PECULIARITIES OF A NEW METHOD FOR EVALUATING FIBROUS PRODUCTS STRUCTURE

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Introduction

In the course of textile processing, spinning industry products such as slivers, rovings and yarns are sequentially formed from the pulp. All these processes are associated with significant difficulties and their implementation efficiency is entirely evaluated by the complex of properties of fibres, being processed, and their arrangement in semi-processed products structure.

One of the main indexes characterizing the state of a semi-processed product for further processing is an index of fibres straightening and orientation in semi-processed product structure. Correct and timely evaluation of this index in conditions of constant changes in the quality of raw materials will allow maintaining the efficiency of textile processing at the appropriate level. This will lead to the rational use of expensive raw materials and an increase in the quality of finished products.

According to the classification of methods for evaluating indexes of fibrous products structure, all research methods, depending on peculiarities of the effect on textile material, are divided into direct and indirect. Methods classification scheme is based on the principle of dividing methods into classification categories: class, group, subgroup, sort and kind. The class of a method evaluates the peculiarities of product structure study, the group – degree of impact on a sample under study, the subgroup – type of physical or mechanical impact on a sample, the sort – methodical aspect of index study, and the kind – measuring index [1].

Direct research methods consist in direct measurement of fibres size and position relative to the axis of a fibrous product. Direct research methods include the method of measuring fibres after extraction from the sample, projection methods, methods of labelled fibres (dyed fibres, radiography, luminescent) [2-4].

In direct methods for estimating the structure of fibrous products, fibres straightening and orientation is evaluated by direct analysis of fibres or their images in a sample. The advantage of direct methods is that most of them give or can give comprehensive information on fibres arrangement in a sample and fibres shape. At the same time, it can be noted that direct methods are very laborious, since they are all associated with obtaining characteristics for a large number of individual fibres. Some of them require additional pretreatment of samples (labelled fibre methods). For these reasons, direct methods cannot be recommended in those cases when it is necessary to quickly estimate the orientation or straightening of fibres in fibrous samples of textile materials and their semi-processed products.

In indirect methods, fibres orientation and straightening in the structure of fibrous products samples is evaluated according to dependence of fibrous product structure and some physical quantity. Depending on what physical quantity change is recorded, indirect research methods are divided into groups: mechanical and weight, mechanical, optical, capillary and others [2, 4-6].

The most widespread indirect method is the mechanical and weight method for evaluating fibres straightening and orientation in spinning industry – the method of combing sample fibres in a special clamp. The method consists in estimating the longitudinal orientation of fibres by preliminary cutting the sample end of an investigated fibrous product at the point of its clamping. After releasing a certain length of a product, one should card and weigh the loose parts of fibres ends, cut and weigh the straightened fibres ends, went beyond the initial clamping line due to straightening at carding. Finally, it is necessary to cut and weigh fibres ends that remain in the area released from the clamp.

Optical methods are quite simple, have low labour intensity. However, the dependence of values characterizing the orientation of fibres is subject to the condition of sample fibres surface, which complicates the interpretation of results or requires rather laborious calibration for each type of fibres. Considering the dependence of sample thickness indexes, optical methods are recommended for sufficiently thick or, conversely, sufficiently thin samples, limiting the possibilities of their use. In addition, these methods make it possible to evaluate the parallelization, straightening, and orientation of the fibres only from sample surface layers and cannot evaluate its internal structure [2, 5, 6].

The indirect methods of estimating straightness and orientation indexes are also quite time-consuming, but their labour intensity is significantly lower than the labour intensity of direct methods. Known indirect methods cannot be applied to various fibrous structures. Indirect methods are used in most cases to obtain comparative, relative characteristics of fibrous products structure. The values of fibrous material structure in the considered indirect methods depend on a number of side factors (fibres properties, sample geometric parameters, etc.), which require testing the method in new conditions or limit its scope. Most indirect methods are used only in static conditions, and just some are used in dynamic conditions, but with sufficiently significant thickness of the investigated fibrous product.

Based on the above, it can be stated that to evaluate the structural peculiarities of sliver-like fibrous products (straightening and parallelization of fibres) one should use methods that have different approach. The above methods are quite complex and require considerable time to evaluate structural indicators. In addition, all of them cannot be used in production conditions, so the development of new rapid methods for estimating the structure of sliver-like fibrous products is relevant.

