Methods for the Structural Analysis of Highly Elastic Materials

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Methods for the Structural Analysis of Highly Elastic Materials

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Abstract. The object of the research is highly elastic knitted fabrics, and the subject is the method of their structural analysis. The aim of the work is to develop a new method for the analysis of the structure of elastomeric materials, which makes it possible to study the parameters of highly elastic knitted fabrics' structure in an equilibrium and stress-strain state, taking into account the assessment of the nature of its changes during various types of influences on the material. The prospects and the possibility of applying the methods of direct observation of the material's microstructure by means of optoelectronic microscopy and the existing technical solution for their implementation in analyzing the structure of highly elastic knitted fabrics are shown in the work. A method for determining the structural characteristics of knitted fabrics, including highly elastic ones, has been developed. The proposed technique provides a quantitative assessment of the parameters of an elastomeric knitted fabric's structure, taking into account the actual material's state, and its changes after external influence using the methods of mathematical morphology, morphological analysis and spectral analysis of the fabric's microstructure images. The results of practical approbation of the proposed method suggest that its application is possible and sufficiently effective.

1. Introduction
Modern garments, especially clothing, can't be imagined without highly elastic materials. The materials in this category include, inter alia, the so-called elastomeric knitted fabrics, containing in its structure polyurethane yarns. The proportion of materials with an investment of elastane yarns in the total production of knitted fabrics, depending on their purpose, varies on average, from 30 to 60% [1, 2]. Due to the extremely high tensile properties and elasticity and the considerable flexibility of polyurethane filaments, consumer properties of finished products such as increased forming ability, dimensional stability, low material consumption, high drapeability and many others, are ensured. This expands the possibilities of clothing designers in designing products of various volumes, silhouettes, shapes, and purposes.

2. Relevance and Scientific Significance of the Issue
As is known [1−3], various factors affect the adoption of design decisions in the design of finished products, among which one of the main factors is the property of the material used. Predicting the behavior of textile materials during processing and operation is a rather complicated process. This is

due to the fact that the value of the characteristic properties of textile materials is influenced by many factors, among which the structure of the material occupies one of the leading places [3]. The forecasting process is especially complicated when it comes to the properties of highly elastic materials. Studies have shown that materials that are similar in fiber composition and basic structural characteristics when applying tensile forces behave extremely ambiguously. All this determines the need for a more detailed study of highly elastic materials' structure, as well as structural changes in the canvases during their transition from an equilibrium state to a stress-strain state. Accordingly, there is a need for accurate methods for analyzing the structure of highly elastic knitted fabrics, providing a study of its parameters, taking into account the actual state of the material. This makes research in the field of developing methods for structural analysis of elastomeric materials relevant and of scientific value.

3. Formulation of the Problem

The purpose of the research was to develop a new method for the structural analysis of highly elastic knitted fabrics, which makes it possible to study the parameters of the fabric structure in an equilibrium and stress-deformed state, taking into account the assessment of the nature of its changes under various types of influences on the material. The object of the study is knitted fabrics with an attachment of polyurethane threads, and the subject is a method of analysis of their structure. When conducting the research, methods of optoelectronic microscopy, standard methods for studying the knitted fabrics structure and preparing samples for testing, were used. The processing of experimental results was carried out using statistical methods.

4. Theoretical Part

The main structural parameters of any knitted fabric, including highly elastic materials, that affect its properties are as follows: the looped row height B, the looped pitch A, the thread diameter d_n, the thread length in the loop L_n and the fill indicators. Currently widely used methods for determining these characteristics fall into the category of direct contact research methods [4, 5]. For this reason, due to the high elongation of a highly elastic fabric and its constituent threads, it is rather difficult to apply classical methods for analyzing the structure of knitwear to determine its structural indicators. In addition, the methods used in practice do not allow, for technical reasons, due to the very methodology of the experiment, to conduct a study of the material's structure in a stress-strain state. These two factors determined the direction of the scientific research. As practice shows, the study of the properties of easily deformable materials [3, 4] and the prevention of the deformation of materials is possible based on the use of non-contact methods. Contactless methods are rarely used to study the structure of textile materials. In this regard, methods for studying the structure of various solids and the technical means for their implementation have been analyzed. The main criteria for the analysis were the following parameters: the possibility of morphological analysis of textile materials' structure, the availability and accessibility of technical means for implementation.

