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Influence of Knitting Parameters on the Mechanical Properties of Plain Jersey Weft Knitted Fabrics

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Abstract
The contribution deals with the influence of selected knitting parameters and the relaxation period on the structure and mechanical properties of plain jersey weft knitted fabrics made of cotton and elastane yarns. There are considerable differences in the behaviour of conventional knitted fabrics and fabrics with elastane yarns incorporated in the structure. Since one of the key factors in knitting is certainly the knitting yarn feeding load - it impacts the structure and properties of such knitted fabrics, the contribution presents the influence of the knitting yarn feeding load on the alteration in the mechanical properties of plain jersey weft knitted fabrics. The results of the investigation indicate that the horizontal and vertical density and the fabric weight grow with a prolonged relaxation period and increase in the knitting yarn feeding load. Increasing the knitting yarn feeding load reduces the length of yarn in the loop. If cotton yarn is platted with elastane yarn, the length of the yarn in the loop is reduced by about 2 to 5%, as compared with yarn in a course without elastane yarn. The most prominent dimensional changes in the course and wales direction occurred for samples knitted with the highest feeding load of yarns. The best results of measuring structural parameters and dimensional changes in knitted fabrics during relaxation were exhibited by knitted samples with the lowest feeding load. Therefore, the feeding load of yarns should be taken into account when constructing knitted fabrics as it considerably affects fabric properties.

Key words: *knitted fabric, elastane yarn, feeding load, relaxation, mechanical properties.*

Introduction

Knitted fabrics have a structure which offers the stretchability and elasticity of knitwear. These advantages make knitwear comfortable and fit well to body contours, providing transpiration as well. Elastane yarns, which are incorporated into knitted fabrics in various proportions, have enabled these properties to be enhanced. Such knitted products exhibit extraordinary stretchability and elasticity, are dimensionally stable in wearing and care, and have become quite popular in the market. There are considerable differences in the behaviour of conventional knitted fabrics and knitted fabrics with elasthane yarns incorporated.

In the literature, some authors have conducted research into the relation between the rate of elastane and selected fabric properties, such as extensibility and relaxation [1 - 4]. Some researches describe the relation between the knitting parameters and mechanical properties of knitwear [5, 7]. Other studies focused on investigating the relation between elastane consumption and fabric dimensional and elastic behaviour characteristics [8]. The authors found that the amount of elastane has a significant effect on the dimensional and elastic properties of cotton/Lycra plated plain knitted fabric. However, the relation between knitting parameters and mechanical properties has not been studied enough in literature. Knitters usually use experience gained during machine adjustments in order to obtain the fabric characteristic required. Knitting is a complex dynamic process, and a number of factors impact the manufacture of knitted structures, the most important of them certainly being the yarn pre-tension and resp. knitting yarn feeding load.

This opens the way to investigations of the impact of the knitting yarn feeding load on knitted fabric properties. Therefore the aim of this research was to discover regularities and to find the optimal feeding load of yarns to result in minimal dimensional changes, thereby ensuring the stability of the structure constructed, and proper mechanical properties of the knitted fabric in question.

Selected rheological phenomena in fibres and yarns

During the knitting process, the yarn is exposed to tension. The tension, occurring in the fabric by loads and resulting in fabric deformations, is a time-related property. When fabrics are exposed to constant loads, the overall deformation grows with the time of loading. The phenomenon is called creep. When the load is removed, a part of the deformation is reduced (elastic deformation), a part disappears at the moment of removing the load (residual elastic deformation), and a part remains as a permanent deformation that cannot be corrected. If the loading lasts for some time, the fibre, or yarn, recovers after the load is removed at the value of the initial elastic deformation. A part of the deformation disappears after

Table 1. Basic characteristics of the yarns.

Characteristics analysed	Unit	Standard concerned	Kind of yarn	
			Cotton yarn	Elastane yarn
Linear density T_t	tex	ISO 2060 [13]; ASTM D2591-07 [14] 830-4	16.8	3.5
Twist T_m	t.p.m.	ISO 2061 [15]	916	-
Breaking force F_b	cN	ISO 2062 [16]	190.9	48.0
Extension at break ε_b	%	ISO 2062 [16]	4.1	512.1
Breaking tenacity σ_s	cN/tex		11.4	13.7

some time, while some of it remains as permanent deformation and cannot be recovered. This recovery, related to the initial elastic deformation, is called total relaxation, while the recovery that depends upon time is called partial relaxation [9]. During the relaxation process, the loops change their form for a certain period until an equilibrium state with minimal energy is reached. The relaxation period depends, above all, on the fibre material, density and construction of the knitted fabric, as well as on the magnitude of forces acting on the fabric during the knitting process. Moreover, outer parameters, such as temperature, relative air humidity and pressure have a certain influence on fabric relaxation.

