DOI 10.1007/s10692-020-10167-w
Fibre Chemistry, Vol. 52, No. 2, July, 2020 (Russian Original No. 2, March-April, 2020)

MATHEMATICAL SIMULATION OF PROCESSES

SIMULATION MODELING OF THE STRUCTURE OF TWISTED YARN WITH EMBEDDED ELECTRICALLY CONDUCTING FIBERS

D. B. Ryklin and V. V. Davidyuk

UDC 677.072

The present article is devoted to simulation of the structure of yarn with embedded electrically conducting fibers. Migration of fibers into different sections of the yarn is taken into account in the simulation. The influence of the linear density and structure of yarn with embedded electrically conducting fibers on the average number of contacts that arise between the fibers in the simulated sections is determined. Through simulation it was possible to assess the degree to which twisting tends to increase the number of contacting electrically conducting fibers, a factor that, in turn, defines the stability of the electrical properties of blended yarn.

Wide-ranging technical re-engineering accompanied by installation of the latest production equipment produced by the world's leaders in textile machine construction has been carried out at most spinning mills in the Republic of Belarus. The development of a wide range of different types of yarn and blended fibers for the manufacture of textile materials for special purposes represents one approach to increasing the efficiency with which already installed equipment is employed. It is precisely the development of special fabrics which represents the basic method of sustaining textile production in most countries of Western Europe.

The modern range of fibers with special properties is quite broad. It includes high-strength, fire- and heat-resistant, and conducting fibers as well as fibers with antibacterial, thermoregulating, and other properties.

Electrically conducting fibers are used as special-purpose to solve one of two problems, either to create an antistatic effect or to shield against electromagnetic radiation.

Bekinox fiber, manufactured by the firm of Bekaert (Belgium), is the most well-known and the most common type of fiber used to create antistatic fabrics. The fiber is in the form of segments of stainless steel wire and is generally produced as tape in pure form (Bekaert Bekinox VS) or in tape (Bekaert Bekinox LT) in which Bekinox fiber is mixed with polyamide fiber [1, 2].

The objective of developing a simulation model of the structure of twisted yarn in which conducting fiber is embedded was to determine an efficient composition of yarn that ensures the stability of its electrical properties. In the present case, the process of ensuring the stability of properties is understood the production of a structure of fiber in which there exists a continuous sequence of contacts of the conducting fibers from the first to the last contact in a given section along a segment of given length.

Vitebsk State University of Technology, Republic of Belarus; e-mail: ryklin-db@mail.ru. Translated from Khimicheskie Volokna, No. 2, pp. 61–64, March–April, 2020.

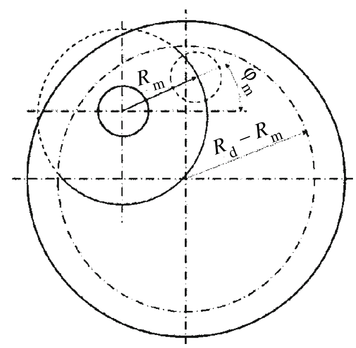

Fig. 1. Schematic diagram of migration of fibers in section of yarn.

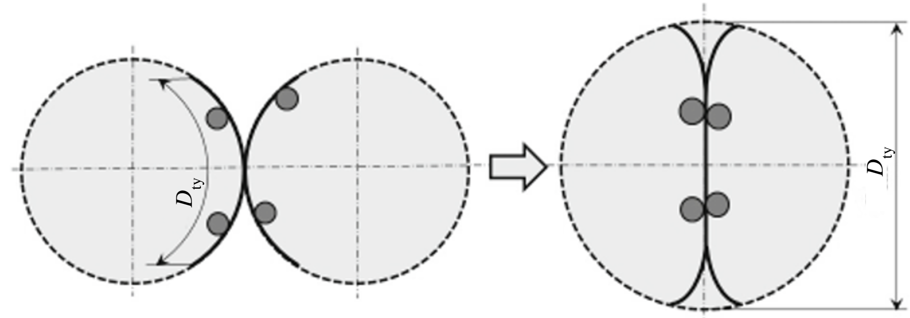

Fig. 2. Increase in number of contacts between conducting fibers in twisted yarn

The newly developed simulation model of twisted yarn is based on a model of an ideal fibrous product according to which the product is considered a flow of fibers where the density of the forward ends of the fibers along a segment of assigned length obeys Poisson's law [3]. That is, it is assumed that the probability that n frontal (or rear) ends of the fibers will be discovered in the time interval $(t, t + \tau)$ is found from the formula

$$p_n = \frac{(\lambda\tau)^n e^{-\lambda\tau}}{n!}, \tag{1}$$

where λ is the rate of flow of the fibers, equal to the mathematical expectation of the number of frontal ends of the fibers per unit time (or per unit length of the product).

