Impact of yarn count, noil percentage and yarn tension on structure of jersey fabric

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Using the combed cotton spinning route, a number of yarns from Egyptian cotton Giza 75 FG with counts of 14.3, 16.7, 20.0 and 25.0 tex were spun. Each of the yarns were spun with a higher twist factor and different noil percentage of 14, 16, 18 and 20%. The yarns are being used to knit two groups of plain single jersey fabrics on a small diameter single bed circular knitting machine with two different yarn tensions at the knitting zone. The first group of samples was knitted with a usual yarn tension used in making knitted fabrics underwear (0.15 cN/tex), while the other group of sample was knitted with a higher tension (0.40 cN/tex). The measurements are statistically analyzed and tested.
Key words: *combed cotton yarn, noil percentage, single jersey fabric, yarn tension, parameters*

1. Introduction

Cotton spun yarns are made from staple fibres using a particular route of yarn production consisting of the following processes: fibre preparation, carding, preparing for combing, combing, drawing after combing, roving as well as ring spinning. In the combing process a certain percentage of short fibres are eliminated (usually from 5 to 25%) where fibres are additionally blended, better parallelized and cleaned from remained impurities and neps. Greater straightness, longitudinal parallelization, better arranging of fibre ends, higher uniformity of fibre length provide a lower mass irregularity and a higher utilization of fibre strength [1]. The percentage of fibres to be eliminated in the fibre combing process depends on average fibre length, percentage of short fibres and the yarn field of application [2].

Single jersey knitted fabrics, especially ready-made knitted garments, t-shirts, underwear and lingerie are an important part of the textile sector. Importance can be explained in facts that it has an elastic and light structure, single jersey fabrics are easily and quickly produced, they have a lighter weight and lower production cost, and finally, because of their smooth surface, they are convenient for printing [3]. Single cotton yarns with counts from 14 to 25 tex are mostly used for making a quality knitted fabric underwear. The knitted fabrics made from yarn counts of 14 and 16 tex can be used for light summer clothing. The knitted fabric made from yarns count of 20 tex are more suitable for common male underwear, whereas the fabrics made from yarns count of 25 tex can be used for women's winter underwear. The stitches of plain single jersey fabrics have the same length, colour and size, i.e. they are made of one yarn count, raw material and structure. The principle of producing plain single jersey fabrics is that one yarn is knitted into one course.

The usual yarn tension in production of plain single jersey fabrics ranged from 0.1 to 0.2 cN/tex. With production of specific or complicated structures knitting tension reaches up to 0.5 cN / tex. Yarn tension influence on many characteristics and properties of fibers and yarns, changing performance and application of products [4-8]. The lengths of the yarn incorporated in structure depend on needle dragging depth and yarn tension at highest point of stitch making [9, 10]. It follows that the consumption of thread in the loop affect on the density of the stitches in horizontal and vertical direction, the surface density, the cover factor etc. The precise analysis shows that consumption of yarn for loop formation depends on surface coefficient of yarn and yarn tension in knitting zone during loop formation. All these parameters and many others are also affected by the yarn count [11].

Basic physical and mechanical parameters of the single jersey fabrics structure knitted from cotton combed yarns with different counts and noil percentage and with different yarn tensions during the knitting process are investigated. Due to an elimination of raw materials influence on knitted fabric properties, it was selected only Egyptian cotton Giza 75 FG for yarn production. Further yarns were spun with higher twist factors. Knitted fabric produced with higher yarn twist factor commonly used for children lightweight summer upper garments.

2. Theory

In the analysis of the parameters of the knitted fabric structure basic parameters such as horizontal fabric density (Dh), vertical fabric density (Dv), stitch length (ℓ), fabric thickness (D_{pl}) and mass per unit area (m), are significant [12. 13]. Beside basic parameters mostly used parameters are: wale spacing (A), height of stitch course (B), coefficient of fabric tightness (C), volume mass of the fabric (V_m) and mass porosity of the fabric (P_m) [13-15]. Knitted fabric parameters are presented and explained in equations 1 to 10.

Shrinkage of the knitted fabric in the course direction after removing the fabric from the machine can be calculated by the following equation:

$$s = (1 - \frac{A}{R})100 \tag{1}$$

Where is: *s* – shrinkage (%), A - wale spacing (mm), R - machine gauge (mm).

The calculated knitted fabric shrinkage in the course direction after taking off the machine and relaxation after 72 hours often ranges from 22 to 32 % Equation (1).

According to the previous studies it is well known that knitted fabrics after manufacturing still "breathe", particularly for the first 72 hours after taking off from a machine. Therefore, it is necessary to leave them under the standard conditions in order to perform its dry relaxation. After relaxation analysis of knitted fabric structure parameters should be done [16, 17].

Wale (2) and course spacing (3) are related to stitch density in course and wale directions:

$$A = \frac{M_{jp}}{D_h} \tag{2}$$

$$B = \frac{M_{jp}}{D_v} \tag{3}$$

Where is: A – wale spacing, mm; Dh – horizontal fabric density, cm^{-1}; B – course spacing, cm; Dv – vertical fabric density, cm^{-1}; M_{jp} is measurement unit, mm.

Stitch length (4) [12]:

$$\ell = 1{,}57A + d\pi + 2B \tag{4}$$

Where is: ℓ_c - calculated stitch length (mm), d - yarn thickness (mm).