Various theoretical and experimental studies have been undertaken to identify the physics of the phenomena of elasticity changes in knitted fabrics and the meaning of the relaxation parameters of knitted fabrics. The importance of the elasticity changes and relaxation parameters of knitted fabric was emphasised by D. L. Munden [10]. D. L. Munden conducted an experimental study showing that plain knitted fabric dimensional changes are due to dimensional changes in the loop. T. Pusch et al. [11] proposed a theoretical model showing the relationship between stitch length and yarn tension during the knitting process.

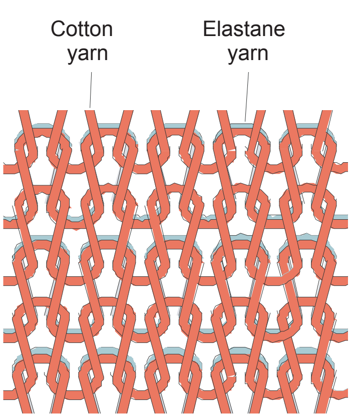

Figure 1. Knitted fabric with platted elastane yarn in every second course.

Behaviour of the fabric in relaxation

The properties and behaviour of knitted fabric can be partially predicted and predetermined through the fabric construction. To achieve optimum parameters of a knitted fabric structure, it is necessary to optimise the yarn input tension. The lower the strain in the yarn, the sooner the fabric will reach equilibrium with a minimum of potential energy [6]. The strains on the yarn occur in the knitting zone and can be up to ten times higher than those at the entrance to the knitting system, which can be reduced by waxing the yarn. The resultant deformation depends upon the resistance of the yarn to the traction force, which acts upon the moving part of the yarn in knitting. The resistance of the yarn to the loads depends upon its viscoelastic properties. Since elastane yarns exhibit a lower elasticity modulus, they offer lower resistance to the loads occurring in knitting [2, 10].

A higher tension of elastane yarns causes them to contract, which impacts changes in the knitted fabric structure, possibly resulting in horizontal streaks. A higher yarn tension also causes higher elastic recovery in the knitting zone, which means the formation of shorter loops, as compared to the loop lengths constructed. In the course of relaxation, the loop shape is changed. Further dimensional changes can be expected in the technological process and end use, providing the fabric has not been exposed to the relaxation required. The relaxation level in the direction of courses RL_W is calculated by the following expression [12]:

$$RL_W = \frac{W_1 - W_2}{W_1} \cdot 100 \qquad (1)$$

where:

RL_W – relaxation of the fabric in the direction of courses, %

W_1 – width of the fabric before relaxation, cm

W_2 – width of the fabric after relaxation, cm.

The relaxation level in the direction of wales RL_l can be calculated using equation [12]:

$$RL_l = \frac{L_1 - L_2}{L_1} \cdot 100 \qquad (2)$$

where:

RL_l – relaxation of the fabric in the direction of wales, %

L_1 – length of the fabric before relaxation, cm

L_2 – length of the fabric after relaxation, cm.

Methodology

To investigate the impact of knitting yarn pre-tension and the resp. feeding load upon the structure and relaxation of knitted fabric, specific samples of plain jersey weft knitted fabric were manufactured. The main characteristics of the yarn used are given in ***Table 1***. The knitted samples were constructed before they were manufactured, for which the platting knitting technique was used, in which elastane yarn was fed parallel with the base cotton yarn. Platting with elastane yarn was carried out in every second course in such a way that the cotton yarn was covered by elastane yarn, shown in ***Figure 1***. The samples were manufactured using a Relanit SE machine, made by Mayer & Cie E 28, with a sinking depth of 10, and using different feeding loads of the yarns, shown in ***Table 2***. The feeding load of both cotton and elastane yarn was measured and controlled using tension measuring equipment produced by Schmidt Control Instrument. The measuring scale was calibrated up to 50 cN. Knitting was performed at temperature T = 22 °C and relative humidity R = 62%. After com-

Table 2. Feeding load of the knitting yarn.

