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CROSS-SECTIONS MODELS OF COMBINED FIBERS AND YARNS

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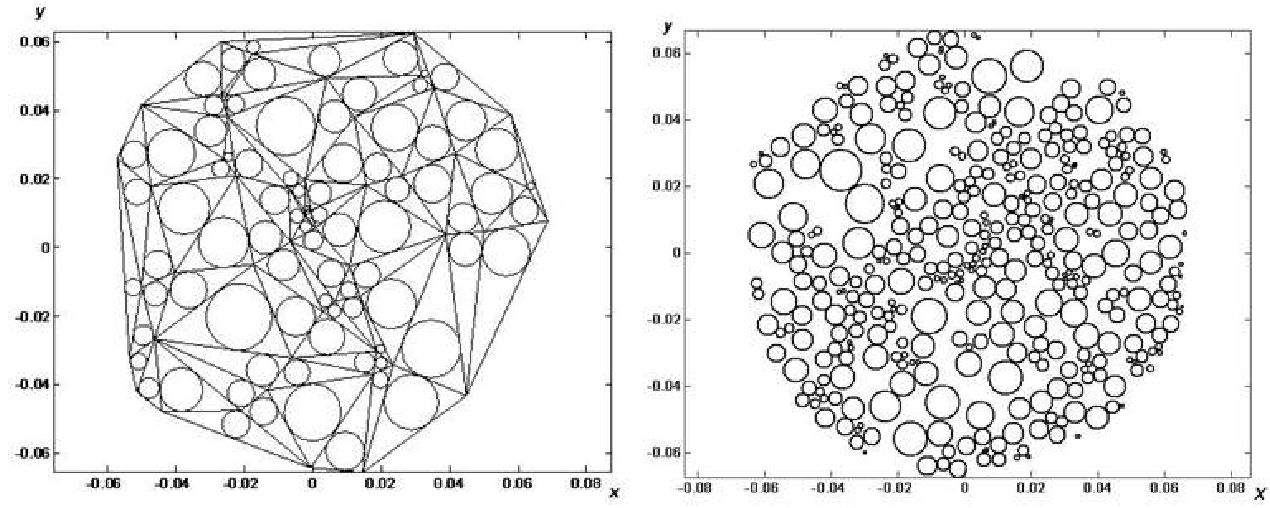
Algorithms for computer simulation of cross-sections of threads, yarns, and combined yarn have been studied and proposed. Comparative assessment of algorithms for utilization of models in applied research into interrelation between the structure of fiber products and their operational characteristics has been presented.

Keywords: statistical simulation, modeling, algorithm, cross-sections of fiber products, Monte Carlo method.

Information on the distribution of fibers in product's transverse sections is used in the investigations of interaction mechanics of fibers, appearance of the filaments and yarns, their porosity and permeability [1]. To improve methods for the study of cross-sections of thread or yarn (CSY), it is necessary to have models of these sections. Such models can be obtained using methods of computer simulation and statistical modeling [2], [3]. Obtaining models of CSY relates to the problems of simulation of the so-called dense packing of objects [4], [5]. Universal algorithm for their solution does not exist. Each category defines a specific set of additional terms and restrictions that must be considered when developing the algorithm [6], [7]. For CSY, these conditions are as follows. Cross-sections of all the fibers in CSY do not necessarily have to touch each other because the elastic forces, even in a strongly twisted product, lead to gaps between the fibers. In many problems, exact reproduction of the features of the cross section of fiber is not important, and therefore, the section can be replaced by simplified forms, for instance, rings. Modeling algorithm must ensure the manageability of obtained simulated CSY to simulate different variants of product's structure, especially in the case of the combined thread or yarn. Simulation speed should be high enough to be able to use the Monte Carlo method to obtain statistically stable results over a reasonable time. The resulting model of CSY should allow to calculate the necessary metrics and performance and to solve applied problems, for which the model was created. Below, description of the proposed algorithms, examples of their work and comparative evaluation is given.

The first of the considered algorithms A1 is based on Delaunay triangulation [1]. According to this algorithm coordinates of points on the plane around the center of CSY are generated. Delaunay triangulation is performed at these points. The circles, the totality of which forms the simulated section, are inscribed into the obtained triangles. Picture 1 shows the results of the algorithm with the average number of fibers N.

