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Non-Instrument Diffraction Control Method Spinning Semi-Finished Products

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Abstract

A new method of computer control of the angular distribution of fibers in semi-finished products of spinning, paper and other fibrous materials with random distribution of fibers is proposed. The method is based on a computer analysis of the Fraunhofer diffraction pattern calculated from a computer micro-image of the surface of the material under study with access to the numerical parameters of the controlled distribution. The method does not depend on the color and nature of the material and, unlike the hardware methods, does not contain speckles in the analyzed diffraction pattern.

Keywords: Digital images; Calculation of the Fraunhofer diffraction patterns; Light scattering diagrams; Computer analysis; Semi-finished spinning mills; Paper

Introduction

On the spinning mills raw material arrives in bales, in which fibers are highly compressed and are in an entangled state. The raw material is subject to loosening, cleaning, and blending. Then the fiber alignment process begins: carding, receiving and stretching tapes, and finally, the preparation of roving tapes-semifinished product directly used in spinning yarns. How well aligned fibers, largely determines the quality of the final product spinning textile yarn.

In developed by the author describes diffraction techniques to monitor the values of the geometric parameters of periodic fabric knitted filaments from the measured parameters of the Fraunhofer diffraction pattern. The methods do not depend on the optical properties of the material [1].

These methods are usually applied in the measurements on the light-transmitting material, but as shown in may be used to control parameters of the periodic geometrical structure is not light-transmitting BCM. In this case, the diffraction pattern is studied from the image surface of the material, obtained on the transparent substrate photographic printer or xerographic means [2].

A disadvantage of hardware methods that use a laser as a light source is the need to qualified service corresponding devices. In addition, the diffraction pattern observed on the screen, there are always the so called "Speckles" spurious interference peaks caused by the presence of uncontrolled optical in homogeneities in the material of the screen. Speckles severely limit the accuracy of the method and the ability to use the software automatically processing the observed diffraction pattern. These difficulties explain aspects of implementation of such methods for monitoring the parameters discussed materials during their production [3]. This uneven light transmitting structure defined by a function f $(\xi.\eta)$, The amplitude of the light signal in the Fraunhofer diffraction pattern of a U screen at coordinates (x, y), observed from a plane of the object illuminated by a monochromatic plane wave of constant intensity length λ perpendicular to its surface, in the scalar approximation (excluding light vector E polarization) in the general case is given by the integral of [4]:

$$U(x,y) = C\iint_{\sigma} f(\xi,\eta)\exp[-ik(p\xi+q\eta)]d\xi\ d\eta, \qquad (1)$$

where C-const; distance from the object to the screen L >> x, y; coordinates (ξ, η), which determine the position of the object points are in the object plane and parallel to the Cartesian coordinates (x, y), and wherein the zeros of the one and the other coordinate systems lie on the same optical axis with the light source; the integration is over the illuminated area of the test microimage σ.

The light intensity in the diffraction pattern is calculated according to the formula:

$$I(x,y) = U(x,y)\ U^{*}(x,y),$$

Where U^*- function complex conjugate function U.

Obviously, in such a way calculated diffraction pattern of speckles are absent because there is no real screen.

Purpose of the Study

Consider the possibility proposed in bezapparatnogo diffraction method, computer control function of the angular distribution of the fibers in the fibrous flat materials free from drawbacks hardware [2].

Materials and Methods

The samples of the spinning production of semifinished products (cotton, polyester fibers), taken from the output in series machines at JSC "The Soviet Star" (St. Petersburg) carded carding-Advanced Band-Band Final-roving. The basic idea of the proposed method is based on the fact that the image of a thin cylindrical fiber scatters monochromatic light incident on the cylindrical fiber perpendicular to its axis only in the plane perpendicular to this axis. Therefore, the direction of the line in the diffraction maximums of the Fraunhofer judge cans unambiguously the orientation of the fiber axis.

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In this case, the angular positions of the main peaks in the diffraction peaks coincide with similar diffraction pattern of the slit width equal to the diameter of the fibers [1].

It is natural to assume that the random distribution of similarly oriented relative to the machine direction pulling the same fibers in the illuminated portion of the test material, the intensity maxima in the respective diffraction patterns arranged in a direction perpendicular to the direction of orientation of the fibers will be greater, the greater the number of such fibers, light spot [2].

It is obvious that the diffraction pattern from isotropic angular image distribution identical cylindrical randomly dispersed fibers with sufficient statistical ensemble of these fibers must be symmetrical about its center, i.e. E. The light intensity at any point on the screen must depend only on the distance from the center. In the case of anisotropic angular distribution of fibers in such a material discussed illumination intensity in the diffraction pattern should also depend on the value of angle φ, measured relative to the machine direction pulling the fibrous material.

