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DESIGNING FABRICS FOR A GIVEN STRETCHABILITY

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Abstract: The article presents the results of determining the geometric parameters of the fabric design method for a given stretchability. While studying literary and analytical studies, it was found that fabrics containing elastomers are very popular with consumers. In literary sources, there are practically no recommendations on the technology of manufacturing stretchable fabrics. The properties of stretchable yarns differ significantly from the properties of traditional yarns used in weaving. Therefore, it is necessary to identify the range of technological weaving modes in which it is possible to obtain stretchable blended fabrics with the inclusion of elastane yarns. The productivity of equipment and labor and the quality of manufactured products depend on the correctly selected technological parameters. The results of the study show that the optimal machine parameters are established mainly empirically, sometimes with the help of experimental studies, and for the experimental fabric they are individual. However, there are general patterns or initial prerequisites that must be taken into account when developing the optimal parameters.

Keywords: Fabric structure, technological parameters, structural parameters, fabric thickness, elastane yarn, design, stretchability.

Introduction. Due to the wide popularity of stretchable fabrics at present, an urgent task is the design and manufacture of modern weaving equipment installed at weaving enterprises. There are no methods for designing stretchable fabrics produced with elastane threads in the literature. Elastane thread, which has unrivaled elastic properties, manifested during the production of fabric on a weaving machine, does not allow designing fabric using known methods [1-2].

In this regard, there is a practical need to develop a method for designing fabrics produced with the insertion of three-component cotton-modal-elastane [3].

To determine the main parameters of the fabric structure necessary for performing filling calculations and determining the conditions of its production on a weaving machine, the paper proposes a technique for determining the processing of the weft yarn in the fabric, which will ultimately allow applying the method of designing fabric for a given stretchability in width [4-5].

Research methods. The following preliminary parameters of raw materials and fabric were adopted for the design work: 100% cotton thread with a linear density of *15.4x2 tex* is used as raw material for the production of stretchable fabric for the warp, and blended cotton+modal+elastane yarn with a linear density of *30 tex* is used for the weft. The share of elastane thread used for the weft in the yarn is *5%* and in the fabric

8%. The designed fabric belongs to group I, with stretchability $S=10\%$, and stretching coefficient $C_{str}=0.85$.

Fabric with such stretchability has a light, non-constricting silhouette on the human body, which allows free movement when worn, without damaging the clothes.

For designing, the fabric extensibility $P=10\%$, plain weave, filling with fibrous material by weft is greater than one ($K_{f.weft}>1$) and by warp is less than one ($K_{f.warp}<1$), the designed fabric is in the IV order of the structure phase. Where the fabric has the maximum density by weft $P_{weft}=242$ *yarns/dm*, and by warp is equal to the maximum $P_{warp}=220$ *yarns/dm* [6], filling coefficient by warp $K_{f.warp}=1$, by weft $K_{f.weft}=1.1$, yarn linear density by warp $T_{warp}=15.4x2$ *tex* and by weft $T_{weft}=30$ *tex*, yarn diameter ratio coefficient, yarn size change coefficients in fabric. The fabric filling coefficient characterizes the tension of fabric production on a weaving loom and is determined by:

$$K_{f.fabric} = K_{f.warp} \cdot K_{f.weft} = 1.1 \quad (1)$$

The closer the fill factor of the fabric is to one, the more intense the fabric production on the loom. The designed stretchable fabric consists of a mixture of cotton and modal fiber with the addition of elastane yarn, and we will determine the values of the coefficient *C* according to the proportion of fiber insertion of each type of yarn. For combined yarn 30 tex. We will determine *C* for the weft yarn before weaving

$$C = 1{,}13/\sqrt{n_1\delta_1 + n_2\delta_2 + n_3\delta_3} = \frac{1{,}13}{\sqrt{0{,}41\cdot 0{,}815 + 0{,}41\cdot 1{,}052 + 0{,}08\cdot 1}} = 1{,}22 \quad (2)$$

where: δ_1 – average density of cotton yarn, taken from table (1) [6];

δ_2 – average density of Modal yarn, taken from table (1);

δ_3 – average density of polyurethane yarn, taken from table (1);

n_1 – proportion of cotton fiber in yarn, 41%;

n_2 – proportion of Modal fiber in yarn, 41%;

n_3 – proportion of polyurethane in yarn is 8%.

According to the proposed method, further design of stretchable fabrics produced using a mixture of cotton + Modal + elastane thread includes the following stages:

- determination of the yarn diameter in the fabric depending on the ratio of diameters and the average yarn diameter;
- determination of the calculated diameter of the yarns in the fabric
- determination of the heights of the bending waves of the warp and weft yarns;
- determination of the geometric density;
- determination of the maximum possible density;
- determination of the yarn wear depending on the parameters of the fabric structure and the type of weaves used;
- determination of the surface density of the fabric.