Sample type	Yarn feeding load F_p, cN	
	Cotton yarn	Elastane yarn
A1	3	2
A2		3
A3		4
B1	5	2
B2		3
B3		4
C1	8	2
C2		3
C3		4

pletion of the knitting process, the fabric was carefully removed from the machine and put on a flat surface in an air-conditioned chamber in order to carry out the relaxation process under standardised climatic conditions i.e. at temperature 20 ± 2 °C and relative humidity 65 ± 2%.

The present research on the structural parameters of the knitted fabrics produced i.e. horizontal D_h and vertical density D_v and mass per unit area was done according to Standards DIN 53883 [17] and DIN 53884 [18] . The tightness factor K was calculated using primary structural parameters. The average yarn length in the loop was measured for 100 loops after 24 hours on the 10th and 20th day of fabric relaxation, with a pre-load of around 0.5 cN tex^{-1}. The relaxation level of the knitted fabrics produced, depending on the relaxation period, was determined on the basis of the distance between control points in the course and wale directions. The measurements were repeated after the first, second, fifth, tenth, fifteenth and twentieth day of fabric relaxation. To study the influence of the knitting yarn feeding load on the alteration of the mechanical properties of knitted fabrics, the mechanical properties of the samples analysed were determined using the KES-FB AUTO measuring system [19].

Table 3. *Relaxation degree of knitted fabrics depending on the relaxation period.*

Sample type	Relaxation degree, %	Knitwear state after the					
		1st day	2nd day	5th day	10th day	15th day	20th day
A_1	RL_w	2.92	3.08	3.67	4.00	4.33	4.50
	RL_l	1.08	1.17	1.67	2.25	2.33	2.67
A_2	RL_w	2.92	3.33	4.17	4.25	4.25	4.50
	RL_l	1.33	1.67	2.17	2.67	2.59	2.83
A_3	RL_w	3.42	3.58	4.25	5.00	5.17	5.92
	RL_l	1.67	2.00	2.25	2.75	2.92	3.08
B_1	RL_w	3.08	3.42	4.25	4.75	5.08	5.58
	RL_l	2.58	2.50	3.25	3.50	3.33	3.17
B_2	RL_w	4.58	4.75	5.50	5.92	5.75	6.00
	RL_l	2.00	2.50	3.00	3.25	3.17	3.30
B_3	RL_w	4.67	4.50	5.33	5.58	5.67	5.67
	RL_l	2.33	2.25	3.58	3.50	3.50	4.17
C_1	RL_w	3.92	4.50	5.08	5.75	5.83	6.17
	RL_l	2.60	2.00	3.00	3.25	3.25	3.42
C_2	RL_w	4.08	4.00	4.83	5.42	5.67	5.75
	RL_l	2.25	2.33	3.08	3.33	3.50	3.58
C_3	RL_w	6.00	6.17	6.75	7.08	7.08	7.25
	RL_l	3.33	4.08	4.58	4.17	4.92	5.25