It is also obvious that any real ensemble cylindrical curved fibers of one diameter may be represented as an ensemble of identical cylindrical discussed straight fibers of the same diameter. To do this, you need to break mentally all the curves and straight cylindrical fiber to the same sites that may be considered straight. The proposed method is based on calculating and analyzing the Fraunhofer diffraction pattern constructed by computer microimage surface of the test material [2]. When this calculation is made by the formulas 1 and 2, where in as a function f $(\xi.\eta)$ is a digital micro-image illuminated with laser light of the material.

As shown in position of the main peaks in the thus calculated diffraction pattern coincides with the position of the maxima in the hardware method, when a laser light of microimages deposited on a transparent substrate [2].

Results and Discussion

The basic idea of the proposed method is based on the fact that the image of a thin cylindrical fiber scatters monochromatic light, incident on a cylindrical fiber perpendicular to its axis, only in a plane perpendicular to this axis. At the same time, the angular positions of the main maxima in the Fraunhofer diffraction pattern coincide with the maxima of a similar diffraction pattern from a slit of the same width [1].

It is natural to assume that with a random arrangement of uniformly oriented with respect to the machine direction of drawing the same fibers in the illuminated part of the material under study, the intensity of the maxima in the corresponding diffraction pattern in the direction perpendicular to the direction of orientation of these fibers will be greater, the higher the number such fibers in the light spot. To correctly simulate a laser light beam in the studied area of a micro image of a light spot with a normal intensity distribution relative to its center, the program was used [5]. It was shown that with such a model of illumination in a computer-generated diffraction pattern, as in the hardware method, there is no numerous system of so-called "additional maxima" in the diffraction pattern associated with the presence of boundaries in the calculated light spot, which greatly simplifies the diffraction pattern and makes its analysis easier [6].

The integral 1 was calculated using the image of the fast two-dimensional Fourier transform program using the image of a laser spot of light applied to it using the program of fast two-dimensional Fourier transform. To process a computer diffraction pattern of the surface of the material under study, a special program was compiled, the work of which is explained in Figure 1, where the diffraction pattern calculated in such a way from an image of a high-speed rail with anisotropic distribution of fibers is schematically shown [5].

The constructed diffraction pattern from the image of the surface of the material under study is presented in the form of dark spots that are symmetrical with respect to the machine direction of drawing of the material under study. The program builds in polar coordinates the dependence of the light flux in the diffraction pattern, measured in a sector with area ΔS, specified by the value of the angle Δφ and circles with radii R1, R2 drawn from the center of the diffraction pattern, depending on the angle φ, that is, the dependence of Φ (φ). In the center of the Fraunhofer diffraction pattern there is always a diffraction maximum having a maximum intensity. Therefore, centering the ring is not difficult.

According to the dependence Φ (φ) constructed in this way, schematically represented in Figure 2, one can judge the function of the angular distribution of the fibers in the material under study. It was shown that the dependence Φ (φ) measured in this way can be approximated by:

$$\hat{O}(\varphi)=\int_{R_1}^{R_2}\frac{I_0\sin^2\left(\frac{\pi ar}{\lambda L}\right)F(\varphi)(\Delta\varphi)^2 rdr}{\left(\frac{\pi ar}{\lambda L}\right)^2}=F(\varphi)\int_{R_1}^{R_2}\frac{I_0\sin^2\left(\frac{\pi ar}{\lambda L}\right)(\Delta\varphi)^2 rdr}{\left(\frac{\pi ar}{\lambda L}\right)^2} \qquad (2)$$

In this case, as follows from formula (2), the measured Φ (φ) for each angle φ in the Δφ range in the case of a chaotic fiber distribution will be proportional to the angular density of the fibers F (φ) = ΔN / Δφ whose orientation is in the range of Δφ from (φ ± π / 2 - Δφ / 2) to (φ ± π / 2 + Δφ / 2).

Therefore, the dependence of Φ(φ) with a sufficiently small angle Δφ and sufficiency of the statistical ensemble of fibers in the illuminated

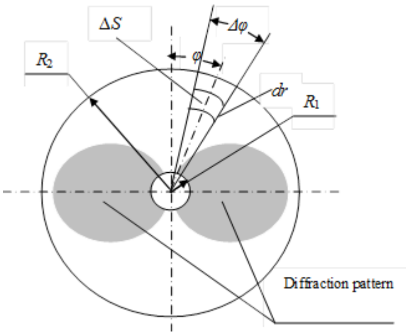


Figure 1: Diffraction pattern processing algorithm.