The numerical values of the specified parameters can be determined using the formulas given in the literature [7-10].

The calculated indicators obtained are of interest in studying the influence of the fiber composition, and the percentage content of elastane yarn on the yarn wear in the fabric in further studies.

To determine the theoretical values of the warp and weft yarn wear in stretchable fabric produced using a cotton + Modal + elastane blend, the following formulas were obtained:

By warp:
$$a_{warp} = \frac{2(t_{warp} \cdot \sqrt{l_{weft\,f}^2 + h_{warp}^2} - l_{weft\,f})}{t_{warp} \cdot \sqrt{l_{weft\,f}^2 + h_{warp}^2} + (R_{weft} - t_{warp}) \frac{d_{weft}}{K_{Fweft}}} K_e \cdot 100 \quad (3)$$

By weft:
$$a_{weft} = \frac{2(t_{weft} \cdot \sqrt{l_{warp\,f}^2 + h_{weft}^2} - l_{warp\,f})}{t_{weft} \cdot \sqrt{l_{warp\,f}^2 + h_{weft}^2} + (R_{warp} - t_{weft}) \frac{d_{warp}}{K_{Fwarp}}} \cdot K_e 100 \quad (4)$$

where: t_{warp}, t_{weft}– the number of transitions of warp yarns and, accordingly, the number of transitions of weft yarns from one side of the fabric to the other side of the fabric within the fabric rapport per yarn; R_{warp}, R_{weft}– the fabric weave repeat for warp and weft, Ke- coefficient of extensibility.

The elasticity of woven fabrics consists of such indicators as the stretchability of the fabric along the warp or weft, the total deformation, and the working of the warp and weft yarns. Total deformation - $\acute{\varepsilon}_s$, of textile materials consists of irreversible parts. The formula determines total deformation:

$$\varepsilon_s = \frac{l_2 - l_1}{l_1 - l_s} * 100\% \quad (5)$$

where: l_s- initial length of sample, mm; l_1- sample length after load application, mm; l_2 – sample length after "rest", mm.

The proportion of irreversible deformation is determined by the formula:

$$\varepsilon_i = 100 - \varepsilon_s \quad (6)$$

With single-cycle indicators of yarns, the tensile deformation depends on the fibrous composition of the material, environmental conditions, and the magnitude of the acting load and is largely determined by the structural features of textile materials [10-12]. To describe the working in the process of developing highly elastic deformation, the working is developed depending on the stretchability coefficient. Since the designed fabric has the property of stretchability along the width of the fabric, it is necessary to take into account the stretchability coefficient when designing.

The coefficient of extensibility is determined by the formula:

$$K_r = \frac{\varepsilon_e}{100}$$

where: ε_e– irreversible tensile strain, %; K_r– fabric stretch coefficient.

Research results.

Table 1. Values of structural parameters of stretchable fabrics

Fabric samples	Type of raw material and content in fabric, %		Yarn diameter, mm		Yarn density, yarns/dm		Height of bending waves of yarns, mm		Geometric density of fabric, mm	
	By warp	By weft	By warp	By weft	By warp	By weft	By warp, h_{warp}	By weft h_{weft}	By warp, l_{warp}	By weft, l_{weft}
Sample 1	100% cotton	100% cotton	0,217	0,217	200	250	0,217	0,217	0,376	0,376
Sample 2	100% cotton	100% modal	0,217	0,214	200	250	0,168	0,281	0,397	0,327
Sample 3	100% cotton	cotton modal elastane	0,217	0,229	220	250	0,167	0,278	0,413	0,349
Sample 4	100% cotton	cotton modal elastane	0,217	0,237	240	250	0,170	0,284	0,421	0,354
Sample 5	100% cotton	cotton viscose elastane	0,217	0,229	230	250	0,169	0,280	0,418	0,350
Sample 6	100% cotton	cotton viscose elastane	0,217	0,237	250	250	0,178	0,286	0,428	0,358

Above Table 1 presents the fundamental structural parameters for various fabric samples created with different compositions and yarn densities in both warp and weft directions. Each sample exhibits variations in raw material content, yarn diameter, yarn density, bending wave heights, and geometric density, which directly affect the fabric's stretchability and overall performance.

Raw Material Composition: The samples vary in composition, with blends of cotton, modal, and elastane. For instance, Sample 3 incorporates a cotton-modal-elastane blend, which contributes to its unique stretch properties. Elastane content, even at relatively low percentages, has a significant impact on fabric elasticity, allowing for enhanced flexibility and movement.