Barella's equation (5) for the calculation of yarn diameter [18]:

$$d = 2\sqrt{\frac{Tt}{\gamma \cdot \pi \cdot 1000}} \tag{5}$$

Where is: d – yarn diameter (mm), Tt – yarn count (tex), γ – yarn density (g/cm^3).

Tightness factor [12]:

$$C_f = \frac{\sqrt{Tt}}{l} \tag{6}$$

Where is: ℓ - stitch length (mm).

Linear module of the stitch (7):

$$\delta = \frac{\ell}{d} \tag{7}$$

Mass per unit area (m) in g/m^2 is determined according to following equation (8) [12]:

$$m = Dh \cdot Dv \cdot \ell \cdot Tt \cdot 10^{-2} \tag{8}$$

Volume mass of the knitted fabric (10):

$$V_m = \frac{m}{(1000 \cdot D_{pl})} \tag{9}$$

Where is: V_m – volume mass of the knitted fabric (g/cm^3), D_{pl} – knitted fabric thickness (mm)

Mass porosity of the fabric (11):

$$P_m = (1 - \frac{V_m}{\gamma_c})100 \tag{10}$$

Where is: P_m – mass porosity of the fabric (%), γ_c – density of cotton fibers (g/cm^3) (usually 1.54 g/cm^3).

3. Experimental

The research work was carried out according to the following plan to produce yarns and knitted fabrics.

In this paper samples was designated as follows:

- Designation of yarn count: C1 is 14.3 tex, C2 is 16.7 tex, C3 is 20.0 tex and C4 is 25.0 tex
- Designation of noil percentage: N1 is 14%. N2 is 16%. N3 is 18% and N4 is 20%

The yarns of count of 14.3, 16.7, 20.0 and 25.0 tex were spun from Egyptian cotton Giza 75 FG.

Each of the mentioned yarns were spun with a different noil percentage of 14, 16, 18 and 20% and their basic physical and mechanical properties were tested (Fig.1). The real yarn count was tested in accordance with the standard HRN ISO 2060:2030 [19], while twist number of yarn was tested on MesdanLab Twist tester in accordance with the standard ISO 17202 [20].

Tab.1 Fibre characteristics of Giza 75 FG cotton [18]

Mean fibre length. (determined by mass), mm	25.1
Mean upper quarter fibre length, mm	29.8
Percentage of fibres shorter than 11 mm, %	4.8
Coefficient of variation of fibre length, %	28.7
Fineness, mtex	189
Tenacity, cN/dtex	5.4
Maturity index, %	80

Tab.2 Characteristics of the retrofitted circular knitting machine for knitting fabric samples

Characteristics of the single bed knitting machine	Values
Machine gauge (E), needles per inch	17
Machine pitch (G_m), mm	1.46
Needle bed diameter, mm (inch)	95 (3.75)
Number of needles (Ni)	200
Speed, rpm	90

Twist factor was calculated according to equation 11.

$$\alpha_{tex} = \sqrt{Tt} \cdot Tm \qquad (11)$$

Where α_{tex} is twist factor in $m^{-1}tex^{1/2}$ and Tm is twist number of yarn in m^{-1}.

The parameters of yarn unevenness were determined according to the standard ISO 16549:2004 [21] on the Keisokki evenness tester, while tensile properties of yarns were tested according to the standard ISO 2062 [22] on the Statimat M strength tester made by Textechno. Yarn hairiness was determined on the basis of counting fibres protruding from the yarn structure in accordance with the standard ASTM D 5674-01 [23] on the Zweigle G 565 tester.

A small diameter single bed circular knitting machine with certain constructional characteristics (Tab.2) was used to knit plain single jersey fabrics. This machine can knit high-quality knitted fabrics from yarn with counts from 10 to 30 tex. For this research the machine was retrofitted and knitting was performed with only one knitting system. The retrofitted knitting machine was fed with one yarn from cop to make one course of the sample.

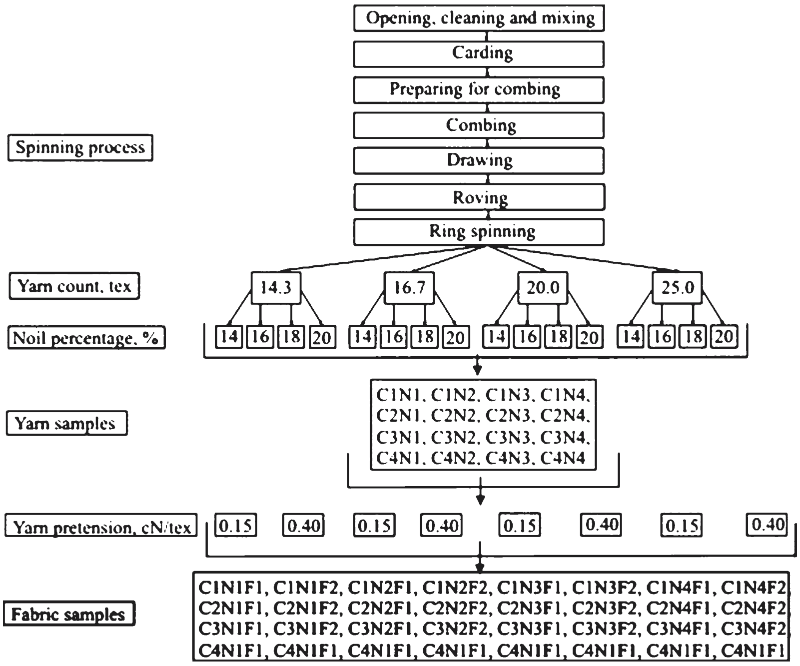

Fig.1 Work plan of yarn and fabric production

There was not positive yarn feeding device that is needles with regulated sinking depth were dragged the certain length of the yarn. Basic sinking depth was set for yarn count 20 tex, therefore knitting with yarn count in range of 14 to 25 tex was possible. Yarn tension was regulated with friction brake which was located 20 cm in front of the knitting zone.

