfaces shall correspond to areas' numbers.

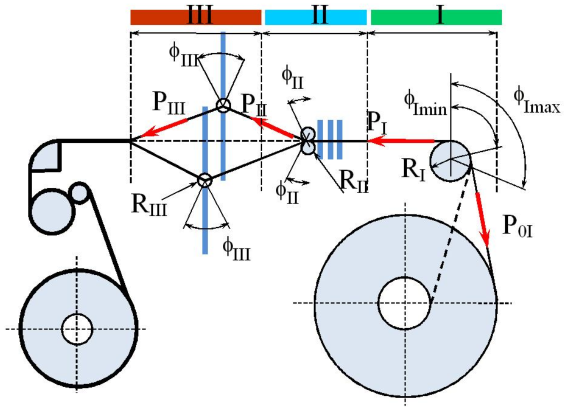

Figure 2 Warp yarn threading system for a loom

2 EXPERIMENT

Three types of yarn have been chosen for experiment.

Series A: carded cotton yarn 18.5 x 2 tex. It is used as warp yarns for spring-autumn fabric of tartan twill weave.

Series B: bleached flax of wet spun 41 tex, obtained from dressed flax. It is used as warp yarns to manufacture sindon.

Series C: wool 31.2 x 2 tex. It is used as warp yarns to manufacture pure-wool suit cloth of boston twill.

For each series A, B, and C to define joint impact of input tension of warp yarn P_0, radius of cylinder guide R and computed value of contact angle φ_P on output tension of the warp yarn P, the secondary orthogonal design was prepared and implemented for three factors [3, 7-8]. Standard form of regression equation shall be 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 factors variability in equation (1) is determined by real conditions of yarns processing on looms. Threading line for warp yarn is divided into three areas: **I** is the area from warp yarn run-off point from beam to stop motion; **II** is the area from warp yarn entrance into stop motion to heddle frame; **III** is the area from warp yarn exit from stop motion to the fell of the cloth (Figure 2). Within the **I** area warp yarn interacts with tension rail. Within the **II** area warp yarn contacts separating stop motion rod. Within the **III** area warp yarn contacts heddle eye.

Factor x_1 is the value of the threading tension within **I** area before tension rail for shuttle looms, shuttleless looms, and pneumatic rapier looms:

A - for carded cotton yarn P_{0I} = 20 cN;

B - for bleached flax of wet spun made P_{0I} = 25 cN;

C - for wool P_{0I} = 35 cN.

Factor x_2 - cylinder (tension rail) radius within **I** area for: shuttle looms R_I = 56 mm; shuttleless looms R_I = 63 mm; pneumatic rapier looms R_I = 32 mm.

Factor x_2 - cylinder (left separating rod in stop motion) radius within **II** area for: pneumatic rapier looms shuttle looms R_{II} = 9 mm; shuttleless looms R_{II} = 4 mm; pneumatic rapier looms R_{II} = 3 mm.

Factor x_2 - cylinder (heddle eye) radius within **III** area for: shuttle looms R_{III} = 1.1 mm; shuttleless looms R_{III} = 0.6 mm; pneumatic rapier looms R_{III} = 0.5 mm.

Factor x_3 - calculated value of the contact angle with cylinder (tension rail) within **I** area for: shuttle looms φ_{IP} = 60° with maximum beam diameter 600 mm and φ_{IP} = 110° with minimum beam diameter 146 mm; shuttleless looms φ_{IP} = 70° with maximum beam diameter 600 mm and φ_{IP} = 100° with minimum beam diameter 220 mm; pneumatic rapier looms φ_{IP} = 90° with maximum beam diameter 600 mm and φ_{IP} = 115° with minimum beam diameter 100 mm.

Factor x_3 - calculated value of the contact angle with cylinder (left separating rod in the stop motion) within **II** area for: shuttle looms φ_{IIP} = 75° with maximum shed opening and 0° with closed shed; shuttleless looms φ_{IIP} = 75° with maximum shed opening and 0° with closed shed; pneumatic rapier looms φ_{IIP} = 76° with maximum shed opening and 0° with closed shed.

Factor x_3 - calculated value of the contact angle with cylinder (heddle eye) within **III** area for: shuttle looms φ_{IIIP} = 29° with open shed and φ_{IIIP} = 0° with closed shed; shuttleless looms φ_{IIIP} = 22° with open shed and φ_{IIIP} = 0° with closed shed; pneumatic rapier looms φ_{IIIP} = 41° with open shed and φ_{IIIP} = 0° with closed shed.