It has been recently established that among the methods of research of various solids, including polymeric, film and other materials [6–23], methods of direct observations of the microstructure of a material by means of optoelectronic microscopy [15–23] are very promising. This led to the choice of this group of methods for the development of methods for the structural analysis of elastomeric knitted fabrics. For the technical support of the implementation of these methods, a set of hardware-software computing and modeling tools for obtaining and processing electron-optical images [24], developed and practiced on the territory of Vladivostok State University of Economics and Service, was chosen. Given that the authors of the article are employees of this university, this choice is optimal in terms of accessibility. Since this complex is designed to study unordered environments, and any textile materials in terms of their internal and external structure can be considered as unordered environments, it is reasonable to assume that this complex can be used to study the structure of highly elastic knitted fabrics.

Analysis of the technical and software capabilities of the complex allowed us to confirm the assumption. It has been established that the software architecture of the complex includes, among other software, digital processing of electron-optical images. The expediency of applying digital processing of electron-optical images is due to a number of factors. First, digital processing includes image enhancement programs that allow both "restoration" of some original image "corrupted" in the registration channels, and improvement in a person's psychophysical perception of certain characteristic features of the analyzed image. These programs provide the ability to perform transformations, the result of which is a "modified" image of an object that serves as the initial information for its analysis. Also, morphological analysis programs are included in the digital processing software package, which ensures the selection of the necessary objects in the image and the quantitative characteristics of the object's microstructure using the methods of mathematical morphology and morphological analysis, in particular, analysis of halftone electron-optical images. In addition, in the framework of digital processing it is possible to use spectral analysis, which traditionally occupies a large place in image analysis. Spectral analysis of the images of the material's microstructure is reduced to the calculation of the integral frequency and spatial characteristics for the images' spectra. The integral frequency characteristic and the integral spatial characteristic are built to obtain statistically stable and visual characteristics of the spectra and are used in assessing the isotropy / anisotropy properties of the analyzed structure, and can also be used to determine its changes after external influence. Thus, the second of the put forward criteria is ensured.

5. Results of the Study and Their Discussion

Based on the use of optoelectronic microscopy methods and software of the complex, a technique has been developed for determining knitted fabrics' structural characteristics, including highly elastic ones. The proposed technique involves the implementation of three successive stages: 1 - preparation of the samples for testing; 2 - obtaining optical images of knitted fabric (in the equilibrium or (and) in the stress-strain state) and the transfer of the fabrics' images into digital form with subsequent input into a computer; 3 – the processing of optical images of materials and calculation of the knitted fabric's structural characteristics, including the determination, if necessary, of the magnitude of the structure parameters changes in the deformed state.

When implementing the technique, three programs of digital processing of electron-optical images were mainly used: a program for filtering and image enhancement; a program for structural and morphological image analysis; a program for spectral analysis.

In the first stage of structural analysis in accordance with [5], the selection and preparation of samples is carried out, in which elementary samples of 180x180 mm are marked. Elementary samples undergo additional tracking for at least 60 minutes, then the boundaries of the working area are marked with a template with a given accuracy (up to 1 mm). In the study of the structure of knitted fabrics in an equilibrium state, the dimensions of the working area are 160x160 mm. To ensure a given amount of deformation of the knitted fabric, the dimensions of the working area are reduced in comparison with the initial width or (and) length of the elementary sample. The calculation of the size of the working zone of the sample, deformed by a given amount, is made by the formula:

$$L_x(L_y) = 1600 / [100 + \varepsilon_x(\varepsilon_y)],$$

where L_x (L_y) - the size for the working area of the deformed elementary sample along the looped rows (along the looped columns) for a given amount of deformation ε_x (ε_y), mm; $\varepsilon_x(\varepsilon_y)$ – given relative deformation of the elementary sample along the looped rows (along the looped columns),%.

In the second stage, the prepared elementary samples are punctured onto a special along the outlined boundaries of the working area frame with needles 160x160 mm in size. This procedure is performed in order to avoid the material skewing in the equilibrium state or for fixing the specified deformations. Then optical images of the knitted fabric are obtained using a digital camera and inputted into a computer using standard technical means. Optical images are stored on a special database, where they are taken as needed for further processing.

Optical image processing, i.e. the third stage of the analysis of the structure of materials is carried out using the above-mentioned digital processing programs. The result is the quantitative characteristics of the knitted fabric's structure. Fig. 1 shows the optical image of the knitted fabric, extracted from the image database and opened in the program "Image Processing".
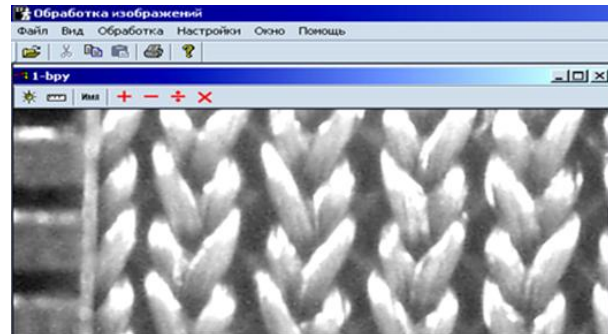

Figure 1. Optical image of knitted fabric, opened in the program "Image Processing".

