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Predicting of Coil Length of Components Spirally Arranged in Complex Structure Yarns

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The present work proposes the theoretical methodology to predict the coil length of components spirally arranged in complex structure yarns. Such types of yarns as the covered yarns and the yarns with structural effects are analysed. The predicting methods are addressed to yarns produced in one process by means of hollow spindles technology. The predictive equations are proposed. As the initial data the technological parameters of manufacture process of complex structure yarn, also the structural parameters of the used components are necessary. The results of predicted coil length and the experimental values of coil length are presented. The comparison of the predicted coil length with available experimental data shows rather good agreement.

Keywords: coil length, complex structure yarn, geometrical yarn model, yarn, yarn structure.

INTRODUCTION

The geometry of the covered yarns and yarns with structural effects is rather complex [1, 2]. Due to the importance of complex structure yarns in knitted and woven materials, the influence of the geometrical parameters of the yarns was studied [3]. Attempts have been made by the use of formulas and graphs to describe the technology of preparing and the properties of complex structure yarns. In the case of the slub yarns, the parameters defined and calculations relate to the slub count, the yarn count, as well as the summation of these parameters along fancy yarn [4, 5]. The way of the effect building and the properties of complex structure yarns made by means of the application of a pressurised-air method on spinning equipment are reported [6]. The quality of the different effects arrived depending on manufacture parameters [6, 7]. Usually, structural, mechanical and etc. indices of complex structure yarns are determinate in experimental way. For example, authors of papers [8, 9] use such way. In these papers the structures of various covered elastomeric yarns are examined. Among the other structural indices of covered yarns a length of the wrapping yarn is tested [9]. It is worth to note that the experimental ways are not good for forecasting the yarns' qualities and designing the new assortment, because there appears a need to manufacture the samples of yarns [10, 11]. Therefore the most effective predicting of the geometry of complex structure yarns may be done theoretically.

A possibility to adjust the geometry of the complex structure yarns including fancy yarns with loops and snarls and to determine it by means of the various parameters of their manufacture process is indicated in [12 – 16]. For instance, the model to predict the parameters of snarl formation in complex structure fancy yarns and to simulate a snarl shape based on the theory of elastic string is discussed in [14]. The structure of the covered yarns was examined theoretically in [12, 13, 15, 16].

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Some components in complex structure yarns have a spiral shape. Therefore length of these components may essentially differ in compare with length of other components of these yarns. The values of the coil length of spiral components are necessary in predicting of consumption of these components, also in calculating a percentage composition and a total linear density of the complex structure yarn.

A typical covered yarn is composed of a core and the one or the two covering yarns arranged spirally around the core [1]. For this purpose the covering machines with the one or the two hollow spindles arranged one above the other are used [16].

A spiral arrangement also is character for a binder component in the yarns with structural effect [10]. These yarns are produced by hollow spindle technology too. The binder component reinforces an intermediate product composed of a core and effect yarn.

A task of the current research is to propose the theoretical methods of predicting of the coil length of covering or binder components in complex structure yarns.

RESULTS AND DISCUSSIONS

Geometrical models of analysed yarns

As a theoretical background of this research the geometrical models of complex structure yarns are used. Structure of these models is determined by the properties of components of the yarns and by the technological peculiarities of the manufacture.

A concentric-spiral geometrical model was used for the covered yarns. Some simplified assumptions mentioned below were made for this model.

There are the two covering components and a core in analysed yarn model. It was assumed that the core component is straight and an axial line of this core serves as an axis of the covered yarn. The first component is spirally arranged around the core. According to the used model a pitch of the spiral coil and the distance between the axial line of the core and the axis of the first covering component remain in a fixed level. Moreover, the yarn, which contains the two covering yarns, usually has different wrapping directions of the first and the second layers. Besides that an assumption, which declares that an intermediate product is cylindrical in shape, was made. The second covering yarn wraps this product. For the pitch of the spiral coil of the second covering yarn also a condition of constancy is valid.