At the first stage the tension within the **I** area after the tension rail is determined. Table 1 shows orthogonal matrix of the second order for three series A, B and C.

Table 1 Orthogonal matrix of the second order for three series A, B and C for zone I

No.	Factors							
	Input tension				Curvature radius		Contact angle	
	x_1	P_{01} [cN] A	P_{01} [cN] B	P_{01} [cN] C	x_2	R_I [mm]	x_3	φ_{IP} [°]
1	+1	25	35	45	+1	65	+1	120
2	-1	15	15	25	+1	65	+1	120
3	+1	25	35	45	-1	35	+1	120
4	-1	15	15	25	-1	35	+1	120
5	+1	25	35	45	+1	65	-1	100
6	-1	15	15	25	+1	65	-1	100
7	+1	25	35	45	-1	35	-1	100
8	-1	15	15	25	-1	35	-1	100
9	-1.215	14	14	23	0	50	0	110
10	+1.215	26	26	47	0	50	0	110
11	0	20	25	35	-1.215	32	0	110
12	0	20	25	35	+1.215	68	0	110
13	0	20	25	35	0	50	-1.215	98
14	0	20	25	35	0	50	+1.215	122
15	0	20	25	35	0	50	0	110

Connection between natural and encoded values for I area shall be as follows:

series A

$$x1=\frac{P_{0I}-20}{5},\quad x2=\frac{R_I-50}{15},\quad x3=\frac{\varphi_{I\,P}-110}{10},\qquad (2)$$

series B

$$x1=\frac{P_{0I}-25}{10},\quad x2=\frac{R_I-50}{15},\quad x3=\frac{\varphi_{I\,P}-110}{10},\qquad (3)$$

series C

$$x1=\frac{P_{0I}-35}{10},\quad x2=\frac{R_I-50}{15},\quad x3=\frac{\varphi_{I\,P}-110}{10}.\qquad (4)$$

At the second stage the tension within the I area after the left separating rod in stop motion is determined. As an input tension P_{0II} we shall take the output tension of the warp yarns after I area P_I. Table 2 shows orthogonal matrix of the second order for three series A, B and C.

Table 2 Orthogonal matrix of the second order for three series A, B and C for zone II

No.	Factors							
	Input tension				Curvature radius		Contact angle	
	x_1	P_{0II} [cN]			x_2	R_{II} [mm]	x_3	$\varphi_{II\,P}$ [°]
		A	B	C				
1	+1	36	48	60	+1	8	+1	80
2	-1	20	18	30	+1	8	+1	80
3	+1	36	48	60	-1	2	+1	80
4	-1	20	18	30	-1	2	+1	80
5	+1	36	48	60	+1	8	-1	10
6	-1	20	18	30	+1	8	-1	10
7	+1	36	48	60	-1	2	-1	10
8	-1	20	18	30	-1	2	-1	10
9	-1.215	18	15	27	0	5	0	45
10	+1.215	38	51	63	0	5	0	45
11	0	28	33	45	-1.215	1	0	45
12	0	28	33	45	+1.215	9	0	45
13	0	28	33	45	0	5	-1.215	3
14	0	28	33	45	0	5	+1.215	88
15	0	28	33	45	0	5	0	45

Connection between natural and encoded values for II area shall be as follows:

series A

$$x1=\frac{P_{0II}-28}{8},\quad x2=\frac{R_{II}-5}{3},\quad x3=\frac{\varphi_{II\,P}-45}{35},\qquad (5)$$

series B

$$x1=\frac{P_{0II}-33}{15},\quad x2=\frac{R_{II}-5}{3},\quad x3=\frac{\varphi_{II\,P}-45}{35},\qquad (6)$$

series C

$$x1=\frac{P_{0II}-45}{15},\quad x2=\frac{R_{II}-5}{3},\quad x3=\frac{\varphi_{II\,P}-45}{35}.\qquad (7)$$

At the third stage the tension within the III area after the heddle eye. As an input tension P_{0III} we shall take the output tension of the warp yarns after II area P_{II}.

Table 3 shows orthogonal matrix of the second order for three series A, B and C.