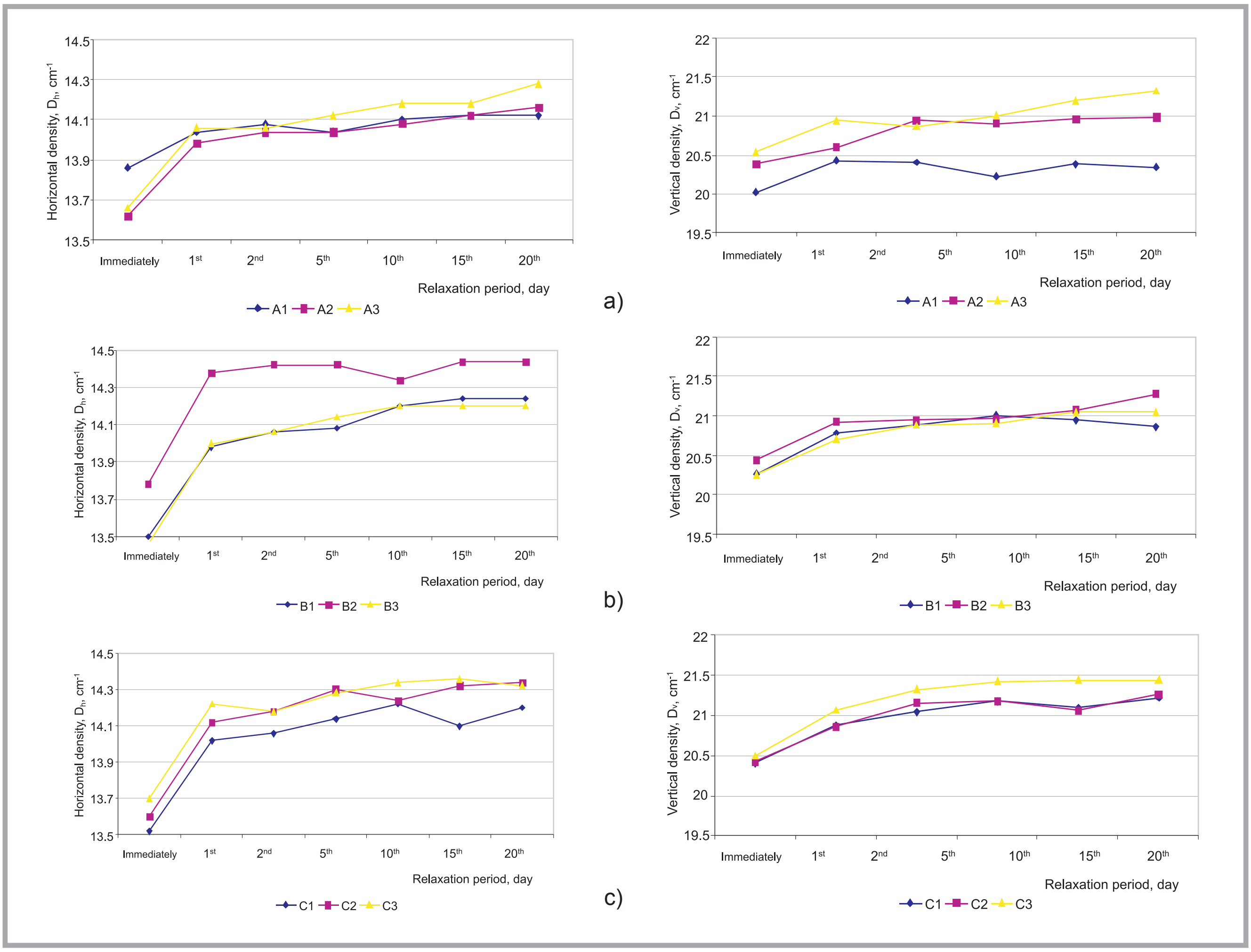

Figure 2. *Horizontal D_h and vertical density D_v of knitted fabrics depending on the relaxation period. a) cotton yarn feeding load F_p = 3 cN, b) cotton yarn feeding load F_p = 5 cN, c) cotton yarn feeding load F_p = 8 cN.*

Table 4. Mechanical properties of the fabrics analysed depending upon the input tension.

Sample type	Yarn feeding load F_P, cN		Mechanical properties								
			Tensile			Shear			Compression		
	Cotton	Elastane	E_{50}	WT	RT	G	2HG	2HG5	h_o	RC	C
A_1	3	2	31.10	7.95	76.58	0.71	1.67	1.62	1.29	50.27	0.468
A_2	3	3	35.40	9.07	61.62	0.72	2.28	2.13	1.34	39.19	0.512
A_3	3	4	35.20	9.32	57.37	0.74	2.28	2.18	1.39	47.86	0.518
B_1	5	2	38.40	10.78	52.27	0.75	2.01	1.94	1.23	39.87	0.434
B_2	5	3	33.80	9.46	53.89	0.80	2.18	2.13	1.29	40.14	0.459
B_3	5	4	35.10	9.80	54.00	0.74	2.21	2.08	1.30	44.12	0.467
C_1	8	2	37.10	10.49	57.28	0.71	2.13	1.98	1.24	40.14	0.455
C_2	8	3	34.80	9.56	52.82	0.78	2.21	2.11	1.25	38.22	0.456
C_3	8	4	33.70	9.61	51.53	0.81	2.16	2.11	1.41	32.37	0.505