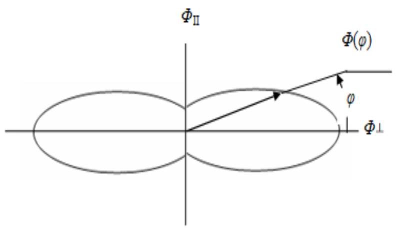


Figure 2: ϕ (φ)

part can be considered as a good approximation to the true form of the monitored function of the angular distribution of fibers in the material under study, when the preferred orientation of the fibers ("machine direction") corresponds to the direction Y-axis (Figure 3).

Light scattering function F (φ) of light fluxes measured in identical angular sectors Δφ = 50 through 50 in the range of φ changes from 0 to 3600. On Figure 4 on the left shows the calculated images of Figure 3 of the lower row of the corresponding diffraction patterns, which are the parameters R1 and R2 radii. Right diagrams show the calculated angular diffraction scattering and the magnitude of the line segment drawn from the center of the chart for each angle φ, the calculated proportional thus F (φ).

If we connect the outer ends of these segments with a smooth curve, then for each of materials, we obtain angular diagrams that are qualitatively similar to the presented value in Figure 2. The light scattering function Φ (φ) of the light fluxes was measured in the same angular sectors Δφ = 50 through 50 in the range of variation of φ from 0-3600. In Figure 4 on the left shows the figures calculated in Fig. 3 from the bottom row of the corresponding diffraction patterns, which show the parameters of the radii R1 and R2. The right shows the calculated angular diagrams of the diffraction scattering. The size of the line segment drawn from the center of the diagram for each angle φ is proportional to the calculated Φ (φ).

If we connect the outer ends of these segments with a smooth curve, then for each of materials, we obtain angular diagrams that are qualitatively similar to the presented value in Figure 2. From the data of Figure 4 that the obtained Φ (φ) dependences indicate that the diffraction light scattering anisotropy is maximum for cotton ribbons (Figure 4a); less for cotton web (Figure 4b) and even less for paper (Figure 4c). From the data of Fig. 4 it is also seen that the direction of the preferential orientation of the fibers in the cotton ribbon, perpendicular to the direction of the maximum value Φ in the dependence Φ (φ), is shifted relative to the vertical direction (Figure 4a).

In Figure 4b this direction approximately coincides with the vertical, and in Figure 4 is closer to the horizontal direction.

The main disadvantage of the above method is the need to process a statistically sufficient ensemble of controlled fibers. It is obvious that in one micro-image of the surface of the semifinished product under investigation there are a clearly insufficient number of fibers under study.

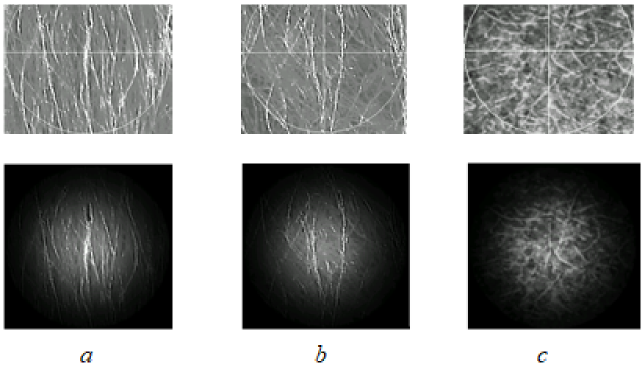


Figure 3: Microimages of the surface of the cotton ribbon from the second transition of the belt machine-a; cotton batting-b and printer paper-c, taken with a computer microscope with illumination "on reflection" (in the top row). In the bottom row-the same images after processing on "laser lighting".