Two groups of samples with different yarn tensions measured approximate 15 cm in front of the knitting zone were made. The first group was knitted with the usual yarn tension used when underwear knitted fabric are made (0.15 cN/tex). The second group had a higher tension of 0.40 cN/tex. Samples of tubular fabric were approximately 10 cm x 2 wide and 1 m long. To make one sample between 800 and 1200 m of yarn was used.

Basic parameters of the structure of the single jersey knitted fabrics were tested. Horizontal and vertical density of the fabric was determined according to the standard BS 5441:1998 [24]. Wale and course spacing was calculated according to the equations 2 and 3. Stitch length was determined according to the standard DIN EN 14970 [25]. Yarn thickness was estimated according to Barella's equation (Equation 5). Fabric thickness was determined according to the standard ISO EN 5084:2003 [26]. Equation 6 was used to calculate tightness factors where experimental stitch lengths were taken. Skewness of courses and fabric spirality were determined by measuring the inclination angle of the wale relative to the vertical line of the fabric. The parameters of the stitch linear module, mass per unit area, volume mass and mass porosity of the fabric were calculated using equations (7) to (10).

4. Results and discussion

Due to the large number of samples and measurements, results and discussion are presented separately for each parameter of the yarns and knitted fabric structures. When measuring characteristics of yarn, emphasis was on the fineness, number of twist and tensile properties of the yarn. When analyzing the knitted fabrics,

Tab.3 Yarn parameters

Samples		Tt_s, tex	Tm, m^{-1}	α_{tex}, $m^{-1}tex^{1/2}$	Unevenness	Tensile properties			
Count, tex	Noil, %				$CV_{m.}$,%	F, cN	ε, %	σ, cN/tex	W, cN×cm
14	14	14.0	1008	3770	15.2	221	4.85	15.8	267
	16	14.7	1007	3860	15.9	242	4.87	16.1	291
	18	14.4	991	3760	17.4	211	4.40	15.1	238
	20	13.3	1007	3670	15.3	268	5.10	16.8	327
Mean value		14.1	1003	3760	15.9	236	4.81	16.0	281
16	14	16.9	951	3920	15.4	260	5.09	15.3	314
	16	17.1	956	3950	14.1	284	5.14	16.7	352
	18	17.4	940	3920	16.0	280	5.23	16.5	333
	20	16.1	963	3860	15.4	210	4.74	16.1	249
Mean value		16.9	953	3920	15.2	259	5.05	16.2	312
20	14	21.0	907	4160	14.2	380	6.00	18.1	528
	16	20.9	886	4050	14.3	381	6.02	18.1	519
	18	20.8	887	4050	14.9	346	5.41	17.3	445
	20	19.7	906	4020	12.3	360	5.56	17.9	478
Mean value		20.6	897	4080	13.9	367	5.75	17.9	493
25	14	24.6	822	4110	13.4	450	5.95	18.0	628
	16	23.6	812	3950	12.5	436	6.48	18.2	612
	18	21.4	771	3570	12.9	402	5.31	16.1	518
	20	24.7	814	4050	12.9	424	5.92	16.9	589
Mean value		23.6	805	3920	12.9	428	5.92	17.3	588

the emphasis was on the measurement of parameters of knitted fabric structure that are important for the use of knitting.

4.1. Yarns

The values of real count, twist number of yarn, twist factor, unevenness parameters (yarn mass coefficient of variation as well as thin and thick places and neps) and breaking properties of the tested yarns are shown in Table 3.

By reducing yarn fineness, twist number of yarn decreases. Twist factor is determined according to equation 11. It is the function of fibre type, yarn count and fabric application. The twist factor ranges from 3570 to 4160 $m^{-1}tex^{1/2}$ for the yarns used in this study. Calculated mean values of twist factor were: C1 (14 tex) 3760, C2 (16 tex) 3920, C3 (20 tex) 4080 and for C4 (25 tex) 3920 $m^{-1}tex^{1/2}$.

The influence of higher twist factor i.e. the higher twist number on yarn

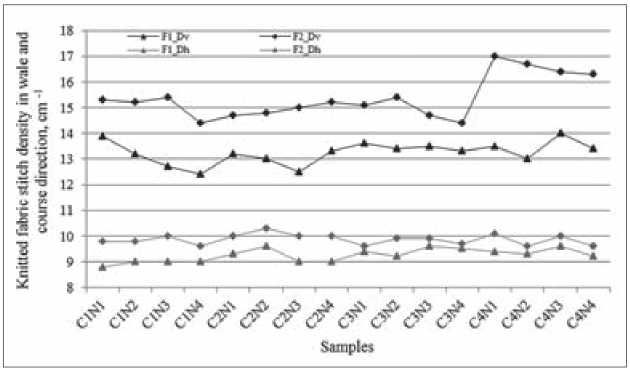

Fig.2 Horizontal (Dh) and vertical (Dv) density of knitted fabric

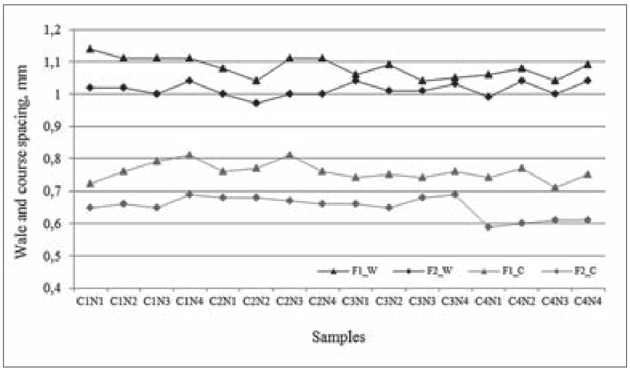

Fig.3 Wale (A) and course spacing (B)