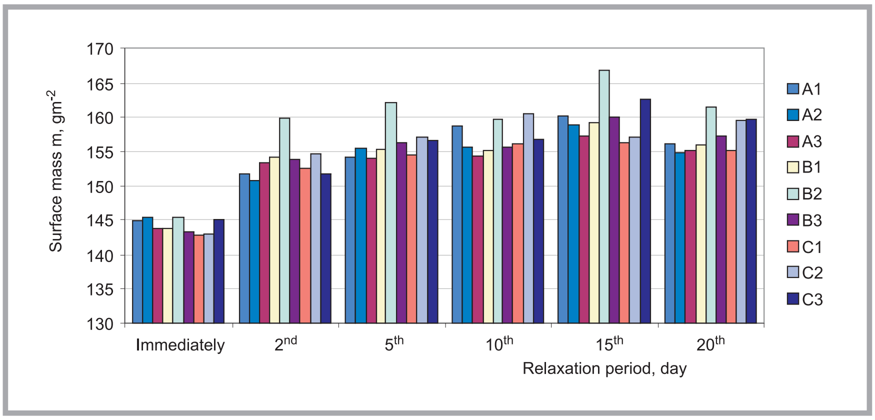

Figure 3. *Changes in mass per unit area of the knitted fabrics depending on the relaxation period.*

Results

Mean values of the measuring structural parameters of the knitted fabrics produced i.e. the horizontal D_h and vertical density D_v and mass per unit area, depending upon the time of relaxation, can be seen in ***Figures 2*** (see page 89) and ***3***. Mean values of fabric relaxation in the course direction, ***Equation 1***, and in the wales direction, ***Equation 2***, calculated depending on the time of relaxation, can be seen in ***Table 3*** (see page 89). Measurement results for the mechanical properties of the knitted fabrics analysed, depending upon the input tension and resp. yarn feeding load, are presented in ***Table 4***.

Results of the analysis of yarn length in a loop of the knitted fabrics analysed as well as resulting differences related to the loop length of a platted and normal loop (produced with the cotton yarn), depending on the feeding load of the yarns, are given in ***Table 5***. The impact of the yarn feeding load on the tightness factor K, representing the relationship between yarn fineness and loop length in the knitted fabrics analysed, is shown in ***Figure 5.***

Discussion of the results obtained

The results of investigating the structural parameters of individual knitted fabrics indicate that the horizontal and vertical density rises throughout the entire sample the longer the period of relaxation, as well as with an increasing yarn feeding load, ***Figure 2***. With respect to samples A_1, A_2 & A_3 , changes in the horizontal D_h and vertical density D_v increased at a higher feeding load of elastane yarn, ***Figure 2.a***. The same trend was observed with samples from series B and C. The lowest values of D_h and D_v are exhibited by samples C_1, C_2 & C_3, ***Figure 2.c***.

Table 5. Analysis of yarn length in a loop depending upon the feeding load of yarn,

Sample type	Yarn length in a loop l, mm		Difference Δl, %
	Cotton yarn	Cotton and elastane yarn	
A1	3.22	3.14	2.50
A2	3.20	3.10	3.20
A3	3.19	3.06	4.10
B1	3.15	3.09	3.09
B2	3.13	3.06	3.06
B3	3.21	3.04	5.30
C1	3.17	3.00	5.40
C2	3.18	3.03	4.80
C3	3.19	3.03	5.11

The sample mass per unit area also increases with a longer relaxation period. More prominent changes in the mass per unit area were recorded for samples with a higher pre-tension and resp. feeding load of yarns. The trend of an increasing surface mass was also recorded with a higher feeding load of elastane yarn and constant tension of cotton yarn, ***Figure 3***.

It can also be seen that the yarn length in a loop is generally reduced for all the samples at an increased knitting yarn feeding load. A higher value of the feeding load of yarn in the knitting zone results in smaller or bigger yarn deformations, i.e. its elongation. Thus, a smaller real length of the yarn ($l_o + \Delta l$) is entangled in the loop formation due to yarn deformation, i.e. its elongation. Due to a higher immediate elastic recovery, this length is further reduced, which results in a shorter loop. It is interesting to note that in the courses where cotton yarns are accompanied with elastane ones, the yarn length for cotton loops is reduced as compared to the courses of elastane yarns, the reduction being in the order of 2 to 5%, ***Table 5***. The changes in loop length are due to the viscoelastic behaviour of the elastane yarn, i.e. the resistance to tensile forces acting in the loop formation. Since elastane yarns exhibit a lower elasticity modulus, they offer lower resistance to loads as well. The difference grows with an increase in the feeding load of elastane yarn. The higher the feeding load of elastane yarn, the more prominent the yarn deformation is, which means a reduced length of elastane yarn in the cotton yarn loop. Because of the differences in the length of elastane and cotton yarns in the loop formation, as well as further reduction resulting from the higher elastic recovery of elastane yarn, the friction of yarns occurs, resulting in the longitudinal compression of the cotton yarn, which in effect reduces the yarn length in the cotton yarn loops. It can also be seen that the tightness factor K increases with a higher feeding load, which was expected, ***Figure 4***.