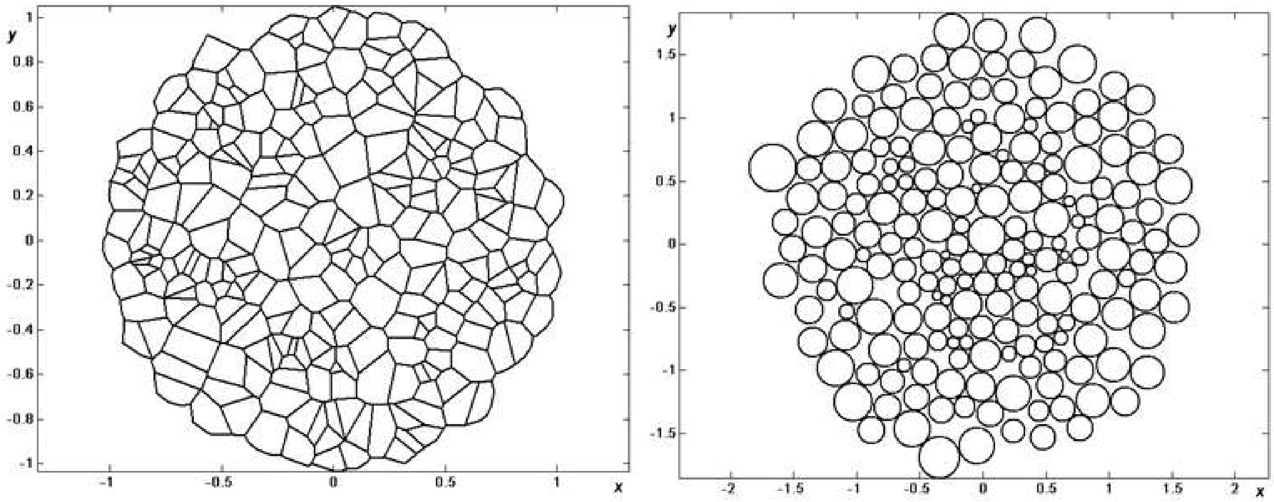


a) N = 50 б) N = 200

Picture 1. Model according to algorithm A1

In those cases where, for the purposes of simulating, it is sufficient to allocate the areas occupied by the fiber; a system of convex polygons of Voronoi, obtained based on Delaunay triangulation, can be used as a model for CSY. Algorithm for simulating the CSY A2, which was built for these purposes, provides the image of CSY, an example of which is shown in Picture 2-a . An important advantage of these two algorithms is the speed of their work. Unfortunately, they do not allow to precisely control over the number of simulated fibers in the CSY, the distribution of their size - the radius or area - distribution within the field of CSY, as well as to obtain the models of combined yarns with complex types of structure of CSY.

Closer to the optimal algorithm in terms of requirements is the algorithm A3. It consists of three stages. During the first stage simulating of the cross-sections of fibers, forming the CSY according to the selected laws of distribution of the radii of fibers and positions of their centers, is carried out. In this case, overlapping of cross-sections of fibers on each other is possible.

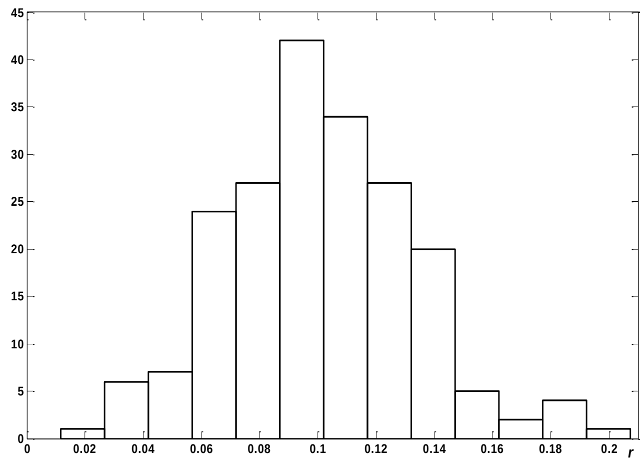


a) model according to algorithm A2 б) model according to algorithm A3

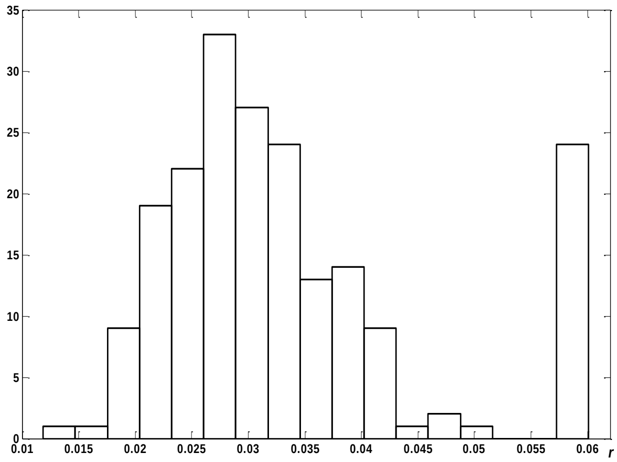
Picture 2

In the second stage cross-sections of fibers move apart in a radial direction from the center of the CSY until intersections disappear. At the third stage compression of sections of fiber to the center of CSY takes place. Cross sections of fibers move along the trajectories, which are on average directed towards the center of CSY, but they contain random variations in the radial and azimuthal directions. Thus, the process of "spillage" of fibers sections is simulated. This process provides a dense packing of cross sections. Measure of quality "spillage" is the sum of squared distances between the centers of cross sections of fibers. Minimum sum corresponds to the minimum of the total elastic energy of interaction between the fibers near the simulated cross-section, which is consistent with the general principles of mechanics of interacting elastic systems.