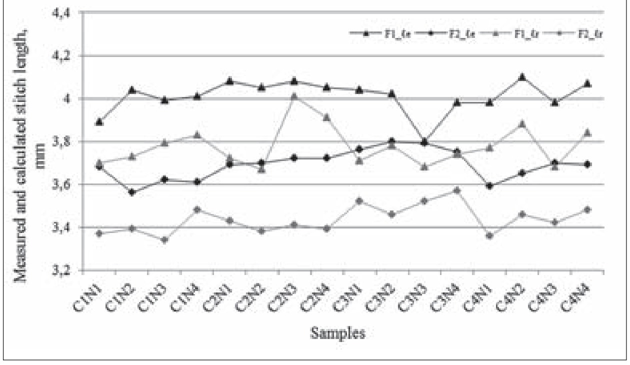

Fig.4 Measured (ℓ_e) and calculated (ℓ_r) stitch length

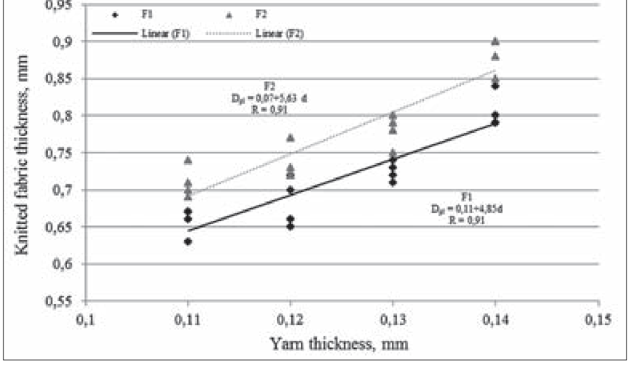

Fig.5 Fabric thickness (D_{pl}) related to yarn thickness (d) with different yarn tension at the entry of the knitting system

Tab.4 Knitted fabric parameters

Samples			Fabric parameters			
Yarn count, tex	Noil, %	Yarn tension during knitting, cN/tex	D_h, cm^{-1}	D_v, cm^{-1}	A, mm	B, mm
14	14	0.15	8.8	13.9	1.14	0.72
	16		9.0	13.2	1.11	0.76
	18		9.0	12.7	1.11	0.79
	20		9.0	12.4	1.11	0.81
Mean value			9.0	13.1	1.12	0.77
14	14	0.40	9.8	15.3	1.02	0.65
	16		9.8	15.2	1.02	0.66
	18		10.0	15.4	1.00	0.65
	20		9.6	14.4	1.04	0.69
Mean value			9.8	15.1	1.02	0.66
16	14	0.15	9.3	13.2	1.08	0.76
	16		9.6	13.0	1.04	0.77
	18		9.0	12.5	1.11	0.81
	20		9.0	13.3	1.11	0.76
Mean value			9.2	13.0	1.09	0.78
16	14	0.40	10.0	14.7	1.00	0.68
	16		10.3	14.8	0.97	0.68
	18		10.0	15.0	1.00	0.67
	20		10.0	15.2	1.00	0.66
Mean value			10.1	14.9	0.99	0.67
20	14	0.15	9.4	13.6	1.06	0.74
	16		9.2	13.4	1.09	0.75
	18		9.6	13.5	1.04	0.74
	20		9.5	13.3	1.05	0.76
Mean value			9.4	13.5	1.06	0.75
20	14	0.40	9.6	15.1	1.04	0.66
	16		9.9	15.4	1.01	0.65
	18		9.9	14.7	1.01	0.68
	20		9.7	14.4	1.03	0.69
Mean value			9.8	14.9	1.02	0.67
25	14	0.15	9.4	13.5	1.06	0.74
	16		9.3	13.0	1.08	0.77
	18		9.6	14.0	1.04	0.71
	20		9.2	13.4	1.09	0.75
Mean value			9.4	13.5	1.07	0.74
25	14	0.40	10.1	17.0	0.99	0.59
	16		9.6	16.7	1.04	0.60
	18		10.0	16.4	1.00	0.61
	20		9.6	16.3	1.04	0.61
Mean value			9.8	16.6	1.02	0.60

tenacity is evident from results shown in Table 2. Namely, increasing the twist factor and number of fibres in the cross yarn section, friction force between fibres increases which leads to increasing the tenacity. The twist factor with samples signed C4 (25 tex) was lower than with samples signed C3 (20 tex) whereby tenacity of sample C3 relatively decreased. Likewise by increasing the twist factor with simultaneously decreasing the yarn fineness (higher number of fibres in yarn cross section) the breaking elongation increases. It was obtained emphatically increasing the work to rupture of yarns, even for 109.3 % (W_{C4}-W_{C1}/W_{C4}) by decreasing the yarn fineness. With garments such as children T-shirts, the higher yarn work to rupture provides their higher durability.