The geometry of the coil of the second covering yarn is rather disordered in reality as the evenness of a surface of the intermediate product depends on conditions of the first wrapping. Therefore only a conditional constancy of the distance between the intermediate product axis and the axis of the second covering yarn may be applied. One more assumption about inextensibility of covering yarns was made. Another condition deals with the core volume. Firstly, this index remains at fixed level. Secondly, the dimensions of the core during wrapping in compare with initial dimensions may differ. In the current research the following precondition on this matter was made: the diameter of the core is decreased in compare with initial diameter, if the core was stretched before wrapping.

The mostly spread case of complex structure yarns with structure effects like loops, snarls, waves, knots, etc. is that the effect intermediate product consists of two yarns, one is core yarn and the other one is effect yarn. Such structure is popular because it could be achieved using one process technology and hollow spindles in fancy yarn manufacture. Besides that the fancy yarns are very decorative and attractive so are in great demand of the textile designers. Very often these two components - core and effect - are the single or plied spun yarns and twisted multifilament yarns. Spun yarns especially plied ones or twisted multifilament yarns get less deformed in the cross direction while processing if to compare with not twisted multifilament yarns or textured yarns. That is why we can maintain, that the cross-sections of such yarns in complex structure yarn remain the circle shaped, and this shape does not change while manufacturing the complex structure yarn.

The coil length of the binder yarn of complex structure yarn made in one process using hollow spindle is being calculated, referring to precondition, that the binder component winds the effect intermediate product at the place of core and effect component contact with screw winding. The contraction of the binder yarn, appearing while the yarn twists round its core, comparing with the length of screw winding is very small and that is the reason why it might be not considered.

Coil length predicting methods

In order to predict a coil length some initial data and calculations are necessary. For example, the coil length of the first covering component l_{11} links with projection of involute p_{11} and coil pitch h_{11} by means of equation (Fig. 1):

$$l_{11} = \left(p_{11}^2 + h_{11}^2\right)^{1/2}. \quad (1)$$

The distances p_{11} and h_{11} can be found using the structural indices of components, also the manufacture parameters of covered yarns:

$$p_{11} = 2\sqrt{\pi}\left(\sqrt{\frac{T_c}{\delta_c(1+\varepsilon_1)}} + \sqrt{\frac{T_1}{\delta_1}}\right), \quad (2)$$

$$h_{11} = \frac{v_d}{n_{s1}} \quad (3)$$

where T_c, T_1 is the linear density of core and first covering yarn, δ_c, δ_1 is the overall density of core and first covering yarn, ε_1 is the core stretch ratio during wrapping, v_d is the delivery speed of covered yarn, n_{s1} is the rotational speed of first spindle.

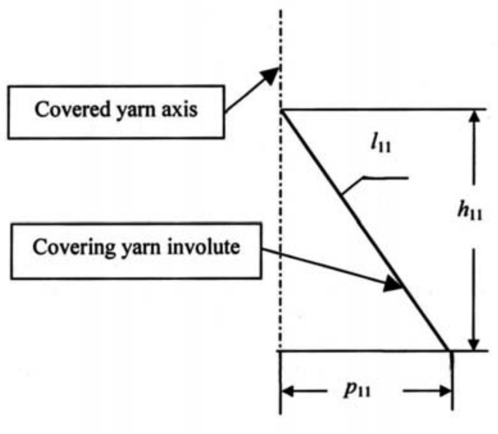

Fig. 1. Triangle of involute of first covering component of covered yarn structure: p_{11} – projection of involute, h_{11} – coil pitch, l_{11} - coil length

Therefore the equation (1) acquires the following form:

$$l_{11} = \left\{4\pi\left(\sqrt{\frac{T_c}{\delta_c(1+\varepsilon_1)}} + \sqrt{\frac{T_1}{\delta_1}}\right)^2 + \left(\frac{v_d}{n_{s1}}\right)^2\right\}^{1/2} \quad (4)$$