Picture 2-b illustrates the algorithm A3, obtained by the following initial data. Fibers in a section are sumulated by circles with random radii, N = 200. CSY radius which is located within the cross section of fibers is taken to as Rp = 1. The average radius of fiber rSr = 0.1, coefficient of variation of the radius CVr = 30%. Bar chart $H_1(r)$ of radii r is given in Picture 3-a. Centres of cross sections of fibers are uniformly distributed within CSY.

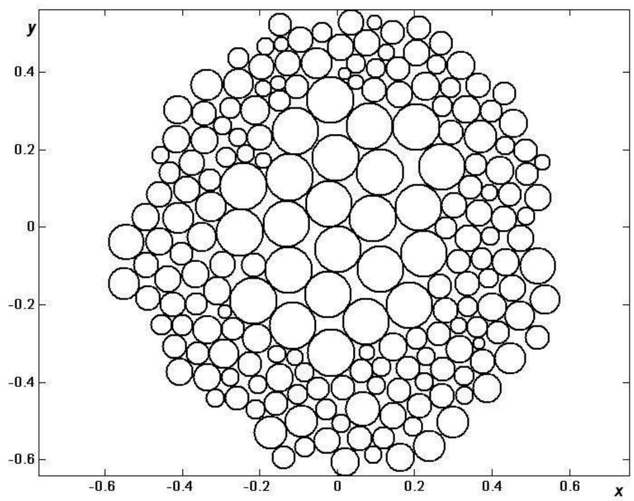


a) bar chart $H_1(r)$

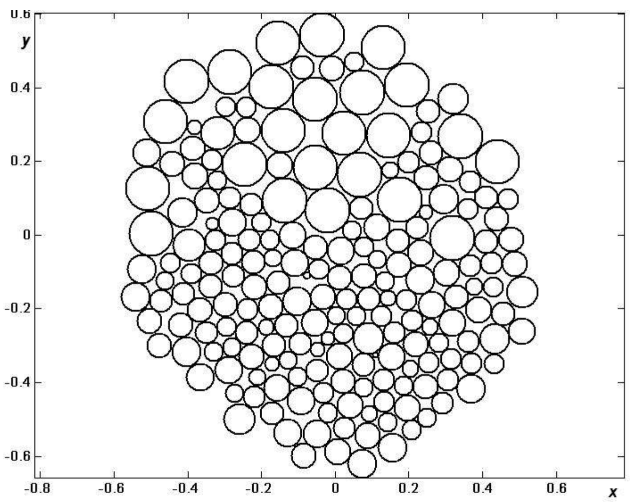


б) bar chart $H_2(r)$

Picture 3



a)



b)

Picture 4

Simple modification of the algorithm A3, it enables to simulate different types of CSY of combined yarn. For example, Picture 4 shows the CSY model obtained with the aid of the algorithm A3 model, whose central part is filled with threads of bigger and of the same thickness, while at the periphery there are more thin fibers with a large scatter in thickness. We shall note that the algorithm "spilling" A3 "squeezes" out the fibers of greater radius from the second group of fibers to the periphery of the CSY. Baseline data for the first group of fibers: $N_1 = 24$; $Rp_1 = 0.2$; $rSr_1 = 0.06$; $CVr_1 = 0.1\%$. The same data for the second group of fibers: $N_2=176$; $Rp_2= 1.0$; $rSr_2 = 0.03$; $CVr_2 = 20.0\%$. Picture 3-b shows a histogram $H_2(r)$ radii of the two groups of fibers in this section.

On Picture 4-b the CSY model of combined yarn of the same two fiber groups is illustrated, but they fill the semicircles of CFY. In simulating, the affected and the randomized nature of simulation of fiber cross-sections was demonstrated, and a process of "spilling" in the algorithm A3.

Waste of computer time to simulate one section increases with increasing of the quantity of fibers in the cross section. On a PC with a single-core Intel-processor with an operating frequency of 2.2 GHz simulation of one section of the N = 200 fibers takes on average 27 sec, which is acceptable for the purposes of statistical simulation.

CONCLUSIONS

1. The algorithms for the simulation of cross-sections of threads and yarns, using Delaunay triangulation and Voronoi polygons have been considered. Their limited suitability for use in applied research has been determined.

2. The algorithm of statistical simulation of transverse sections of the yarn and combined strands, which is satisfactory both in terms of its capabilities, as well as quick action, has been proposed.

3. Examples of the proposed algorithm for simulating of transverse cross-sections of uniform yarns and combined fibers with different structures have been given.

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