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Parameters of Limiting States of the Loop Structure during Stretching of Knitted Fabrics

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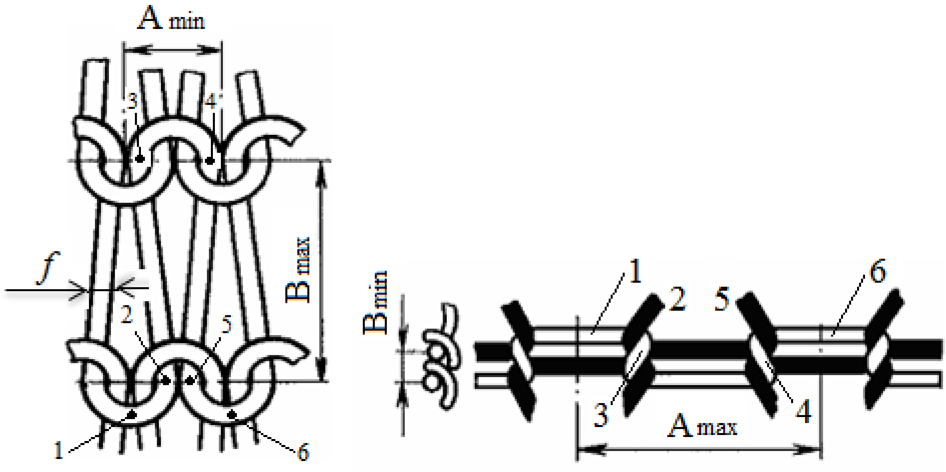
ABSTRACT: The article presents the results of a study of the mechanism for stretching of knitwear in limiting states of loop.The obtained values of the introduced concept of the technological length of the thread in the loop l_T, thus, is found as the estimated length of the thread l , adjusted for the values of the plastic deformation of the thread, equivalent to the plastic deformation of the knitted fabric under the action of loads.

KEYWORDS: knitting, fabric, loop, structure, compression deformations, deformation characteristics, elasticity, stiffness, shrinkage, coefficient of elastic properties, loop length coefficient.

I. INTRODUCTION

For each stitch, there are limiting values for the height of the loop row B and the size of the loop step A. The stretchability of the satin stitch is distinguished by length and width. When stretched in length, the knitwear contracts in width and the loop structure takes the form shown in Figure 1, a, in which the arcs of adjacent loops touch. In this case, the loop length l will consist of arcs 1-2, 3-4 and 5-6 and two loop sticks 2-3 and 4-5.



a b

Figure 1. View of the surface when stretched in length (a) and in width (b)

The sum of all arcs is a circle with a diameter of d = 3f, where f is the minimum thickness (diameter) of the thread. The length of one loop stick, if we neglect its slight slope, can be taken equal to the height of the loop row B_{max}. Then the length of the thread in the loop for the smooth surface in accordance with the data of A.S. Dalidovich will be.

$l = 3\pi f + 2\, B_{max};\ B_{max} = \frac{l-3\pi f}{2}$, (1)

and the maximum minimum value of the height of the loop row:

$B_{min} = 2f$(2)

When knitwear is stretched in width, it shortens in length and corresponds to the view in Figure 1, b. Then the length of the loop will be made up of sections 1-2, 3-4, 5-6, the sum of which is equal to the maximum loop step A_{max}

and two arcs 2-3 and 4-5, which are equal to the length of a circle with a diameter of d=3f. Therefore, the length of the thread in the loop is:

$l = 3\pi f + A_{max}; A_{max} = l - 3\pi f$, (3)

the limiting minimum value of the loop step is equal to

$A_{min} = 4f$(4)

From expressions (1) and (3) it follows that with increasing loop length l and decreasing thread thickness f, the elasticity of the satin surface increases. The ratio of the limiting maximum values of the parameters of the loop A_{max} / B_{max}=2 for the geometric model of the loop adopted in knitwear technology, when the mechanical properties of the thread are not taken into account [1]. V.P. Shcherbakov [2], based on the consideration of biaxial stretching of culinary knitwear and the study of the shape of an elastic line when a needle (platinum) arc of a circle of radius R is bent by radially tensile forces P, obtained the ratio A max / B max =1.465. This value follows from a numerical example of calculating the deformations of the satin stitch when stretched across the width (the deformation along the loop columns is zero) taking into account the factors: linear density of the viscose thread (thread diameter); loop step A; height of loop row B; bending rigidity of the thread; diameter of the center line of the needle arc; length of half of the needle arc; radial tensile force R. Thus, if we take into account the mechanical properties of the thread, then the ratio A_{max} / B_{max} differs from two and is approximately 1.5.