Structural characteristics such as the looped row height B, the looped pitch A, the thread diameter $d_н$ and the thread length in the loop L_n are determined using morphological processing and morphological analysis. In this case, the command "Object selection" is used, which allows to select parts of the image that define the desired parameters. To determine the looped row height B, rectangular sections between like points of two adjacent loop rows are allocated, and to determine the loop pitch A, between like points of two adjacent loop columns. When determining the diameter of the thread, the visible part of the thread is selected by a rectangle, while the selected object should be perpendicular to the thread axis. To determine the thread length in the loop, a curvilinear contour is selected that runs along the center line of the thread in the loop. To reduce possible measurement errors according to the dispersion law, the number of measurements for each of the parameters to be determined should be at least 100. After the required amount of discharge is made, the average value of the selected objects is determined using the additional Statistics program. Since the results of statistical processing are given in pixels, the coefficient of conversion of pixels into millimeters is found using the "Line parameters" indicator and the values of the desired characteristics of the structure in the accepted units of measurement are calculated. Taking into account the already calculated characteristics, the horizontal density $П_г$, vertical density $П_в$, linear filling horizontally $E_г$ and vertically $E_в$, surface filling E_s, linear m and surface m_n modules of a loop are determined by the known formulas [3, 4]. The calculation of the listed characteristics and their changes during the transition of the material into the stress-strain state is carried out automatically with the help of a specially developed program.

For the purpose of establishing the type and extent of impact on the knitted fabric, in addition to the procedures described, spectral image analysis can be used. For this purpose, for a particular image of the fabric, two different spectra and two integral spatial characteristics are obtained, which are circular diagrams (Fig. 2) corresponding to one of the states (before and after the influence). The changes in the analyzed structure are estimated by the type of the obtained integral spatial characteristics.

In order to test the developed methodology, establish the possibilities of its application and the accuracy of the results, the structural characteristics for ten highly elastic knitted fabrics of various fibrous composition and weaves in the equilibrium and deformed state (under the action of a small operating load) were determined. The results of the tests are described in detail in [25] and show sufficient effectiveness of the developed technique.
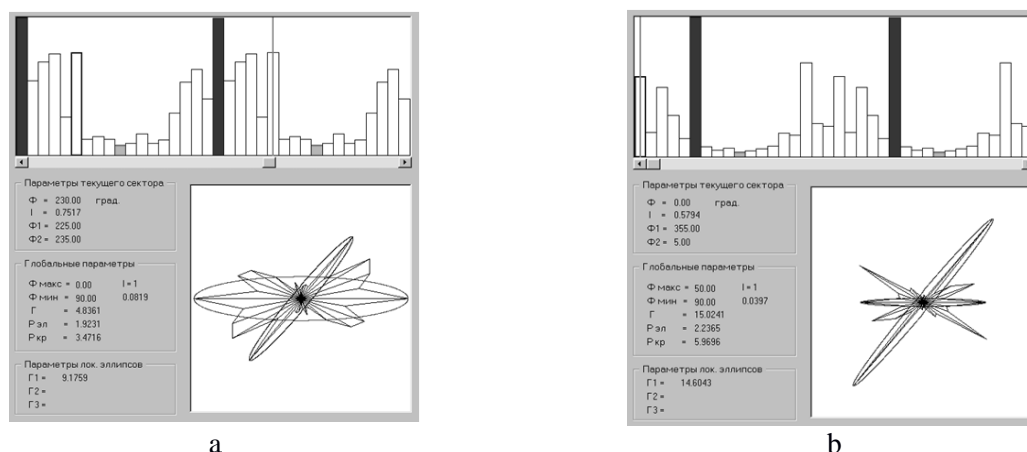
Figure 2. Integral spatial characteristics of the spectra of highly elastic knitted fabric:
a - before influence; b - after influence.

6. Conclusion

The developed method is based on the use of methods of direct observation of a material's microstructure by means of optoelectronic microscopy and is implemented through the use of a well-known technical and technological solution of a hardware-software complex for obtaining and processing electron-optical images intended for the study of disordered media. The method ensures the fulfillment of the requirements specified by the study and can be used for the structural analysis of highly elastic knitted fabrics of various structures and production methods. The results of the analysis of the data obtained during testing show that the proposed development is sufficiently effective.

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