Table 3 Orthogonal matrix of the second order for three series A, B and C for zone III

No.	Factors							
	Input tension				Curvature radius		Contact angle	
	x_1	P_{0III} [cN]			x_2	R_{III} [mm]	x_3	$\varphi_{III\,P}$ [°]
		A	B	C				
1	+1	50	58	70	+1	1.4	+1	40
2	-1	20	18	30	+1	1.4	+1	40
3	+1	50	58	70	-1	0.6	+1	40
4	-1	20	18	30	-1	0.6	+1	40
5	+1	50	58	70	+1	1.4	-1	4
6	-1	20	18	30	+1	1.4	-1	4
7	+1	50	58	70	-1	0.6	-1	4
8	-1	20	18	30	-1	0.6	-1	4
9	-1.215	17	14	26	0	1	0	22
10	+1.215	53	62	74	0	1	0	22
11	0	35	38	50	-1.215	0.5	0	22
12	0	35	38	50	+1.215	1.5	0	22
13	0	35	38	50	0	1	-1.215	0
14	0	35	38	50	0	1	+1.215	44
15	0	35	38	50	0	1	0	22

Connection between natural and encoded values for II area shall be as follows:

series A

$$x1=\frac{P_{0III}-35}{15},\quad x2=\frac{R_{III}-1}{0.4},\quad x3=\frac{\varphi_{III\,P}-22}{18},\qquad (8)$$

series B

$$x1=\frac{P_{0III}-38}{20},\quad x2=\frac{R_{III}-1}{0.4},\quad x3=\frac{\varphi_{III\,P}-22}{18},\qquad (9)$$

series C

$$x1=\frac{P_{0III}-50}{20},\quad x2=\frac{R_{III}-1}{0.4},\quad x3=\frac{\varphi_{III\,P}-22}{18}.\qquad (10)$$

Figure 3 shows experimental setup, which includes 9 units. The first unit 1 is a device for threading and tension of warp yarn. In order to avoid ballooning, warp yarns 9 were wound on a cylindrical take-up which fed it into the measurement zone. Slack-side tension was created using cymbal tension device.

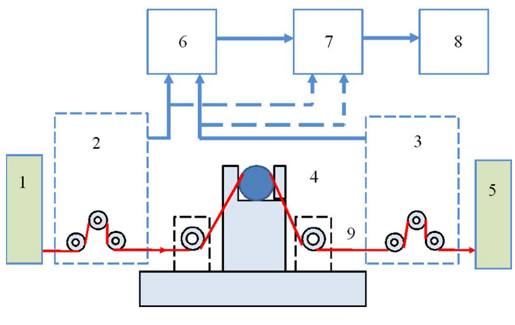

Figure 3 Scheme of the experimental setup:
1 - warp yarn threading unit; 2 - metering unit for warp yarn input tension; 3 - metering unit for warp yarn output tension; 4 - environment modelling unit; 5 - warp yarn take up unit; 6 - amplifier; 7 - analog to digital converter ADC; 8 - personal computer; 9 - warp yarn

The second 2 and third 3 units (Figure 3) are intended to measure input and output tension of the warp yarn 9. Based on the value of the input tension of the warp yarn 9 two types of measuring assembly were used in the work.

For tension range 50 cN to 500 cN the fixed tension meter for moving monofilament MT 320M by METROTEKS company with movable outer rollers was used (Figure 4): range of the motion speed for warp yarn 9: 1-6000 m/min, metering accuracy 2%, velocity 0.1 sec, analog output 0-1 B. For tension range 20 cN to 50 cN the second type of the measuring assembly was used. The one that includes two rollers mounted in bearing parts on the fixed axles. The third roller mounted on the cantilever fitted beam in such a way that inner bearing ring was fixed on the beam itself, and outer bearing ring stiffened to roller that interacts with yarn. Friction forces in bearings can be ignored. A warp yarn was supplied to the pulleys in such a manner that slack-side and tight-side appeared to be on the sides of an isosceles triangle. The middle bar flexed under the warp yarn tension, and that led to changing resistance of the tension meter. This has been registered at the corresponding channel of the amplifier 8АНЧ-7М [1, 2].

Crosswise and lengthwise dimensions of the beam have been chosen to make its natural oscillation frequency equal to 1400 Hz. This frequency is many times higher than the frequency of the highest component of tension.