The high extensibility of the surface in width can also be explained by the fact that with an increase in the length of the thread in the loop, the degree of orientation of the thread along the row decreases, and along the column it increases. According to I.I. Shalov, the processes of changing the configuration of the loop and shifting the contact points during stretching of the knitted fabric are always accompanied by a change in the orientation of the thread in the loop. In the equilibrium state, knitted stitches loops have a minimum degree of orientation:

$\frac{\sum n}{l} = \omega_{min}$(5)

where $\sum n$is the sum of the projection of the thread segments;

ω_{min}- the degree of orientation of the thread;

l - loop length.

The sections of the loop, as they stretch, tend to take a position along the perturbing forces, and the sum of the projection of the segments of the thread $\sum n$on the direction of action of the tensile force tends to l , but then ω = 1.

However, it is only theoretically possible to bring the fabric to such an orientation of the loops in the case of an ideal thread of infinitely small thickness. Under real conditions of deformation at the maximum possible tension $\sum n<l$ by an amount depending on the thickness of the thread F and the type of stitch.

So, for smooth [3]:

$\omega_{max} = \frac{\sum n_{max}}{l} = \frac{l-4F}{l}$, (6)

where F is the thickness of the thread in the free state, mm.

The degree of orientation of the loops in the free state of knitted fabric can serve as an indicator of the potential extensibility of the fabric: the greater ω, the less extensibility.

Using expressions (1) and (3), we can estimate the maximum relative changes in the size of the loop step A_ε and the height of the loop row B_ε in relation to the loop parameters corresponding to the equilibrium state of the knitwear (A_0 ; B_0):

$$\left.\begin{aligned} B_\varepsilon &= \frac{B_{max}-B_0}{B_0} = \frac{B_{max}}{B_0} - 1; \\ A_\varepsilon &= \frac{A_{max}-A_0}{A_0} = \frac{A_{max}}{A_0} - 1, \end{aligned}\right\}(7)$$

Table 1

Calculation formulas for determining the values of A_0 and B_0 knitwear after finishing [4]

Stitch	Type of yarn	A_0 , mm.	At_0 , mm.
Plain	Cotton	$0.20l+\frac{0,7\sqrt{T}}{31,62}$	$0.2\ 7l-\frac{1,5\sqrt{T}}{31,62}$
Rib 1+1	Cotton	$0,3\ 0\ l+\frac{0,1\sqrt{T}}{31,62}$	$0.2\ 8l-\frac{1,3\sqrt{T}}{31,62}$
Double rib (interlock)	Cotton	$0.13\ l+\frac{3?4\sqrt{T}}{31,62}$	$0.35\ l-\frac{3,0\sqrt{T}}{31,62}$

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Table 2
Calculation formulas for determining the values of A $_{max}$ and B $_{max}$ knitwear of some stitchs, stretched to break (without taking into account the stretching of the thread in the loop) [5]

Stitch	Loop step A_{max}, mm.	Height of a loop row In $_{max}$, mm.
Plain	l - 3πd$_y$	$\frac{l - 3\pi dy}{2}$
Rib 1+1	$2l$ - 6πd$_y$	$\frac{l - 3\pi dy}{2}$
Double rib (interlock)	l - 3πd$_y$	$\frac{l - 3\pi dy}{2}$