Mass unevenness decreases by reducing yarn fineness. With sample signed C1N3 it was obtained a higher unevenness due to a periodical faults caused by eccentricity of a roll in drawing device of ring spinning machine. It was obtained that the impact of noil percentage on the yarn unevenness was not significant. Impact of percentage of noil on the hairiness of the tested yarns was not significant (conducted t-test).

4.2. Single jersey knitted fabric

Parameters of the horizontal and vertical density of the knitted fabric, wale and course spacing, stitch length, yarn thickness, knitted fabric thickness and tightness factor are shown in Table 4.

Horizontal and vertical density, wale and course spacing

The calculated knitted fabric shrinkage in the course direction after taking off the machine and relaxation ranges from 22 to 32% (Equation 1). In single jersey knitted fabrics stitch density in the wale direction (Dv) is always higher than stitch density in the course direction (Dh) (Tab.4, Fig.2). Stitch density in the course direction (Dh) ranges from 8.8 to 10.3 stitches/cm. The samples knitted with a lower yarn tension (0.15 cN/tex) mainly have a greater wale spacing (A) ranging from 1.04 to 1.14 mm than the samples knitted with a higher yarn tension during knitting (0.40 cN/tex) ranging from 0.97 to 1.04 mm (Fig.3). Stitch density in the wale direction (Dv) ranges from 12.4 to 16.7 stitches/cm. Course spacing of samples knitted by lower yarn tension ranges from 0.71 to 0.81 mm. whereas knitted by higher yarn tension ranges from 0.59 to 0.69 mm. However, by increasing yarn tension during knitting stitch density in the course direction (D_h) and wale spacing (A) significantly doesn't change

Tab.5 Knitted fabric parameters

Samples			Fabric parameters					
Yarn count, tex	Noil, %	Yarn tension during knitting, cN/tex	ℓ_e, mm	ℓ_r, mm	$\Delta\ell$, %	d, mm	D_{pl}, mm	C_f, $tex^{1/2}cm^{-1}$
14	14	0.15	3.89	3.70	4.9	0.11	0.67	9.72
	16		4.04	3.73	7.7		0.66	9.36
	18		3.99	3.79	5.0		0.67	9.48
	20		4.01	3.83	4.5		0.63	9.43
Mean value			3.98	3.76	5.5	0.11	0.66	9.50
14	14	0.40	3.68	3.37	1.6	0.11	0.70	10.28
	16		3.56	3.39	4.8		0.71	10.62
	18		3.62	3.34	7.7		0.74	10.45
	20		3.61	3.48	3.6		0.69	10.48
Mean value			3.62	3.40	4.43	0.11	0.71	10.46
16	14	0.15	4.08	3.72	8.8	0.12	0.70	10.02
	16		4.05	3.67	9.4		0.72	10.09
	18		4.08	4.01	1.7		0.65	10.02
	20		4.05	3.91	3.5		0.66	10.09
Mean value			4.07	3.83	5.9	0.12	0.68	10.06
16	14	0.40	3.69	3.43	7.0	0.12	0.73	11.07
	16		3.70	3.38	8.6		0.77	11.04
	18		3.72	3.41	8.3		0.72	10.99
	20		3.72	3.39	8.9		0.72	10.99
Mean value			3.71	3.40	8.2	0.12	0.74	11.02
20	14	0.15	4.04	3.71	8.2	0.13	0.74	11.07
	16		4.02	3.78	6.0		0.71	11.12
	18		3.80	3.68	3.2		0.72	11.77
	20		3.98	3.74	6.0		0.73	11.24
Mean value			3.96	3.73	5.9	0.13	0.73	11.30
20	14	0.40	3.76	3.52	6.4	0.13	0.80	11.89
	16		3.80	3.46	8.9		0.75	11.77
	18		3.79	3.52	7.1		0.79	11.80
	20		3.75	3.57	4.8		0.78	11.93
Mean value			3.78	3.52	6.8	0.13	0.78	11.85
25	14	0.15	3.98	3.77	5.3	0.14	0.84	12.56
	16		4.10	3.88	5.4		0.79	12.20
	18		3.98	3.68	7.5		0.80	12.56
	20		4.07	3.84	5.7		0.79	12.29
Mean value			4.03	3.79	6.0	0.14	0.81	12.40
25	14	0.40	3.59	3.36	6.4	0.14	0.90	13.93
	16		3.65	3.46	5.2		0.88	13.70
	18		3.70	3.42	7.6		0.90	13.51
	20		3.69	3.48	5.7		0.85	13.55
Mean value			3.66	3.43	6.2	0.14	0.88	13.67

while stitch density in the wale direction (D_v) and course spacing (B) significantly change and primarily influence on a tensile properties of knitted fabric. Other investigators obtained the similar results where yarn diameter and stitch length have direct influence on the wales and courses per unit [27, 28].

Stitch length

Stitch length depends on sinking depth which is adjusted with respect to yarn fineness and product application. The smaller stitch length, knitted on the one machine, is giving more compact fabric structure and greater stitch density and vice versa [27]. For the purposes of this research knitted fabrics with one sinking depth and two yarn tensions during knitting were knit resulting in different stitch lengths for its formation.