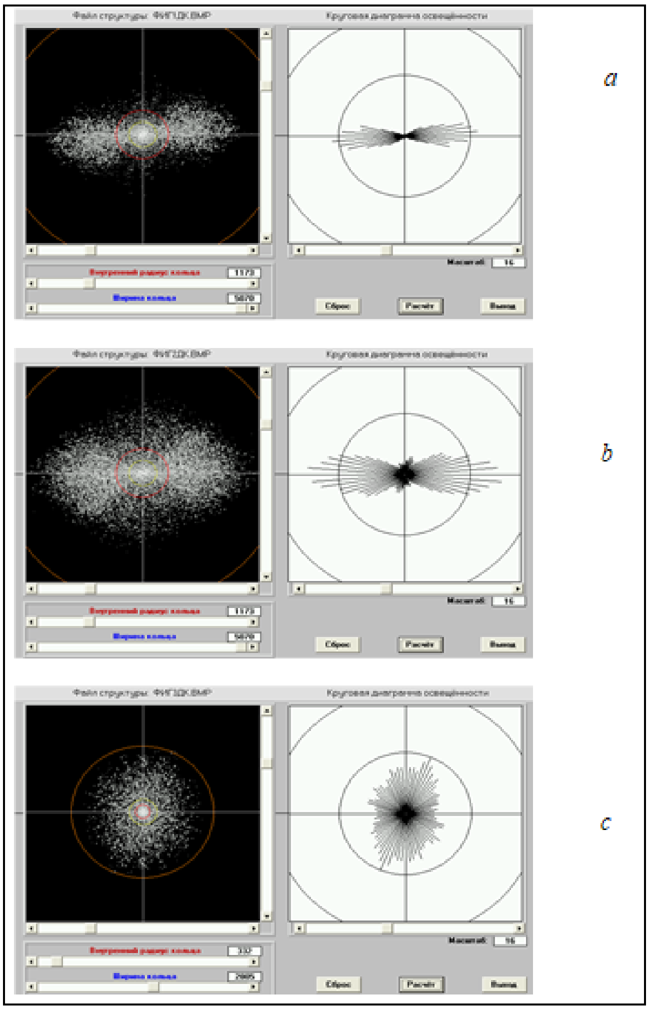


Figure 4: Computer diffraction patterns and corresponding circular light patterns.

This is explained by the fact that the transverse size of each fiber should not be more than one pixel; otherwise it is impossible to speak about diffraction in the image area of a cylindrical surface. This circumstance leads to the need for optical zoom, which automatically reduces the number of captured fibers in the image. Therefore, to obtain statistically reliable data, it is necessary to process a large number of microimages of the surface of the semifinished product under study, taken in identical conditions in its various sections.

In order to realize the possibility of automatic data processing of a large number of such micro images, a corresponding computer program was proposed in [7], which implements the following algorithm for processing micro images of the material under study:

1. A set of digital microimages of different sections of the same test sample of the spinning mill production, having a sufficient total statistical ensemble of the number of fibers made under identical shooting conditions (magnification, lighting, etc., is created as the source data).
2. A light spot imitating laser lighting is superimposed on each such image. An example of an image with a superimposed spot is shown in Figure 5a.

3. For each microimage, the Fraunhofer diffraction pattern is calculated using the fast Fourier transform method according to the technique described in the form of a computer image, where each pixel has a certain intensity [8-10];

4. When the zero is located at the location of the diffraction maximum (it is always in the center of the picture) for each microimage, an angular diagram of the distribution of the average intensity of the light in the diffraction pattern is plotted as follows:

   - on the image of a diffraction pattern calculated from the computer image of the test filament, a ring with radii R1 and R2 is superimposed symmetrically with respect to its center (point O);

   - the sector of a ring with an area ΔS with an angular size Δα, limited by the radii of the ring and located at an angular distance φ from the axis OX, is allocated, and the average intensity inside the sector is calculated by the formula:

$$I_m(\varphi) = \frac{\sum_{\Delta S} \hat{O}_{pix}(\varphi)}{\Delta S}$$

- Where in the numerator - the total luminous flux emitted by all pixels of the image that fall into the selected sector ΔS;

- measurements according to this formula are repeated for all values of the angle φ from 0 to 2π with step Δφ at a constant value of ΔS, and the obtained values of Im joined by a smooth closed curve (Figure 5b), normalized to the maximum value.

5. Denote by the letter M the point farthest from the origin of the coordinates of each angular diagram. A straight line is drawn through this point and the origin of coordinates, and the diffraction pattern is rotated through an angle αi so that the maximum of the M diagram is on the 0X axis [11]. This rotation eliminates the influence of local bends of the semi-finished product relative to the direction of its transfer during manufacture (Figure 5b).

6. Oriented, as mentioned above, all diffraction patterns are added pixel-by-pixel. The intensity of pixels in the total diffraction pattern is normalized to the maximum value (255), observed in its center, and the angular diagram for the total diffraction pattern is constructed similarly to positions 4 and 5 (Figure 5c).