Yarn Diameter and Density: Yarn diameter is consistent across warp and weft in samples made solely of cotton (e.g., Sample 1), while samples containing elastane and modal exhibit slightly larger yarn diameters. This is observed particularly in the weft direction, where modal and elastane add bulkiness, enhancing stretchability. Yarn density also plays a crucial role; for example, Samples 4 and 6 have higher yarn densities (240-250 yarns/dm) in both warp and weft, leading to greater compactness and structural stability, albeit with reduced flexibility.

Bending Wave Heights and Geometric Density: The bending wave heights (hwarp, hweft) and geometric density values reflect the flexibility and surface characteristics of each sample. Fabrics with higher bending wave heights, such as Samples 4 and 6, exhibit more pronounced texture and resilience, beneficial for applications requiring fabric with both stretchability and recovery characteristics. The increased weft density seen in these samples also suggests better stretch across the weft, enhancing the fabric's adaptability to movement.

Overall, Table 1 illustrates the relationship between structural properties and functional outcomes. Fabrics with a balance of cotton, modal, and elastane achieve desired stretchability and comfort, with each parameter carefully optimized to enhance fabric performance without compromising structural integrity.

Calculations for determining the geometric parameters of stretchable fabric are given in Table 2.

Table 2. Values of the structural parameters of fabric samples

Fabric samples	Fabric density, yarns/dm		Filling coefficient			Fabric wear, %	
	By warp	By weft	By warp	By weft	Fabrics	By warp	By weft
Sample 1	230	230	0,868	1,08	0,94	2,9	10,5
Sample 2	201	250	0,868	1,077	0,93	4,5	14,6
Sample 3	219,7	246,6	0,98	1,1	1,08	7,74	14,9
Sample 4	220	242	1	1,1	1,1	7,7	15,0
Sample 5	230	268	0,98	1,1	1,08	7,74	16,9
Sample 6	250	279	1	1,1	1,1	9,0	18,9

Table 2 provides values related to fabric density, filling coefficients, and fabric wear, which allow a deeper understanding of the production tension, durability, and resilience of each fabric sample.

Fabric Density and Filling Coefficients: The filling coefficients indicate the density of yarn packing within the fabric, reflecting the intensity of weaving and how tightly the yarns interlace. For example, Sample 1 has a filling coefficient of 0.868 in the warp and 1.08 in the weft, showing a less dense warp and a more compact weft structure. In contrast, Samples 5 and 6, which have higher densities and filling coefficients close to or above 1.0, are packed more densely, creating fabric that can withstand more mechanical stress, particularly in applications demanding durability.

Fabric Wear and Durability: Wear values are notably higher in fabrics with elastane, modal, and cotton blends (e.g., Samples 4 and 6), which experience greater wear in the weft due to the elasticity added by elastane. Sample 6, with a wear percentage of 18.9 in the weft direction, demonstrates the impact of high elastane content and greater fabric density. Higher wear percentages indicate that while these fabrics offer more flexibility, they may require additional finishing processes to enhance durability and reduce wear.

Impact of Fiber Composition on Warp and Weft Density: The density values show that increasing the modal and elastane content raises the overall density and wear resistance, as seen in Samples 3 to 6. This is attributed to the elastane's elasticity and modal's smooth texture, which allow for a more compact weave without sacrificing stretchability. This blend enables a balance between strength and elasticity, making it suitable for applications where stretch and recovery are required.

The analysis of Table 2 shows that the tension of the production of stretchable fabrics on the weaving machine is within the permissible values. The wear of the weft yarns of the IV sample is higher by 3% compared to the II sample and by 42% for the warp. In the IV fabric sample, the density of the warp yarns increased by 7% compared to the density of the warp yarns of the II sample. The increase in the density of the warp yarns was influenced by the fiber composition of the yarn, which is expressed through the diameter of the yarn.

In summary, Tables 1 and 2 underscore the critical relationship between fabric composition, structural parameters, and performance characteristics. They indicate that optimizing yarn density, diameter, and bending wave height can create fabrics that offer both stretch and durability. Additionally, higher elastane percentages increase stretchability but also result in increased fabric wear, suggesting a need for a strategic approach to balancing flexibility and durability in the design of stretchable fabrics.

Conclusion. The design and production of stretchable fabrics, particularly those using elastane yarn, require a specialized approach that integrates precise structural and technological parameters. This study demonstrated the importance of determining key fabric characteristics, such as yarn diameter, bending wave heights, and geometric density, to achieve optimal stretchability and durability. Through a systematic method of calculating structural parameters, including the effects of fiber composition and extensibility coefficients, we were able to outline effective design strategies for creating fabrics that balance elasticity with structural integrity. The findings suggest that careful calibration of warp and weft densities, combined with an understanding of the behavior of blended yarns, is essential in producing high-quality stretchable fabrics. Future research could expand on these methodologies by exploring alternative fiber compositions and weft tensions, further refining the design of fabrics suited to various functional and aesthetic requirements.

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