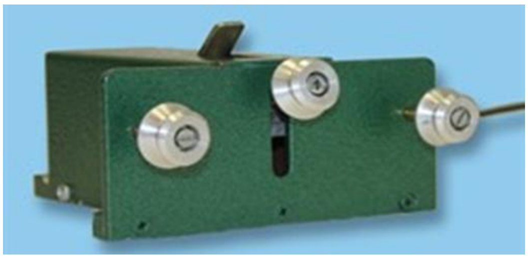

Figure 4 Input and output warp yarn tension metering unit MT 320M

Figure 5 shows the fourth main unit 4 of the experimental setup. It is intended for simulation of interaction conditions between warp yarn 9 and cylinder guides [1, 2]. Two slider pairs, on which aluminium rollers are fixed in rotation bearings, are installed on the foundation in the horizontal grooves. The position of the slider pairs with respect to the central fixed bracket is changed by turning the two levers on the left and on the right. The central, fixed vertical bracket serves to secure the cylinder guides of different diameters, needles of knitting machine, heddles. The fastening is carried out by two screw pairs and clamping bars.

The warp yarn 9 speed was varied due to a fixed-ratio round belt transmission (the fifth unit in Figure 3). Driving pulley of the transmission is rotated by AC motor that was firmly fixed to the foundation of the main measurement system.

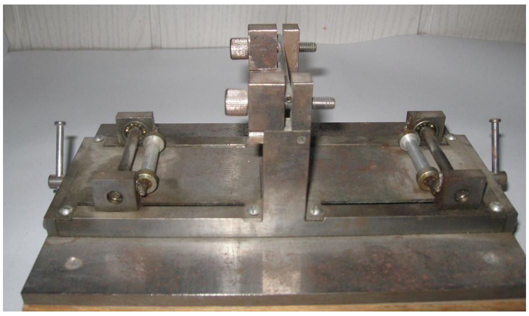

Figure 5 Unit for simulation of interaction conditions

Analog signals from the 3^{rd} and 4^{th} units measuring warp yarn tension (for the first type of the measurement assembly) or from the amplifier 6 (for the second type of the measurement assembly) is being received by analogue-to-digital converter ADC 7 (Figure 6), enabled as a multifunction board L-780M with signalling processor ADC 14 bit/400 kHz having 16 differential input analog and output digital channels, which is connected to the PCI-connector 8. It is possible to generate interrupts after filling a part of FIFO-buffers of ADC and DAC.

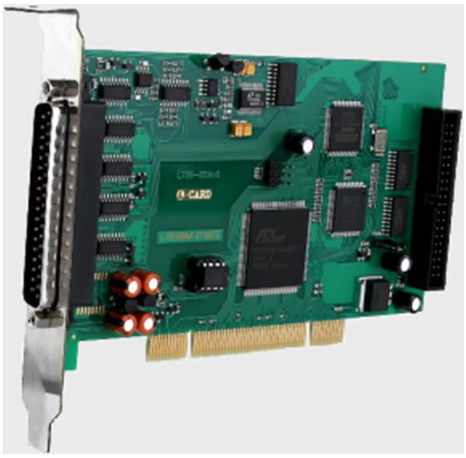

Figure 6 Analogue-to-digital converter ADC

3 RESULTS AND DISCUSSION

As a result of implementation of experimental designs (Tables 1-3) for each series A, B, and C, as well as for each area I, II, and III, 10 concurrent metering were conducted. Table 4 shows their average values.

Applying well-known methods to determine coefficient in the regression equation (1) for orthogonal design of the second order [1-2], taking into account dependences (2-10), the following regression dependences are obtained:

For area I:

series A

$$P_I = 0.02 + 0.91P_{0I} + 0.01R_I + 0.01P_{0I}\varphi_{IP}, \quad (11)$$

series B

$$P_I = 211.44 + 1.91P_{0I} - 0.72R_I - 3.71\varphi_{IP} + 0.003P_{0I}\varphi_{IP} - 0.02P_{0I}^2 + 0.01R_I^2, \quad (12)$$

series C

$$P_I = 0.37 + 0.92P_{0I} + 0.02R_I + 0.01\varphi_{IP} + 0.001P_{0I}R_I + 0.003P_{0I}\varphi_{IP} - 0.0002R_I^2, \quad (13)$$