Methods

To quickly evaluate the characteristics of fibres location in fibrous products, the most promising are indirect methods that can be used in dynamic production conditions. Among the indirect methods of evaluating fibrous products structure, which can be used in production conditions, it is most appropriate to use methods to evaluate a complex index that takes into account both fibres straightening and orientation [7, 8].

Given the above, the resonance method is considered to be the most promising for estimating the structure, because it can be used in dynamic production conditions and it allows you to evaluate the complex index of fibres straightening and orientation. The resonance method belongs to the group of electrowave methods and is based on the anisotropy of textile fibres dielectric constant in different directions [9, 10].

It is known that the study of textile materials' electrical and dielectric parameters was carried out mainly for technical-purpose textiles. However, due to the development and introduction of new electrophysical methods in the textile industry, an interest to the processes occurring in fibrous products under the action of constant and alternating electric fields has significantly increased.

Studies of electrophysical textile fibres properties were caused by the introduction of a capacitance method for measuring the unevenness of yarn products, a resistive method for evaluating the moisture content of fibres, as well as problems of occurrence and elimination of textile fibres static charges during processing on manufacturing equipment.

Nowadays, the influence of electric and magnetic fields on textile materials is widely used in textile industry for fibres orientation and straightening during carding, in the production of carcass yarn, for obtaining compound yarn and nonwovens.

However, for the design and rational use of devices for evaluating the structural characteristics of fibrous products by electrophysical methods, it is necessary to have basic information about the processes occurring in fibres under the action of constant and alternating electric fields [11, 12].

Since almost all textile fibres have more or less anisotropy, the dielectric constant is also different in different directions. Thus, cotton fibres were pre-dried to constant weight and had a dielectric constant $\varepsilon = 6$, when arranged along the field lines, and $\varepsilon = 3$ in the case of their transverse arrangement. Measurements were performed at a frequency of 1.755 MHz.

The main disadvantage of evaluating structural indexes by indirect methods, including resonance, is the presence of various side factors that create measurement errors. After analyzing the existing resonant devices for evaluating the structure of fibrous products, it was found that the device circuits contain multiple conversion of the information signal, which leads to uncontrolled parameters. To eliminate this drawback, we set the task of creating the device for evaluating the dielectric parameters of materials. The introduction of new circuit elements and change in functional connections between them in the electrical circuit would ensure the evaluation of textile materials properties with increased accuracy by directly measuring the resonant frequency of the reference and measuring resonators, and exclusion of information signal multiple transformation. This significantly reduces the number of uncontrolled parameters that affect the errors in evaluating the properties of textile materials, namely straightening and orientation factor.

Experimental and results

The offered resonant device for evaluating the structure of fibrous materials contains a super-high-frequency (SHF) generator G, connected by the first output from a two-position SHF switch SW, to the outputs of which the reference Q1 and measuring Q2 resonators are connected. To the second output of SHF generator a prescaler ST is connected, from the output of which the pulse sequence is fed to the input of the microprocessor MR. An indicator device (digital) HL is connected to the first output of the microprocessor MR, and the second output is connected to the second SHF switch SW.

The device works as follows: in the first operating cycle, on command from the microprocessor MR, two-position SHF switch SW commutates to a certain position 1 and connects the reference Q1 resonator to the SHF generator G, the settings of which will evaluate the operating frequency of the SHF generator G. From the second output of SHF generator G, electromagnetic oscillations are fed to the previous ST frequency divider, which is required to match the high operating frequency of SHF generator G (hundreds of MHz) with the operating frequency of the microprocessor MR (units or tens of MHz) [11, 12].

Generated frequency value in the digital code is entered in the first memory register of the microprocessor MR. In the second operating cycle on command from the microprocessor MR, two-position SHF switch SW commutates to another position 2 and connects to the SHF generator G measuring Q2 resonator tuned to the value of SHF G. From the second output of the SHF generator G, electromagnetic oscillations are fed to the previous frequency divider ST and generated frequency value in the digital code is entered into the second memory register of the microprocessor MR. In the following operating cycles of the microprocessor MR, the program calculates the change in generation frequency, its relative change and, in fact, fibres straightening and parallelization factor according to the formula:

$$\eta_f = 1 - \frac{\Delta f_1 / f_{01}}{\Delta f_2 / f_{02}}; \quad . \tag{1}$$

where f_1 is the quality factor of resonator during contact with the fibrous sample along its axis; f2 is the quality factor of resonator in contact with the fibrous sample perpendicular to its axis;

The measurement result is fed from the first output of the microprocessor MR to the indicator device HL.