For each (k-th) component of blended yarn,

$$\lambda_k = \frac{T_y}{T_{fk}} \frac{\Delta}{l_k} \beta_k, \tag{2}$$

where T_y is the linear density of the yarn, tex; T_{fk}– average linear density of fibers in k-th component, tex; Δ – discreteness of model, i.e., distance between two successively modeled sections, mm; l_k – average length of fiber in k-th component, mm; and β_k – fraction of k-th component in yarn.

In the course of the simulation segments of fibers that have migrated from their initial position end up in each section of the yarn other than the first. It is assumed that in each succeeding section of the yarn a segment of yarn is displaced by a magnitude called the radius of migration R_m in a given direction specified by the angle φ_m relative to some null direction (Fig. 1).

In order to describe the process of migration the radius R_m and angle φ_m are introduced into the model as random variables distributed according to a normal and uniform laws with particular characteristics.

The initial position of the fiber, i.e., the position of its segment in the first section in which it occurs, is determined by the periphery of the yarn based on the assumption that in the course of being twisted, all the rear ends of the fibers

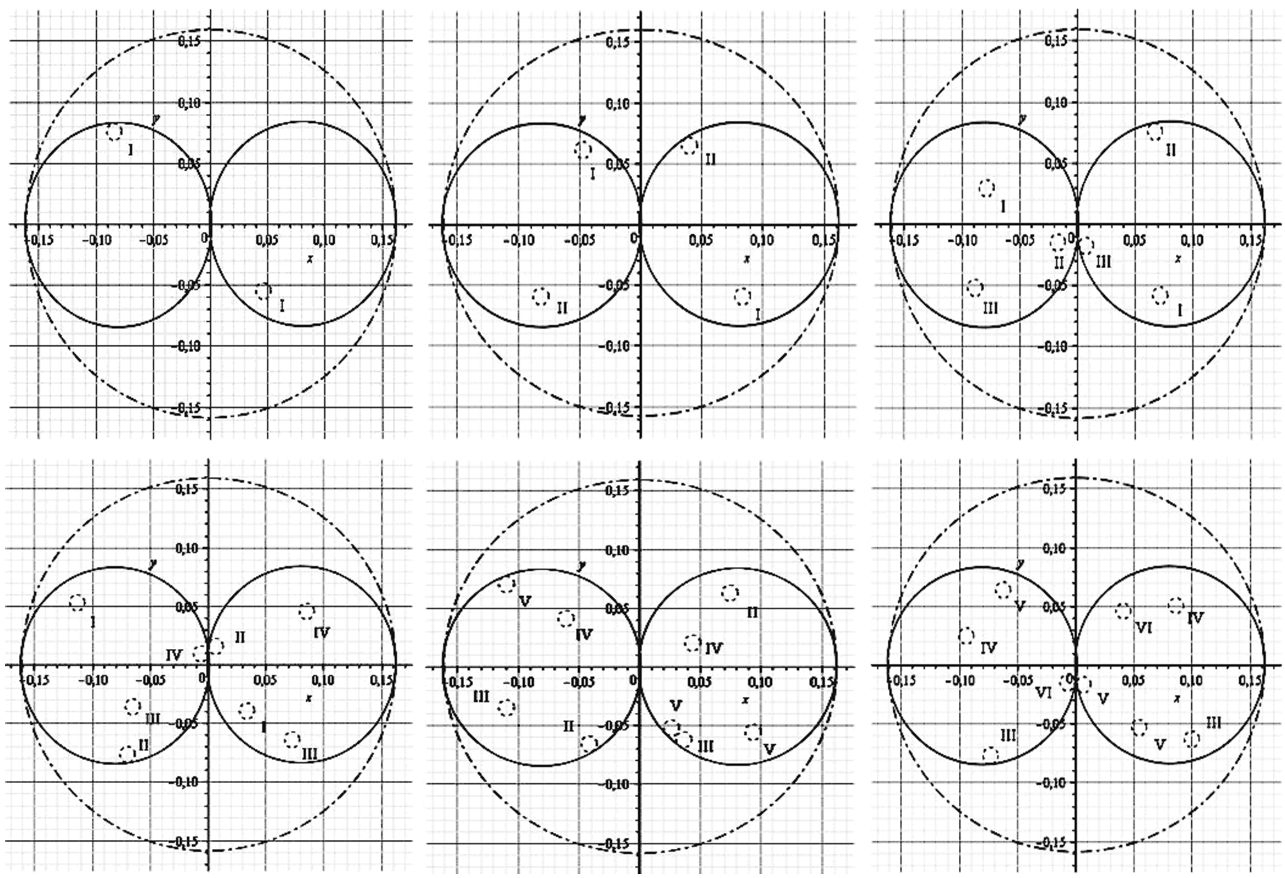

Fig. 3. Results of simulation of sections of strands of twisted yarn in which conducting fibers are embedded