For area II:

series A

$$P_{II} = 1.28 + 0.99P_{0II} - 0.32R_{II} - 0.001\varphi_{IIP} + 0.003P_{0II}\varphi_{IIP} + 0.001R_{II}\varphi_{IIP} + 0.02R_{II}^2, \quad (14)$$

series B

$$P_{II} = 1.68 + 0.98P_{0II} - 0.29R_{II} - 0.002\varphi_{IIP} + 0.002P_{0II}\varphi_{IIP} + 0.0012R_{II}\varphi_{IIP} + 0.018R_{II}^2, \quad (15)$$

series C

$$P_{II} = 2.45 + 0.99P_{0II} - 0.44R_{II} - 0.002\varphi_{IIP} + 0.002P_{0II}\varphi_{IIP} + 0.002R_{II}\varphi_{IIP} + 0.03R_{II}^2, \quad (16)$$

For area III:

series A

$$P_{III} = 2.86 + 1.08P_{0III} - 4.21R_{III} + 0.004\varphi_{IIIP} + 0.002P_{0III}\varphi_{IIIP} - 0.05P_{0III}R_{III} + 2.02R_{III}^2, \quad (17)$$

series B

$$P_{III} = 2.66 + 1.06P_{0III} - 3.67R_{III} + 0.004\varphi_{IIIP} + 0.002P_{0III}\varphi_{IIIP} - 0.04P_{0III}R_{III} + 1.77R_{III}^2, \quad (18)$$

series C

$$P_{III} = 3.96 + 1.07P_{0III} - 5.54R_{III} + 0.007\varphi_{IIIP} + 0.002P_{0III}\varphi_{IIIP} - 0.04P_{0III}R_{III} + 2.62R_{III}^2. \quad (19)$$

Figure 7 shows response surfaces warp yarn tension dependence on tension and radius of the cylinder were obtained subject to fixed value of the calculated contact angle of the cylinder. This value corresponded to the centre of the experiment (Tables 1-3).

Adequacy of the obtained regression dependences was verified using SPSS software application for statistical processing of experimental findings [2]. Analysis of significance of the coefficient of the regression equations (11-19) allowed to discard insignificant ones [3, 7-8].

Obtained graphical dependences between warp yarn tension and cylinder radius are of interest, taking into account fixed value of the input tension and calculated contact angle of the cylinder. These values corresponded to the center of the experiment (Tables 1-3).

The analyse of graphical dependences provided existing bending points. These points have the minimum warp yarns tension within I, II, and III areas. This allows to raise a question of geometric sizing of guiding and working components of a loom.

Using regression dependences (11-19) we have found values of the warp yarn tension in the III area before fell of the cloth for different moments of the cloth components formation at the shuttleless looms. Values of the deflection of warp yarns, during shedding, battening and removal of cloth, was taken into account as a value of the input tension in I area.

Table 4 Average values of tension by zones I, II and III

Experiment No.	Output tension of warp yarn *Pi* [cN]								
	Cotton yarn 18.5 x 2 tex			Flax 41 tex			Wool 31 x 2 tex		
	i=I	*i*=II	*i*=III	*i*=I	*i*=II	*i*=III	*i*=I	*i*=II	*i*=III
1	36.12	44.77	56.71	48.06	57.72	64.45	60.08	70.48	77.03
2	21.92	25.06	22.84	20.99	21.92	20.18	33.91	35.61	33.27
3	35.67	44.79	58.75	47.47	57.60	66.32	59.18	70.32	79.55
4	21.64	25.08	23.71	20.71	21.88	20.81	33.38	35.53	34.44
5	33.97	37.20	52.12	45.59	49.35	60.05	57.26	61.56	72.65
6	20.58	20.69	20.89	19.85	18.54	18.69	32.24	30.83	31.23
7	33.63	37.76	54.23	45.13	49.96	62.05	56.56	62.42	75.35
8	20.36	21.02	21.79	19.63	18.79	19.36	31.82	31.29	32.49
9	19.75	20.52	18.81	18.98	16.82	15.28	30.29	29.84	28.27
10	36.22	43.03	58.25	34.81	56.67	67.08	60.84	69.12	79.85
11	27.78	32.62	40.17	33.22	37.51	42.63	45.17	50.61	56.20
12	28.17	31.81	38.05	33.69	36.80	40.78	45.95	49.54	53.45
13	27.00	28.51	36.62	32.45	33.51	39.47	44.34	45.71	52.20
14	29.05	35.59	40.59	34.58	40.47	43.05	46.95	53.73	56.08
15	28.00	31.81	38.56	33.49	36.78	41.22	45.62	49.51	54.11