7. This diagram is further symmetrized and averaged relative to the 0У axes (direction of the semifinished product pulling) and 0X under the assumption that the total statistical ensemble of fibers in the studied micro-images is sufficient, in which deviations in the orientation of the fibers at any angle to the right or left of the direction of pulling are equally likely. In Figure 5c in, straight lines are drawn symmetrical about the coordinate axes, which can be extended for any angle φ and - φ. The distances OA, OB, OC and OD are added up and the sum is divided by four. The value obtained is assigned to the OÁ, OB, OĆ and OD segments of the new angular diagram (Figure 5d), inclined at the same angles φ and - φ. Having performed a similar operation for all values of the angle φ from zero to ± π / 2 and connecting the obtained points of a smooth closed curve, we obtain the final angular diagram (Figure 5d).

8. Calculate the area bounded by the final angular diagram, which is a criterion for the quality of the semi-finished product under investigation.

Using this algorithm, a program was written that was used to process images of the surface of samples of semi-finished products made from polyether fibers taken sequentially from different parts of the spinning production line at the "Sovetskaya Zvezda" factory (St. Petersburg). A study was carried out of 40 microimages of the surface of semi-finished products (10 from each section) taken with a computer microscope under the same lighting conditions and with the same magnification.

The program performed the processing automatically, producing as a result the final total diffraction pattern for the selected sample with the total diagram built in the same program window and the calculated area of this diagram, the value of which is displayed in the upper left corner of the window in the form "S = <value area in pixels> " (Figure 6).

From the data of Figure 6 it can be seen that by the criterion "S" - the area bounded by the angular diagram, the semi-finished products considered are confidently different.

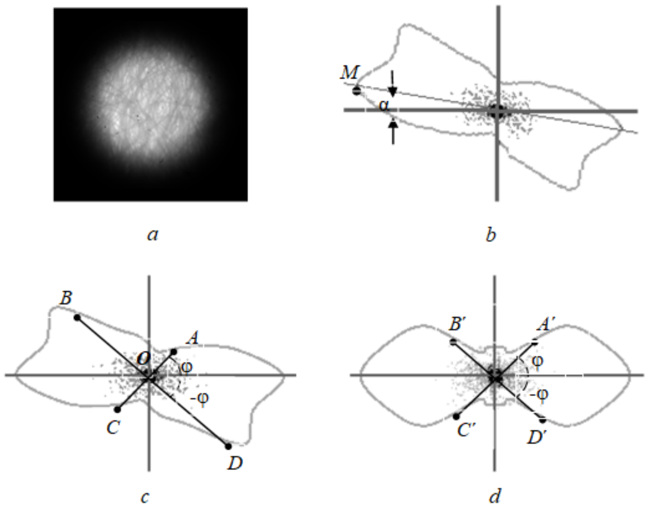
With an increase in the quality of the semi-finished product under consideration, anisotropy of the constructed total angular scattering diagram of light scattering grows in accordance with an increase in the order of the fibers along the batt direction (it already becomes in the direction perpendicular to the batt direction). Accordingly, the value of the parameter "S" entered by us decreases.

Conclusion

The algorithms and the corresponding programs of the non-computerized computer calculation of the diffraction pattern from the digital micro-image of the surface of the fiber-containing material under study, observed in the hardware method when illuminating the micro-image with laser light, are proposed.

An algorithm and a corresponding program for computer processing and analysis of the calculated diffraction pattern with an output to the parameter S are proposed, which makes it possible to digitally estimate the anisotropy of the angular distribution of fibers in the material under study.

Using these programs, samples of industrial semi-finished spinning products were studied at different stages of production and it was shown that by S-criterion these stages are confidently different.



a b c d

Figure 5: Illustration of the successive stages *(a, b, c, d)* of computer processing of the studied microimages using the algorithm given in positions 1-7 in the accompanying text.

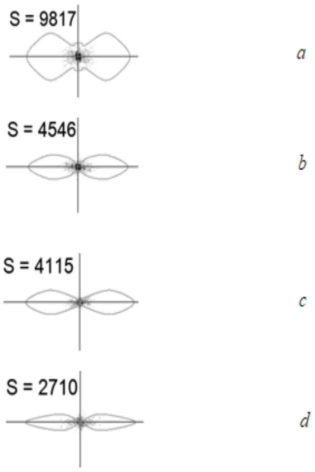


Figure 6: The Results of computer analysis of the studied semifinished products: a- tapes from the carding card; b-pre-stretched tapes; c-tapes, the last exhaust hood; d-rove.`

The proposed method in the above form is promising for laboratory quality control of spinning semi-finished products when solving the problem of obtaining micro-images of controlled semi-finished products under the same lighting conditions and the same arrangement of samples on the microscope table (along the machine direction).

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