In this study the stitch length ranged from 3.56 to 4.10 mm (Tab.5, Fig.5). By knitting with lower yarn tension it ranges from 3.80 to 4.10 mm, whereas by knitting with a higher yarn ten-

Tab.6 Linear stitch module, skewness of courses, spirality, mass per unit area, volume mass and mass porosity

Samples			Parameters of knitted fabric					
Yarn count, tex	Noil, %	Yarn tension during knitting, cN/tex	δ	α, °	β, °	m, g/m²	V_m, g/cm³	P_m, %
14	14	0.15	25.9	67	-23	70	0.104	93.2
	16		26.9	69	-21	66	0.100	93.5
	18		26.6	69	-21	63	0.094	93.9
	20		26.7	70	-20	57	0.090	94.2
Mean value			26.5	69	-21	64	0.097	93.7
14	14	0.40	24.5	68	-22	72	0.103	93.3
	16		23.7	68	-22	82	0.115	92.5
	18		24.1	67	-23	73	0.099	93.6
	20		24.1	69	-21	62	0.090	94.2
Mean value			24.1	68	-22	72	0.102	93.4
16	14	0.15	25.5	71	-19	83	0.119	92.3
	16		25.3	68	-22	83	0.115	92.5
	18		25.5	72	-18	78	0.120	92.2
	20		25.3	72	-18	69	0.105	93.2
Mean value			25.4	71	-19	78	0.115	92.6
16	14	0.40	23.1	73	-17	89	0.122	92.1
	16		23.1	69	-21	97	0.126	91.8
	18		23.3	73	-17	89	0.124	91.9
	20		23.3	71	-19	91	0.126	91.8
Mean value			23.2	72	-19	92	0.125	91.9
20	14	0.15	22.4	71	-19	112	0.151	90.2
	16		22.3	74	-16	102	0.144	90.6
	18		21.1	72	-18	103	0.143	90.7
	20		22.1	71	-19	106	0.145	90.6
Mean value			22.0	72	-18	106	0.146	90.5
20	14	0.40	20.9	72	-18	109	0.136	91.2
	16		21.1	75	-15	117	0.156	89.9
	18		21.1	73	-17	115	0.146	90.5
	20		20.8	72	-18	108	0.138	91.0
Mean value			21.0	73	-17	112	0.144	90.7
25	14	0.15	19.9	72	-18	126	0.150	90.3
	16		20.5	74	-16	126	0.159	89.7
	18		19.9	73	-17	122	0.153	90.1
	20		20.4	75	-15	118	0.149	90.3
Mean value			20.2	74	-17	123	0.153	90.1
25	14	0.40	20.0	74	-16	155	0.172	88.8
	16		18.3	76	-14	143	0.163	89.4
	18		18.5	75	-15	145	0.161	89.5
	20		18.5	77	-13	135	0.159	89.7
Mean value			18.8	76	-15	145	0.164	89.4

sion stitch length ranges from 3.56 to 3.80 mm. Stitch length decreases by increasing yarn tension during knitting which was confirmed by t-test with the degree of significance of p=0.05.

The measured stitch length was compared with the calculated stitch length obtained with equation 4 and then obtained results were compared. The values of the differences of the measured and calculated stitch lengths ($\Delta\ell$) are given in the Tab.5. There was a significant difference between measured and calculated stitch length. There are different forms of equations for calculation stitch length [13, 14 i 28]. Equation 4 used in this research for calculating stitch length is the mostly used equation, primarily because of its simplicity and practicability. In that equation two parameters of the knitted fabric, one parameter of the yarn and three different coefficients are used. The equation was derived under certain conditions where stitch is observed in one plane. Wale spacing (equation 2) was determined from stitch density in the course direction (Dh), course spacing

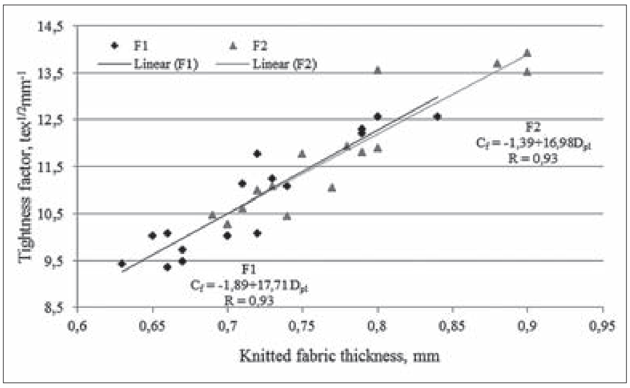

Fig.6 Fabric tightness factor (C_f) related to fabric thickness (D_{pl}) with different yarn tension at the entry of the knitting system

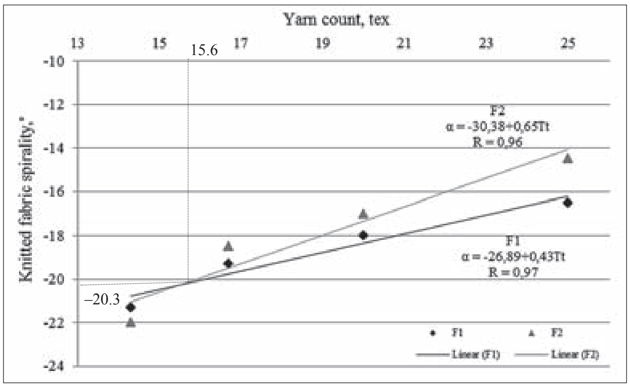

Fig.7 Fabric spirality (α)