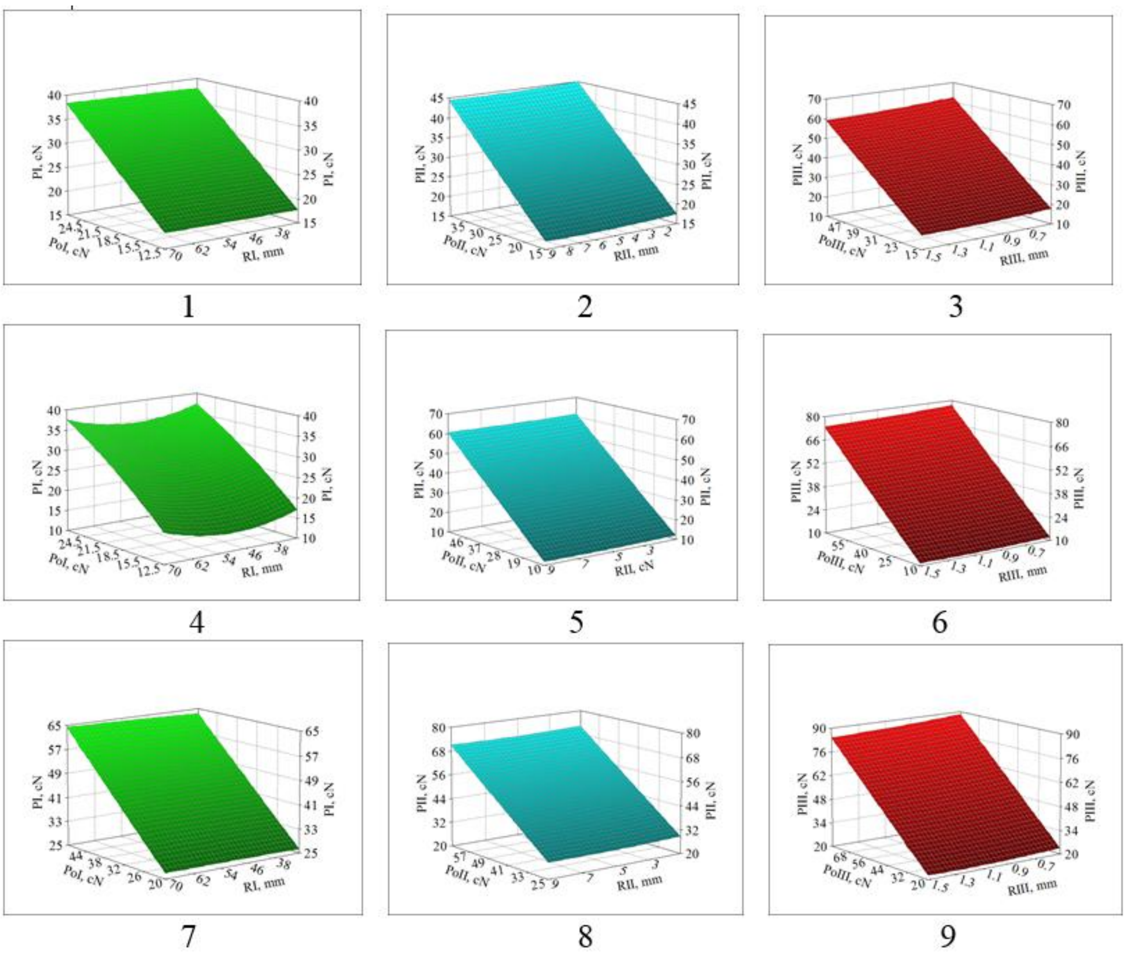

Figure 7 Curve based on warp yarn tension according to loom zones (■ - zone I, ■ - zone II, ■ - zone III): 1, 2, 3 - for series A; 4, 5, 6 - for series B, 7, 8, 9 - for series C