In order to estimate the evenness of the intermediate product the following coefficient of evenness was proposed:

$$k_{e1} = \frac{2n_{s1}}{v_d}\sqrt{\frac{T_1}{\pi\delta_1}}. \quad (5)$$

This proposition enables us to predict the average coil length of second covering yarn. Not easy to show that after estimation of the evenness of the intermediate product this length links with the structural indices of components and with the manufacture parameters of covered yarns by means of the following equation:

$$\overline{l_{21}} = \left\{4\pi\left(\sqrt{\frac{T_c}{\delta_c(1+\varepsilon_1)}} + \sqrt{\frac{T_2}{\delta_2}} + 2k_{e1}\sqrt{\frac{T_1}{\delta_1}}\right)^2 + \left(\frac{v_d}{n_{s2}}\right)^2\right\}^{1/2} \quad (6)$$

where T_2 is the linear density of second covering yarn, δ_2 is the overall density of second covering yarn, n_{s2} is the rotational speed of second spindle.

The research has shown that for the intermediate product without gaps between the adjacent coils the $k_{e1} = 1$. Therefore for this case the coil length of the second covering component $l_{21} = \overline{l_{21}}$.

Cross-section of yarn with structure effects is shown in Fig. 2.

Table 1. Raw material of the components of complex structure yarns

Variant	Raw material of the components and linear density			
	Core	Effect	Binder	Cover
A, E	Cotton spun yarn, 18.5 tex x 2	Linen spun yarn, 46 tex	PA multifilament yarn, 5 tex	–
B	Cotton spun yarn, 11.7 tex x 2	Linen spun yarn, 46 tex	PA multifilament yarn, 10 tex	–
C	Cotton spun yarn, 18.5 tex x 2	Linen spun yarn, 46 tex	PES multifilament yarn, 5 tex	–
D	PES multifilament yarn 11 tex	Linen spun yarn, 33 tex	PES multifilament yarn, 11 tex	–
F, G	Polyurethane elastomeric multifilament yarn, 89.6 tex	–	–	CV multifilament yarns, 16.5 tex

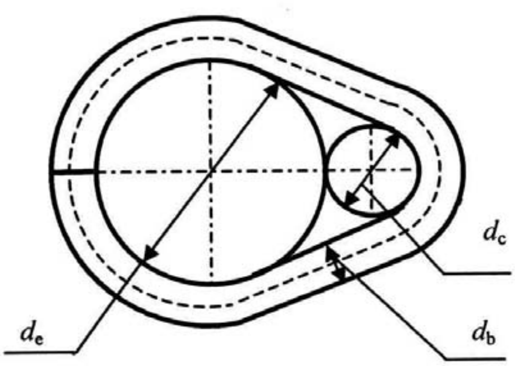

Fig. 2. Cross-section of yarn with structure effects: d_c – core yarn diameter, d_e – effect yarn diameter, d_b – binder yarn diameter

The cross-sections of yarns making the effect intermediate product are circles, with diameter d_c and d_e. The binder component twists the effect intermediate product in screw windings.

The axial line projection of coil length of the binder yarn to the other axis, vertical for complex structure yarn's axis, is equal for the length of curve, showed with dotted line in Fig. 2.

After calculating the length of straights and arcs:

$$p = 2\sqrt{d_e d_c} + \pi(d_e + d_b) - \frac{1}{180^{\circ}}\pi(d_e - d_c)\arctan\frac{2\sqrt{d_e d_c}}{d_e - d_c}. \quad (7)$$

It is easy to express the diameters d_c, d_e, d_b by the linear density of core, effect, binder yarns – T_c, T_e, T_b, respectively and overall density of yarns – δ_c, δ_e, δ_b, respectively.

The coil length of the binder yarn l_{b1} is equal to hypotenuse of triangle, which one cathetus is equal to the coil pitch of binder yarn h; the second is equal to length of the projection of involute p.

The value h can be written as follows:

$$h = 1/K, \quad (8)$$

where K is the twist of complex structure yarn.

Now the K can be expressed in the manufacturing parameters of the complex structure yarns: rotational speed of hollow spindle n_s and delivery speed of complex structure yarn v_d.