The objects of research to evaluate the optimal position of the fibrous products on the resonant device were slivers for obtaining wool yarn by worsted spinning system. Evaluation of the optimal sliver position was carried out on the device shown in Fig. 1, according to our methodology.

The device consists of clamps 1 that rotate around the axis and the resonant device 2. Before filling the tape in the clamp is determined by the position of the tape at the exit of the equipment on which it was received. To study the anisotropy of the propagation of an electromagnetic wave through a fibrous product, the tape was tucked into a clamp under preload and the value of the frequency of the electromagnetic wave as it passed through the textile material was determined. For the initial position of the tape - the angle 0˚ took its position when released from the equipment. Then the clamps were simultaneously rotated counterclockwise at an angle of 30˚, 60˚, 90˚… 360˚ and again recorded the value of the change in the indicator.

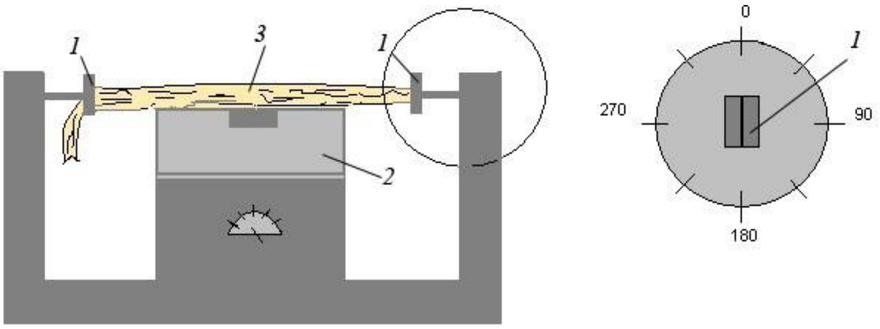

Fig. 1. Attachment for evaluating sliver anisotropy structure
1 - clamps; 2 - resonant device; 3 - fibrous product (sliver)

To estimate the anisotropy of fibrous products structure by electrowave method, a polar coordinate system was used. You can use it to display the relationship between the angles of fibrous product rotation and the magnitude of the change in parameters of electromagnetic wave.

The polar coordinate system is given by a ray called zero or polar axis. The polar axis in a fibrous product is the line passing through the centre of cross section of the product parallel to the position of a sliver when it exits the equipment. The point from which the polar axis emerges is called the origin or pole. Any other point on the graph is defined by two polar coordinates: radial and angular.

The radial coordinate corresponds to the distance from a certain point to the origin. In the offered method of evaluating the structure of fibrous products, the radial coordinate evaluates the amount of change in the frequency of electromagnetic wave.

The angular coordinate, called the polar angle φ, is equal to the angle at which counterclockwise the polar axis of the fibrous product must be rotated in order to reach the above point. The radial coordinate determined in this way can take values from zero to infinity, and the angular coordinate varies in the range from 0 ° to 360 °.

Graphs of change in the resonant frequency depending on the position of a sliver are presented in Fig. 2.

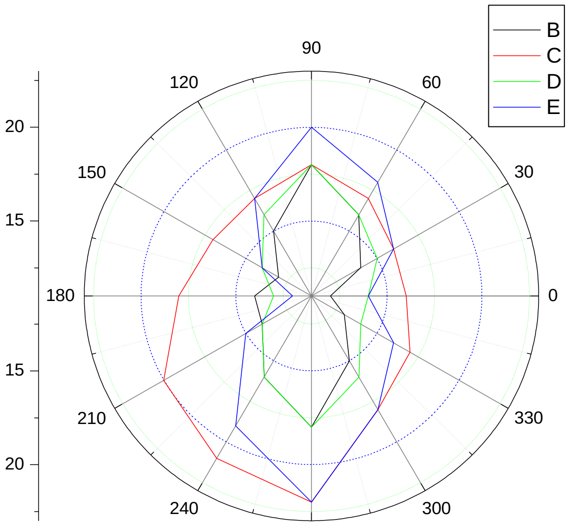

Fig. 2. Change in the resonant frequency when an electromagnetic wave passes through the sliver, depending on its position

$$t_R = \frac{\left|\overline{Y_1} - \overline{Y_2}\right|}{S\left\{\overline{Y}_1 - \overline{Y}_2\right\}} = \frac{\left|\overline{Y}_1 - \overline{Y}_2\right|\sqrt{m}}{2S\left\{\overline{Y}\right\}} \qquad (2)$$

where Y_1 and Y_2 – the arithmetic mean, $S^2\{Y_1\}$ and $S^2\{Y_2\}$ – the standard deviation, m_1 and m_2 – the sample sizes ($m_1 = m_2 = 30$).