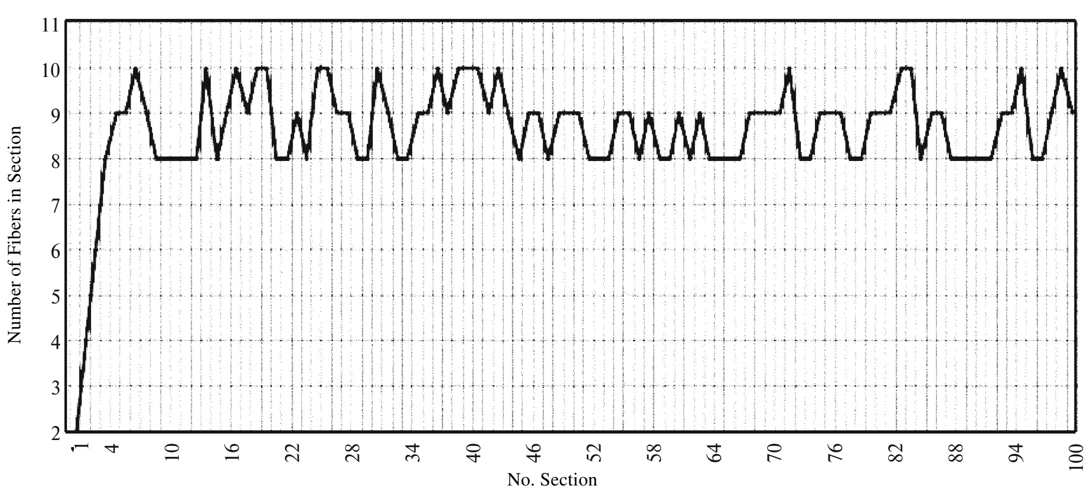

Fig. 4. Variation in number of conducting fibers in sections of simulated yarn with structure 20tex × 2

reach the surface of the yarn in the form of hairs [4]. Thus, simulation of the yarn occurs in the direction in which the yarn is rolled from the spinning cob in the course of being rewound.

An analysis of the market of textile products in which the conducting fibers are embedded shows that twisted yarn is generally used to manufacture fabrics with antistatic properties. This is due to the fact that single-ply yarn produced by spinning mills exhibits an unstable structure and is heterogeneous in terms of physical properties. As the yarn is twisted into several plies, its state of equilibrium, breaking load, and other properties all increase [5]. Based on the specific nature of the subject of investigation, the hypothesis was also advanced to the

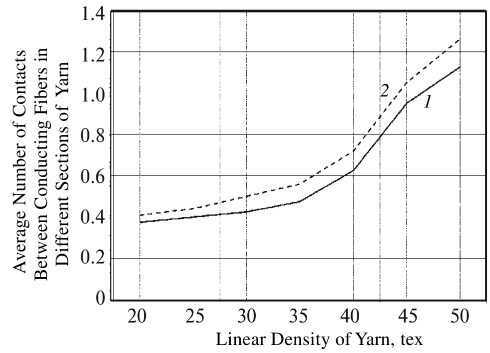

Fig. 5. Influence of linear density T of single-ply (*1*) and twisted (*2*) yarn in which 20% conducting fibers is embedded on the average number of contacts between the fibers m.

effect that, in light of the fact that conducting fibers reach the surface of the yarn in the course of twisting two strands, the number of contacts between these fibers increases, which leads to an increase in the stability of the electrical properties.