Thus the l_{b1} can be written in the form:

$$l_{b1} = \left\{ \left[\frac{4}{\sqrt{\pi}}\sqrt[4]{\frac{T_e T_c}{\delta_e \delta_c}} + 2\sqrt{\pi}\left(\sqrt{\frac{T_e}{\delta_e}} + \sqrt{\frac{T_b}{\delta_b}}\right) - \frac{\sqrt{\pi}}{90^0}\left(\sqrt{\frac{T_e}{\delta_e}} - \sqrt{\frac{T_c}{\delta_c}}\right)\arctan\frac{2\sqrt[4]{\frac{T_e T_c}{\delta_e \delta_c}}}{\sqrt{\frac{T_e}{\delta_e}} - \sqrt{\frac{T_c}{\delta_c}}} \right]^2 + \left(\frac{v_d}{n_s}\right)^2 \right\}^{1/2}. \quad (9)$$

Experimental comparison

The experimental tests were done with complex structure yarns of A, B, C, D and E variants (Table 1), having been produced on one process twisting machine with hollow spindles with technological parameters v_d: 0.50 – 0.68 m/sec, n_s: 253.3 – 283.3 sec^{-1}.

Additionally the experimental data of covered yarns (variants F and G), proposed by author of work [16] were used in the current comparison. The samples F and G were manufactured by means of well-known covering technology. The following manufacture parameters for these samples were used: $n_{s1} = 258.3$ sec^{-1}, $n_{s2} = 216.7$ sec^{-1}, $v_d = 0.18$ m/sec, ε_1=2.95-3.45.

As the initial components the cotton and linen spun yarns, also the polyester (PES), polyamide (PA), polyurethane elastomeric and viscose (CV) multifilament yarns are used (Table 1).

The theoretical and experimental results of the coil length of the covered yarns and the yarns with structural effects are given in Table 2.

Table 2. Theoretical and experimental results of the coil length

Variant	Values of the coil length, mm		Deviation, %
	Theoretical	Experimental	
A	2.45	2.32	+5.6
B	2.59	2.37	+9.3
C	2.86	2.76	+3.6
D	1.99	1.78	+11.8
E	3.19	3.14	+1.6
F	1.17*/1.40*	1.38*/1.48*	-15.2*/-5.4*
G	1.19*/1.42*	1.28*/1.34*	-7.0*/+6.0*

*The values for the first and the second covering components

It is worth to note that all the calculated values of the coil length of fancy yarns exceed the experimental results. The deviation fluctuates between +1.6 and +11.8 %. The deviation for covered yarns is between –15.2 and +6.0 %. Cotton plied spun yarns as core component (A, B, C, E variants) and linen spun yarns as effect component get less deformed in cross direction while processing complex structure yarn. So, the precondition, that the cross-sections of the effect intermediate product yarns in complex structure yarn remain the circle shaped, and it does not change while manufacturing process, is fulfilled. Somewhat different conditions are acting for samples of covered yarns (F and G variants). The polyurethane elastomeric core of these yarns has stretched to considerable degree. Therefore there are reasons to believe that the round shape of cross-section of the core remains during covering process.

CONCLUSIONS

The suggested equations, based on the concentric-spiral geometrical model of covered yarns, links the coil length of spiral components with the structural indices of used yarns, also with the manufacture parameters of the covered yarns. The coil length of first covering component depends on such factors as delivery speed of covered yarn, rotational speed of first spindle, core stretch ratio during wrapping, linear density and overall density of core and first covering yarn. The coil length of second covering yarn is under influence of linear density and overall density of this yarn, of rotational speed of second spindle, also of all the factors mentioned in the case of the first covering component.

The presented analysis of geometrical model of yarn with structure effects results the method for calculating of the coil length of the binder yarn. It is presented that the coil length of the binder yarn is conditioned by the linear density and overall density of core, effect, binder yarns, respectively as well as the manufacture parameters of complex structure yarns: rotational speed of hollow spindle, delivery speed of complex structure yarn.

The proposed methods, despite the great simplifying assumptions, provide a suitable predictive tool for designing of new yarns containing spiral components.

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