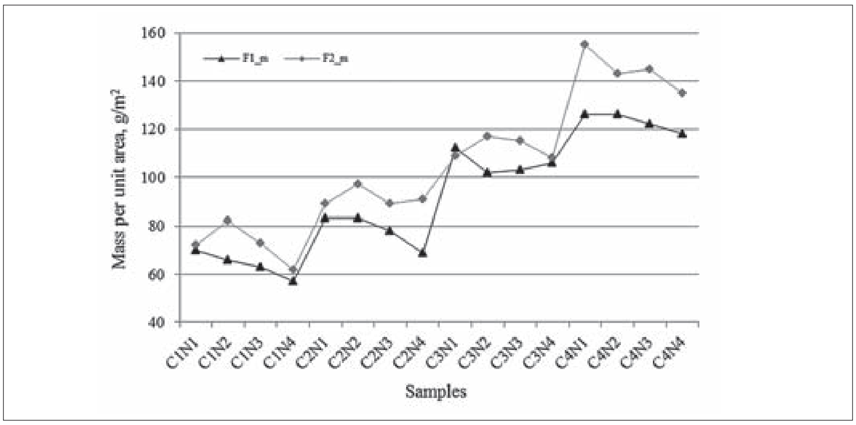

Fig.8 Mass of knitted fabric (m) produced by different yarn count and yarn tension

(equation 3) from the stitch density in the wale direction (Dv), and yarn thickness using Barella's equation (equation 5). For example, experimentally by unravelling the yarn from the knitted fabric for sample C1N1F1 a stitch length was 3.89 mm and using the equation 4 a stitch length of 3.70 mm was obtained or 4.9% lower. With all samples calculated lengths of stitch are lower than the experimental ones ranging from 1.6 to 9.4% or about 6.5% on average. These values indicate that equation 4 does not describe the form of stitch in knitted fabrics entire properly. If lower differences between the experimental and calculated data are desired, an equation which more accurately describes the analysed structure of the fabric should be used, referring to analysing a stitch in three planes, where fabric thickness (D_{pl}) would be a significant parameter. Stitch length is the most important factor affecting the course and wales per unit length and other variable such as tightness factor, linear density, stitch density, thickness, tensile properties of knitted fabric etc. [27, 28].

Fabric thickness and tightness factor

The knitted fabrics knitted with greater tension had a shorter stitch length and greater fabric thickness, meaning that force of tension at the entry of the knitting system affects the geometric stitch form. In some theoretical considerations, the thickness of plain single jersey fabrics is two to three times greater than the thickness of the yarn [12]. In this research, the fabric thickness is 5.4 to 6.8 times higher than the average yarn thickness, which again leads to the conclusion that the precise geometric form of the stitch should be analysed in three dimensions (Tab.5, Fig.5).

The obtained data were statistically analyzed where relationship between yarn thickness and knitting tension during knitting on knitted fabric thickness were obtained.

At the entrance of knitting system with the yarn tension of 0.15 cN/tex equation has following form:

$$D_{pl15} = 0.11 + 4.85d;\ R = 0.91;\quad 0.11 \leq d \leq 0.14,$$

while at the yarn tension of 0,40 cN/tex equation is as it follows:

$$D_{pl40} = 0.07 + 5.63d;\ R = 0.91;\quad 0.11 \leq d \leq 0.14$$

The cover factor were determinate according to the equation 6 where stitch length in equation was in cm. Experimentally determined cover factor is in the range 9.36 to 13.93 $tex^{1/2}cm^{-1}$ (Tab.5) and decrease with increase of yarn count. The knitted fabric produced with higher yarn tension have higher cover factor since lower stitch length were obtained. Similar results were reported by other researchers [29]. The statistical analysis of data revealed correlation of covering factor and knitted fabric thickness where mathematical dependence between these parameters was calculated (Fig.6).

The correlation between the knitting fabric thickness and the cover factor of knitted fabric produced with the yarn tension of 0.15 has following form:

$$C_{f15} = -1.89 + 17.7D_{pl};\ R = 0.93;\quad 0.60 \leq D_{pl} \leq 0.90,$$

While knitting with yarn tension of 0.40 cN/tex is as it follows:

$$C_{f40} = -1.39 + 16.98D_{pl};\ R = 0.93;\quad 0.60 \le D_{pl} \le 0.90.$$

The knitted fabrics with cover factor of 12 are usually porous and mostly are used for light spring clothes. Knitted fabrics with cover factor in range of 12 to 14 are considered as quality knitted fabrics with optimal porosity and they are used for quality summer shirts. More voluminous and less porous knitted fabrics have cover factor under 12 and they are used for various autumn/winter shirts.

Linear stitch module, skewness of the courses and spirality

Linear stitch module, i.e. ratio of yarn length in the stitch and yarn thickness, depends on sinking depth and yarn tension during knitting process [12, 30, 31]. Since all fabrics were made with one sinking depth, only yarn tension was influenced on linear stitch module and it ranges from 18.3 to 26.9 (Tab.6). The lowest obtained linear stitch module amounths 16.6 and that knitted fabric had the most compact structure with lowest elasticity. The largest tolerated linear stitch module are up to 30, and knitting is used to a light and porous summer clothing. Linear stitch modules obtained in this study is in the practical limits. The linear stitch module was higher in the yarns with nominal counts 14 and 16 tex than in the yarns with nominal counts 20 and 25 tex. The linear stitch module is also slightly higher, in the range of 4.8 to 10.0% , for the fabrics made with less tension during knitting. (Tab.6)

Knitted fabric spirality or skewness of the courses (α) relating to the longitudinal axis of the fabric depends on many parameters [32-35]. First of all, it depends on the rotation direction of the machine cylinder and the twist direction of the yarn as well as on the structure and number of yarns knitted into the course. Fabric without spirality has courses parallel to the edge of the fabric. The skewness of the courses can be to the left or to the right side, i.e. positive or negative fabric spirality occurs. Direction of fabric course skewness is mainly decided by the twist direction of the yarn, and when the Z yarn is used to knit, the courses of the fabric inclines rightward, and when the S yarn is used to knit, the courses of the fabric inclines leftward [34]. The study of the effect of yarn count, yarn twist, and fabric tightness on spirality revealed that the yarn twist direction and fabric tightness were the most predominant factors contributing to fabric spirality [35].