The values $A_ε$ and $B_ε$ cannot be interpreted as loop deformations because the loop is a geometric image, and deformation is a change in the shape or size of a body (or part of a body) under the influence of external forces, during heating and other influences, causing changes in the relative position of a body part [6].
Expression (7), taking into account dependences (1) and (3), takes the form
$\frac{l-3\pi f}{2B_0} - 1 = B_\varepsilon; \frac{l-3\pi f}{A_0} - 1 = A_\varepsilon,$
Where is the length of the thread in the loop
$$\left.\begin{array}{l} l = 2B_0(B_\varepsilon + 1) + 3\pi f; \\ l = A_0(A_\varepsilon + 1) + 3\pi f \,, \end{array}\right\} (8)$$
In knitwear theory, the minimum thread thickness f in a highly compressed state is equated to the conditional diameter d $_{y,}$ as evidenced by almost identical values. Thread thicknessin the free state F is accordingly identified as the calculated diameterd $_p$ \u003d 0.0357 $\sqrt{T\sigma^{-1}}$\u003d 1.13 $\sqrt{N^{-1}\sigma^{-1}}$, mm. Thus, we have f = d $_y$, F = d $_r$.
The values of the density of the substance and the bulk density of some textile yarns and yarns are given in table 3.

Table 3
Density of matter and bulk density of textile threads [7]

Threads and yarn	The density of the substance of threads and yarn γ, g / cm ^{3}	Bulk weight of threads and yarn δ, g / cm ^{3}
Cotton yarn	1.52	0.75-0.85
Wool yarn	1.32	0.50-0.60
Polyacrylonitrile threads	1.17-1.19	0.60-0.70
Elastic threads	1.14-1.15	0.032-0.035

All geometric characteristics of the knitted loop structure are determined by calculation based on the nominal diameter d $_{of}$ the thread, which is included when determining the loop modulus. It should be noted that in the calculation formulas for the loop length L.A. Kudryavin uses the average thickness of the thread (loop structure in a free state), determined by the formula
d = F ≈ (d $_p$ + d $_y$)/2, mm.
To quantify the length of the thread in the loop (8), one should use the empirical formulas of I.I. Shalov for A_0 and B_0 - the parameters of the stitch weaving loop in the equilibrium state:
$A_0 = 0{,}2l + \frac{0{,}7}{\sqrt{1000/T}}; B_0 = 0{,}27l - \frac{1{,}5}{\sqrt{1000/T}}$, (9)
Then expression (8) takes the form
$$l = 2\left(0{,}27l - \frac{1{,}5}{\sqrt{\frac{1000}{T}}}\right)(B_\varepsilon + 1) + 3\pi f;$$
$$l = \left(0{,}2l + \frac{0{,}7}{\sqrt{\frac{1000}{T}}}\right)(A_\varepsilon + 1) + 3\pi f;$$
which after transformations can be presented in the form of formulas

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$$\left.\begin{aligned} l &= \frac{-\frac{3}{\sqrt{\frac{1000}{T}}}(B_\varepsilon+1)+3\pi f}{1-0{,}54(B_\varepsilon+1)}; \\ l &= \frac{\frac{0{,}7}{\sqrt{\frac{1000}{T}}}(A_\varepsilon+1)+3\pi f}{1-0{,}2(A_\varepsilon+1)} \end{aligned}\right\}(10)$$

The length of the thread in the loop (10), as indicated above, must be adjusted taking into account the plastic (residual) deformation of the total length l_Σ of the thread, composed of n number of loops within the size of the test sample in the tensile direction:

$l_\Sigma = l \cdot n$, mm (11)

Since the total tensile deformation of knitwear ε_p consists of three parts: elastic ε_y , elastic ε_e and plastic ε_{pl}, i.e.

$\varepsilon_п = \varepsilon_у + \varepsilon_э + \varepsilon_{пл}$(12)

As is known, the total deformation ε_p stretching knitwear consists of three components: elastic ε_y, elastic ε_e and plastic, which are single-cycle characteristics.

Let's transform (12) and select from it the plastic component ε_{pl} in the following form, after dividing by the total deformation ε_p:

$$1 = \frac{\varepsilon_у + \varepsilon_э}{\varepsilon_п} + \frac{\varepsilon_{пл}}{\varepsilon_п}$$

or

$1 = К_{у.э} + К_{пл},\ К_{пл} = 1 - К_{у.э}$(13)

where $К_{у.э} = \frac{\varepsilon_у+\varepsilon_э}{\varepsilon_п}$is the coefficient of elastic-elastic deformation of the sample;

$К_{пл} = \frac{\varepsilon_{пл}}{\varepsilon_п}$- coefficient of plastic deformation of the sample.