Simulation of twisted yarn is based on an assumption to the effect that in the course of deformation of sections of a single-ply strands, all the contacts in the structure of the twisted yarn that are present between the conducting fibers are preserved, while fibers that occur on the surface of the strands in their zone of contiguity form new contacts (Fig. 2).

The newly developed algorithm is implemented in the Maple computer algebra system.

Let us now consider the results of a simulation of the structure of twisted yarn with structure 20tex×2 in which 80% of cotton fiber and 20% conducting fibers are embedded. Bekinox fibers with linear density 0.9 tex are considered the conducting fibers. The diameter of these fibers reaches 12 μm with nominal length 47 mm.

The first six sections of the twisted strands of yarn are successively represented in Fig. 3, on which the conducting fibers are indicated with roman numerals corresponding to the ordinal numbers of the sections of the yarn in which these fibers occur. The position of the cotton fibers in the newly developed model is not defined. Their parameters are taken into account only in the calculation of the diameter of the yarn. The distance between the simulated sections amounts to 10 mm.

From the graph presented in Fig. 4 it is evident that there is an increase in the number of conducting fibers of yarn (like the increase in the number of fibers of the other components) from section 1 to section 3. Beginning with section 4, the number of fibers oscillates about the average value.

The influence of the linear density of a single-ply yarn and the structure of twisted yarn in which 80% cotton fiber and 20% conducting fiber are embedded exerted on the average number of contacts between the conducting fibers was determined as a result of the simulation (Fig. 5).

Analyzing the resulting dependence, it may be noted that the number of contacts between the conducting fibers increases with increasing linear density of the yarn. Moreover, the number of contacts in the twisted yarn is 5–10% higher than in single-ply yarn with the same linear density.

This indicator, like the number of contacts between the steel fibers characterize, though not exhaustively, the degree of stability of the electrical properties of yarn, since they do not take into account the length of the fiber and depend on the distance between the simulated sections of the yarn. Accordingly, another indicator, for example, the number of contacts created in a segment of the length of yarn equal to the length of the conducting fiber, may be used to arrive at more correct assessment. In view of the nominal length of the fiber, which is equal to 47 mm, it was determined as a result of the simulation that the number of contacts along the given length in single-ply yarn of linear density 40 tex amounts to 2/9, while in twisted yarn with structure 20 tex × 2 the value of this indicator increases to 3/4.

Thus, simulation made it possible to assess how twisting tends to vary the number of contacting electrically conducting fibers, which in turn defines the stability of the electrical properties of blended yarn.

The newly developed model of twisted yarn will serve as a basis for performing complex investigations designed to assess the degree of influence of the structure and composition of yarn in which conducting fibers are embedded on the properties of the yarn.

REFERENCES

1. *Proc.* https://vostok.ru (upload date: Jan. 3, 2020).
2. *Proc.* https://bekaert.com (upload date: Jan. 3, 2020).
3. *D. B. Ryklin*, *Simulation of Technological Processes in the Treatment of Heterogerneous Fibrous Mixtures* [in Russian], Vitebsk State University of Technology, Vitebsk (2006), 170 pp.
4. *D. B. Ryklin and A. G. Kogan*, *Production of Multicomponent Yarn and Blended Fibers. Monograph* [in Russian], Vitebsk State University of Technology, Vitebsk (2002), 215 pp. 170
5. *I. G. Borzunov, K. I. Badalov*, et al., *Spinning of Cotton and Chemical Fibers (fabrication of roving, greige and melange yarn, twisted fibers and filamentary articles)* in Russian], 2nd ed., rev., exp., Legprombytizdat, Moscow (1986), 392 pp.