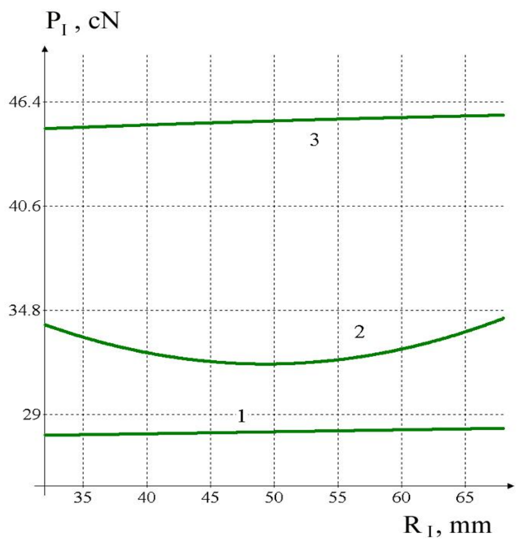

Figure 8 Dependence of the warp yarns tension after I area: 1 - for series A; 2 - for series B; 3 - for series C

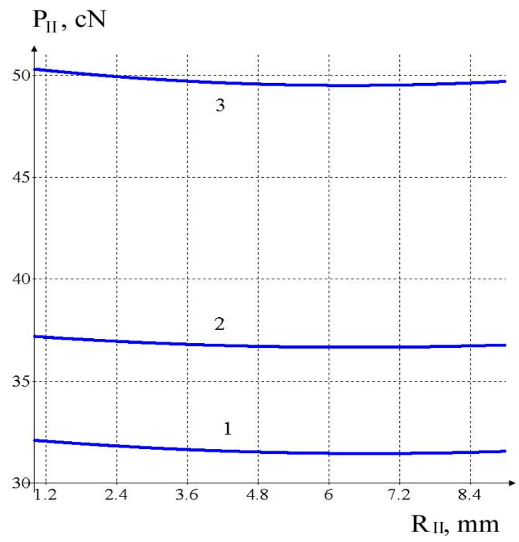

Figure 9 Dependence of the warp yarns tension after II area: 1 - for series A; 2 - for series B; 3 - for series C

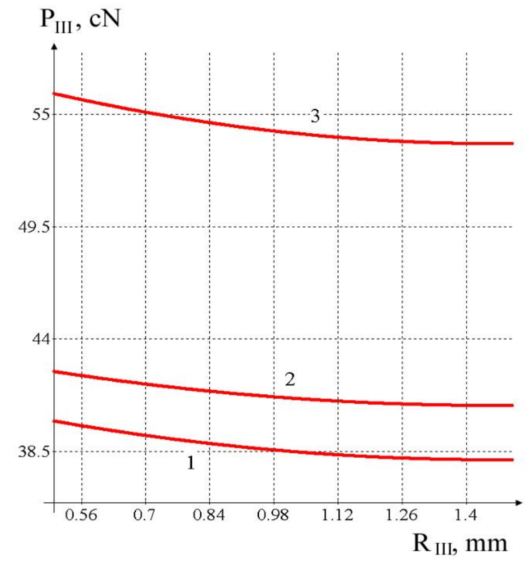

Figure 10 Dependence of the warp yarns tension after III area: 1 - for series A; 2 - for series B; 3 - for series C

From analyse of graphical dependences (Figure 11) allowed to determine that the toughest formation conditions will be for series B during manufacture of sindon; above mentioned is based on bleached flax of wet spun 41 tex. This can be explained by the high value of the rigidity coefficient of the strain and flexure of the warp yarns.

Obtained results can be applied for weaving development to determine the tension at a primary stage when forming fabric.

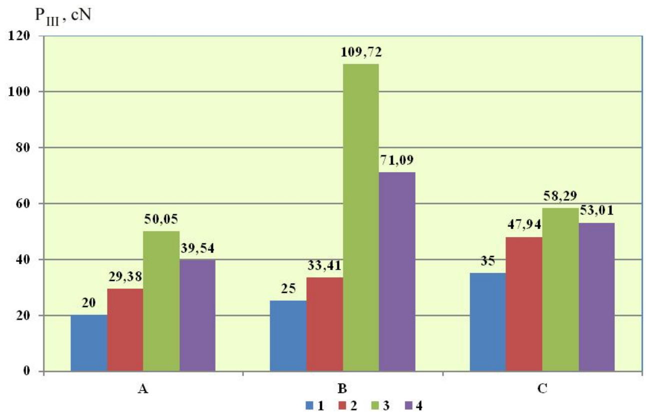

Figure 11 Warp yarns tension P_{III} histogram before fell when forming fabric: A - tartan (warp - carded cotton yarn 18.5x2 tex); B - sindon (warp - bleached flax of wet spun 41 tex); C - boston twill (warp - wool 31.2x2 tex); ■ - threading tension of warp yarns; ■ - warp yarns tension working with closed shed; ■ - tension of warp yarns with fully opened shed; ■ - tension of warp yarns during battening