Skewness of the samples stitch courses lies at an angle from 67° to 77°, or the fabric has a negative spirality ranging from -13° to -23° (Tab.6, Fig.7). Coarser yarns caused lower spirality. By knitting with coarser yarns and higher yarn tensions, less fabric spirality was obtained.

The regression curves "Spirality-Yarn count" with two levels of yarn tension crosses to point -20.3^0 for spirality and 15.6 for yarn count (Fig.7). Namely, there were two different fabric behaviour area regarding spirality. It practically means that fabrics knitted with coarser yarn than 15.6 tex at the tension level of 0.4 cN/tex had a lower spirality and it pronouncedly decrease.

Mass per unit area

The mass per unit area were determined experimentally. The length and the width of the samples were measured and used for calculation of surface area. The samples were weighed where is from mass and surface area mass per unit area calculated.

It is well known that knitting at one machine, with one sinking depth and with coarser yarn compact knitted fabric is produce. Mass per unit area depends on many parameters of the knitting process as well [36-38]. The samples produced with yarn counts of 14 tex and with yarn tension of 0.15 cN/tex (tensile force of 2 cN) provides the lowest mass per unit area, 64 g/m^2 on average (Tab.6, Fig.8). Knitting with the coarse yarns i.e. with yarn count of 25 tex and higher yarn tension, i.e. 0.40 cN/tex (tensile force of 10 cN), higher mass per unit area were obtained, 145 g/m^2 on average, which is more than double compared to the yarn count of 14 tex. Increasing of the yarn tension leads to the increase of mass per unit area in the range of 5.6 to 17.9 %. It is noticeable that knitting with the lower yarn tension and higher noil percentage, mass per unit area decreases. Knitting with the higher yarn tension this change is not easy noticeable, it is more variable.

Volume mass and mass porosity

Knitted fabric volume mass (V_m) describes relation of knitted fabric mass per unit area and fabric thickness. Volume mass of samples were calculated according to the equation 9 and it ranged from 0.090 to 0.172 g/cm^3. Since sinking depth was same for all samples knitting with finer yarns lower volume mass was obtained. Increase of yarn tension, mass per unit areas and thickness of fabric increase which mostly leads to increase of volume mass, from 5.1 to 8.7%. Only the yarn count of 20 tex has lower volume mass of 1.3%. Different noil percentages of the same yarn count have not significant influence on the volume mass of fabric. Mass porosity of the fabric shows the percentage portion of holes in the fabric [19, 31]. The porosity of the knit is affected by the yarn count, the length of the loop and knitted fabric thickness [9]. The effect of the loop length has more influence on porosity than the stitch density and the thickness [32]. Based on volume mass and density of fibres, mass porosity of the fabric was calculated by using equation 10, and it is ranging from 88.8 to 94.2%. Generally mass porosity is higher by knitting with the lower yarn tension.

5. Conclusions

The lightest knitted fabrics of 57 g/m^2 is made with the finest yarns of 14

tex with 20% of noil where the yarn tension at the entrance to the knitting system was 0.15 cN/tex. The most massive knitted fabric of 155 g/m^2 is produced with the most coarse yarns count of 25 tex with 14% of noil where the yarn tension at the entrance to the knitting system was 0.4 cN/tex. Thus, the count and the yarn tension in the knitting process increases the mass per unit area up to 2.7 times.
Knitting with yarn tension of 0.15 and 0.40 cN/tex, significant differences in the horizontal and vertical density of the knitted fabrics was not obtained. For all samples the calculated stitch lengths ranged from 9.0 to 10.1 stich/cm, or 9.5±0,5 stitch/cm on average which is in the range of allowed practical deviations. Increase of the yarn tension, vertical density noticeable increase, from 10 to 22 %. For all samples is noticeable that calculated stitch length is lower than experimentally determinate stitch length of 6.5%. If lower differences between the experimental and calculated data are desired, an equation which more accurately describes the analysed structure of the fabric should be used, referring to analysing a stitch in three planes, where fabric thickness (D_{pl}) would be a significant parameter.
Knitted fabric produced with higher yarn tension have higher cover factor i.e. yarn tension during knitting effects on the knitted fabric porosity and voluminosity.
Knitting with finer yarns the linear stitch module is significantly higher. Knitting with the higher yarn tension the linear stitch module is slightly lower and it ranges from 18.3 to 26.9 Decreasing yarn count from 14 to 25 tex knitting by tension of 0.15 cN/tex to 0.40 cN/tex spirality of knitted fabric decreases from -22° to -15°. Increase of yarn count increases knitted fabric spirality knitting by the one machine and with one sinking depth. The knitted fabric spirality slightly decreases knitting with the higher yarn tension since compression of stitches in a row increase. By increasing the noil percentage in the yarns, spirality has tendency of slight decrease.

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