The complex index of fibres straightening and orientation, evaluated by formula (1), is practically not affected by the change in resonant frequency depending on the amount of a fibrous product. In fact with an increase in resonant frequency, the frequency difference also increases when the fibrous samples are placed along and across the resonator. Table 1 shows the change in the complex index of fibres straightening and orientation, according to the position of sliver sample from the carding machine.

Student's t-test (t) was used to estimate whether the differences between the two adjacent mean values of fibres straightening and orientation factor were significant. In this case, the formula (2) is used for two dependent samples, the size of which differs insignificantly.

The calculations results are given in the table 1.

Table 1. Changes in fibres straightening and orientation index according to the position of sliver sample from the carding machine (for T_c = 17.3 kTex)

Sample position, degrees	Along resonator f_1	Across resonator f_2	Fibres straightening and orientation factor
0-360	9	12	0,67
30	10,5	14	0,67
60	12	16	0,67
90	13,5	18	0,67
120	11	15	0,64
150	9,5	13	0,63
180	10,5	14	0,67
210	10,5	14	0,67
240	12	16	0,67
270	13,5	18	0,65
300	11	15	0,63
330	9,5	13	0,65

Table 2. Evaluation of an impact in changing two average values of fibres straightening and orientation factor according to the sample position

Sample position, degrees	Fibres straightening and orientation factor $\bar{Y}_n$	Samples under study, at angles, degrees	Expected value t_R	Tabular value t_T	Null hypothesis $M\{Y_1\}=M\{Y_2\}$
0 (360)	0,67	0-30	0	1,980	is not rejected
30	0,67	30-60	0	1,980	is not rejected
60	0,67	60-90	0	1,980	is not rejected
90	0,67	90-120	1,172	1,980	is not rejected
120	0,64	120-150	0,455	1,980	is not rejected
150	0,63	150-180	1,831	1,980	is not rejected
180	0,66	180-210	0,037	1,980	is not rejected
210	0,67	210-240	0	1,980	is not rejected
240	0,67	240-270	1,921	1,980	is not rejected
270	0,65	270-300	1,833	1,980	is not rejected
300	0,63	300-330	1,724	1,980	is not rejected
330	0,65	330-0	1,910	1,980	is not rejected

If the calculated value of Student’s t-test is greater than the tabular one $|t_R| > t_{T2}[\alpha, f]$, the null hypothesis was rejected. If $|t_R| > t_{T2}[\alpha, f]$, there was no reason to reject the hypothesis H_o of equality of means, that is, both series of measurements were attributed to the same set.

Similar results were obtained for slivers from other processing steps of spinning production. The straightening and orientation factor is relative, so the position of the sliver will not affect its change. The main condition for the study is only the constant position of the sample during the process both along and across the resonator. Therefore, it can be stated that sliver position affects the value of resonant frequency, but does not affect the value of complex factor for fibres straightening and orientation.

In the course of textile processing, the pulp is sequentially formed into slivers, rovings and then yarns. All these processes are associated with significant difficulties and their implementation efficiency is entirely evaluated by the complex of properties of fibres, being processed, and their arrangement in semi-processed products structure.

One of the main indexes characterizing the state of a semi-processed product for further processing is an index of fibres straightening and orientation in its structure.

Correct and timely evaluation of this index in conditions of constant changes in the quality of raw materials will allow maintaining the efficiency of textile processing at the appropriate level. This will lead to the rational use of expensive raw materials and an increase in the quality of finished products.

Conclusions

The device for evaluating the dielectric parameters of materials with increased accuracy due to direct measuring the resonant frequency of reference and measuring resonators, eliminating multiple conversion of the information signal was offered. This significantly reduces the number of uncontrolled parameters that affect the errors in evaluating the properties of textile materials, namely straightening and orientation factor. To estimate fibres straightness and orientation, it is advisable to use the frequency range between 500 and 1500 MHz. In the offered device, the operating frequency of 800 MHz is selected.

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