4 CONCLUSIONS

Resulting from conducted integral experimental research of the interaction process between warp yarns and cylinder guiding surfaces - the latter simulate guiding surfaces and working components of looms - we obtained regression dependences, that allow to determine changes in tension of the warp yarns in the areas from warp beam to the area of fabric formation. Dependences were obtained taking into account types of feedstock processed and construction of the specific looms. Obtained results may be used to optimize weaving process flow in terms of optimizing construction peculiarities, reducing number of yarn breaks, and improving quality of the manufactured fabrics.

***Acknowledgement**: We are really grateful to the management of the T-Style Ltd., housed by Rivne "Lyonokombinat" Factory, for supporting our experiments with feedstock and providing us with possibility to test results of the investigation in a production environment. This study could not be completed without LGraph2 program for registring, visualising and processing of the analog signals and technical support in processing of the experiments results provided by the L-Card Company.*

5 REFERENCES

1. Shcherban’ V.Yu., Khomiak O.N., Shcherban’ Yu.Yu.: Thread mechanics, Library of official editions, Kyiv, 2002
2. Shcherban’ V.Yu., Kolysko O.Z., Sholudo M.I., Kalashnyk V.Yu.: Algorithmic, software of mathematical components of CAD in industry, Education of Ukraine, Kyiv, 2017
3. Vasilchenko V.N., Shcherban’ V.Yu.: Equations of ground warp thread equilibrium in the area of multilayer technical fabric formation, Izvestiya Vysshikh Uchebnykh Zavedenii. Technology of Textile Industry 5, 1986, pp. 44-47
4. Shcherban’ V.Yu.: Determination of the geometrical characteristics of the axis form for thread moving along the deformable guiding surface, Izvestiya Vysshikh Uchebnykh Zavedenii. Technology of Textile Industry 6, 1990, pp. 52-55
5. Koo Y., Kim H.: Friction of cotton yarn in relation to fluff formation on circular knitting machines, Textile Research Journal 72, 2002, pp. 17-20
6. Vasconcelos F.B., Marcicano J.P.P., Sanches R.A.: Influence of yarn tension variations before the positive feed on the characteristics of knitted fabrics, Textile Research Journal 85, 2015, pp. 1864-1871
7. Shcherban’ V.Yu.: Determination of the technological efforts during the beating process when forming multilayer technical fabric, Izvestiya Vysshikh Uchebnykh Zavedenii. Technology of Textile Industry 3, 1990, pp. 44-47
8. Shcherban’ V.Yu.: Determining the technological forces during beating-up in the production of multilayer industrial fabrics, Izvestiya Vysshikh

Uchebnykh Zavedenii. Tekhnologiya Tekstil'noi Promyshlennosti 4, 1990, pp. 41-44
9. Kovar R.: Impact of directions on frictional properties of a knitted fabric, Vlákna a textil (Fibres and Textiles) 2, 2007, pp. 15-20
10. Sodomka L., Chrpová E.: Method of determination of euler friction coefficients of textiles, Vlákna a textil (Fibres and Textiles) 2-3, 2008, pp. 28-33
11. Donmez S., Marmarali A.: A Model for Predicting a Yarns Knittability, Textile Research Journal 74, 2004, pp. 1049-1054
12. Weber M.O., Ehrmann A.: Necessary modification of the Euler-Eytelwein formula for knitting machines, The Journal of The Textile Institute 103, 2012, pp. 687-690
13. Liu X., Chen N., Feng X.: Effect of Yarn Parameters on the Knittability of Glass Ply Yam, Fibres&Textiles in Eastern Europe 16, 2008, pp. 90-93
14. Hammersley M.J.: A Simple Yarn-friction tester for use with knitting yarns, The Journal of the Textile Institute 64, 1973, pp. 108-111