The results obtained indicate that dimensional changes in the relaxation are affected by the length of the relaxation time, as well as by the pre-tension and resp. feeding load of the knitting yarn

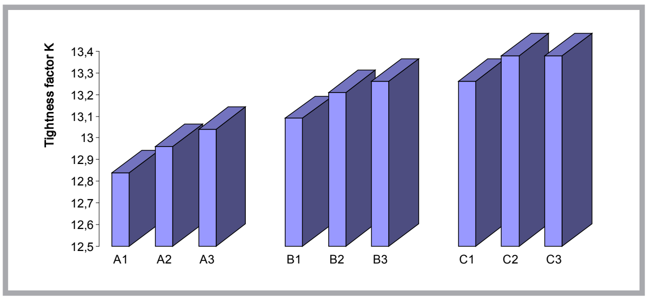

Figure 4. *Tightness factor K as dependent on the yarn feeding load.*

used, ***Table 3***. The degree of fabric relaxation widthways RL_w and lengthways RL_l increases with a longer relaxation period, ***Table 3***. The highest relaxation was recorded for fabrics with the highest feeding load of the yarn: C_1, C_2, and C_3. It is also important to note that the degree of relaxation in the course and wales direction increases with a higher pre-tension of the elastane yarns, at a constant feeding load of cotton yarns.

The investigations of the mechanical properties of the fabrics analysed reveal that the yarn feeding load impacts individual parameters of the fabric mechanical properties. A higher feeding load of yarns results in a higher fabric extension EMT, while a higher feeding load of cotton yarn and increased feeding load of elastane yarn reduce elasticity. For the samples analysed the tensile energy or work done in the tensile deformation, WT, ranges from 7.95 cN cm cm^{-2} to 10.78 cN cm cm^{-2}, the highest being with samples B1 and C1, ***Table 4***. The tensile resilience RT or the ability to recover from tensile deformation is reduced for all samples with an increase in the feeding load of both cotton and elastane yarn, which means that softness and elasticity are increased with a higher feeding load for all samples analysed. The shear rigidity G is also reduced with a higher value of the feeding load of the knitting yarn used.

Analysis of the compressive properties of the fabrics analysed shows that a higher value of the feeding load results in higher fabric thickness h_0 and fabric compressibility C, which is due to higher fabric relaxation. It is interesting to note that higher compressibility is achieved with a lower feeding load of the knitting yarns used.

Conclusions

The relaxation time, pre-tension, and resp. feeding load of yarn impact the structure and behaviour of the resultant knitted fabric. The horizontal and vertical density as well as the surface mass increase with a longer relaxation period and higher feeding load of yarn.

A higher yarn feeding load results in reduced yarn length in a loop. If cotton yarn is plated with elastane yarn, the yarn length in a cotton yarn loop is reduced by 2 to 5% compared with that in the course without elastane yarn, which can result in horizontal streaks.

The most prominent dimensional changes in the course and wales direction were recorded for samples with the highest feeding load of the knitting yarn used.

Increasing the value of the yarn feeding load accumulates strains in the yarn, impacting loop formation as well as the fabric structure, appearance and behaviour in relaxation, which is why it is advisable to knit with a minimal knitting yarn feeding load.

The best results of measuring the structural parameters and dimensional changes of the fabric in the course of relaxation were obtained with samples of the lowest feeding load of yarn (for cotton yarns used in the experiment it was 3 cN, and for elastane yarn - 2 cN).

Knitted fabrics should be constructed before manufacturing in order to ensure proper physical-mechanical properties and dimensional stability in wearing and care. The feeding load of the knitting yarn used should be taken into account as it impacts fabric properties to a considerable degree.

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