The importance of single-cycle characteristics in the study of the stretching of fibers and threads is predetermined by the fact that they well reflect the features of the deformation of textile materials. Since obtaining these characteristics is usually associated with rather long experiments, it becomes possible to take into account the time factor, which plays an important role in the deformation of such materials.

Single-cycle characteristics, always determined without bringing the sample to destruction, most fully characterize the state of textile materials in processing processes due to the fact that they rarely experience stretching, leading them to rupture. In most cases, during processing processes and during use in products, fiber threads are subject to tension for some time, and then they break down and rest. Therefore, it is of great scientific and practical interest to study the behavior of textile fibers and threads in fabrics in the load-unload-rest cycle.

To determine the proposed technological length $l_T$loop that takes into account plastic deformations, we take into account the introduced plastic deformation coefficient

$l_T = l - lK_{пл} = l(1 - К_{пл}) = lК_{у.э}$, (14)

where *l* is the estimated length of the thread in the loop.

Thus, to determine the technological length (14), it is necessary to have data on irreversible (plastic) deformations of control samples from the studied knitted fabrics, determined experimentally in accordance with GOST 8847-85 [8].

When processing the data of experimental studies of single-cycle characteristics, it is necessary to make an assumption about the uniform loading of each loop column and each loop inside the column within the clamping length (10 cm) and width (5 cm) of the tested samples of knitwear. The consequence of this is the equality of deformations (absolute and relative) of all loop columns among themselves and, accordingly, loop rows. This assumption allows us to establish the relationship between the experimentally found value of the plastic deformation $\varepsilon_{пл}$of the sample, the number of loops in the column *n* and the plastic deformation of one loop $\varepsilon_{1пл}$:

$$\frac{\varepsilon_{пл}}{n} = \varepsilon_{1пл}$$

where $\varepsilon_{пл} = \sum_{i=1}^{n} \varepsilon_{i\,пл}$is the total plastic deformation of all loops in one column of the control sample.

Then the loop length coefficient $k_l$can be calculated from the relation

$k_l = \left(1 - \frac{\varepsilon_{1пл}}{\varepsilon_п}\right) = (1 - \frac{\varepsilon_{пл}}{n\varepsilon_п})$(15)

Taking into account the above, the technological loop length $l_T$in accordance with formulas (10), (14) and (15) will be determined from the relations:

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$$\left.\begin{aligned} l_T &= \frac{-\frac{3}{\sqrt{\frac{1000}{T}}}(B_\varepsilon+1)+3\pi f}{1-0{,}54(B_\varepsilon+1)}\left(1-\frac{\varepsilon_{пл}}{n\varepsilon_{п}}\right), мм \\ l_T &= \frac{\frac{0{,}7}{\sqrt{\frac{1000}{T}}}(A_\varepsilon+1)+3\pi f}{1-0{,}2(A_\varepsilon+1)}\left(1-\frac{\varepsilon_{пл}}{n\varepsilon_{п}}\right), мм \end{aligned}\right\}(16)$$

The obtained values of the introduced concept of the technological length of the thread in the loop l_T, thus, is found as the estimated length of the thread l, adjusted for the values of the plastic deformation of the thread, equivalent to the plastic deformation of the knitted fabric under the action of loads.

Table 4

Technological length of the thread in the loop, taking into account the limiting relative changes in the dimensions of the loop structure and the level of residual deformation of the thread during axial tension

No.	Type of yarn, stitch	Thread length in loop, mm					Loop length coefficient K_l
		through the modulus of the loop σ	Taking into account the limiting relative changes in the dimensions of the loop structure			Average technological length l_{tf}	
			Step A_ε	By column height B_ε	Average length l_s		
1	Cotton yarn, rib	4.704	4.703	4.466	4.585	3.911	0.853
2	Cotton yarn, plain	4.704	4.705	4.697	4,701	4.103	0.873
3	Cotton yarn, interlock	5.152	5.028	2.193	-	4.510	0.897

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