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Interrelation between the Geometrical and Structural Indices of Fancy Yarns and their Overfeed and Twist

Abstract
The aim of this research was to develop the interrelation between twist and the overfeed of the effect component and such structural and geometrical indices of fancy yarns as the linear density, the height of the effects, the width of the effects, the distances between effects, and the number of effects per unit length. For this purpose fancy yarns were produced in one process using hollow spindles. The statistical dependencies of the indices mentioned are also presented in this paper. This research was performed using a mathematical model testing method taking into account its informativeness. The indices of the fancy yarns investigated primarily depend on the overfeed of the effect component. With an increase in this factor, the values of the linear density of fancy yarns, the height and the width of the effects, and the number of effects per unit length also increase, in which case the distances between effects decrease.

Key words: *fancy yarns, structural indices, mathematical model, overfeed, twist.*

Introduction

Fancy yarns - textile yarns with virtually unlimited pattern designs - are a kind of textile product. The assortment of fancy yarns is very wide, and in recent years their structure has become more and more complex. At the moment they can not be called a «classical» structure with loops, boucle, knobs a spiral structure and combined effects, but they have very different colour effects and/or form. Using one manufacturing process, it is possible to produce fancy yarns with different specific properties. Other advantages of using only one manufacturing process are a big delivery speed and output of fancy yarns [1 - 3].

The geometrical and structural indices of fancy yarns, such as the linear density, the height of the effects, the width of the effects, distances between effects, the number of effects per unit length, the variety of effects, and the placing of the effects depend on machine settings, i.e. the technological parameters of manufacture, such as the speed of supply of the effect component, the delivery rate of the fancy yarn, the rotational speed of the hollow spindle, and the core yarn tension during the technological process of spinning [1, 4 - 7]. Furthermore, the indices mentioned above depend on the different raw materials and properties of the yarn components [8, 9].

Materials

Fancy yarns were produced by one process method using hollow spindles of the FAG (Germany) type on a fancy yarn twisting machine - "Jantra PrKV12" ("Jantra", Bulgaria) according to "Prenomit" technology. Core and effect components were supplied separate from each other at different speeds. These components took on a false twist in the hollow spindle, and an effect blank was manufactured as a result. After that this effect blank was twisted on a real twist with a binder component, which fixed the effects in the fancy yarns. The object of the subsequent research was fancy yarns with the following components:

1st type: 50 tex worsted woollen yarns were used as core and effect components; the binder component – was 5.6 tex multifilament PES yarns;

2nd type: plied 16.7 tex multifilament textured PES yarns and 13.3 tex viscose yarns were used as core components; 32 tex worsted woollen yarns as an effect component; the binder component was 5.0 tex multifilament PA yarns.

These components were chosen because soft, friable woollen yarns allow to form effects of regular form. Such fancy yarns can be used in woven and knitted fabrics for clothing and decorative textiles.

A second order composite model with experimental points on the cube was chosen [10]. Characteristics of the model are the following: number of levels and number of variables – 3, and the number of factor level combinations – 14. This design was highly suitable for the study because of its obvious advantages: the corner points can be successively investigated, enabling to study the larger part of the space. It is important to investigate the points that correspond with maximum values of the factors because they determine machine productivity and operational possibilities. All the combinations of factors are easily compatible due to the drive

Table 1. *Code and real independent variables of manufacturing fancy yarns.*

Variant number	Code independent variables			Real independent variables			
	X_1	X_2	X_3	X_1, m/min	X_2, m/min	X_3, min^{-1} for 1st type of fancy yarn	X_3, min^{-1} for 2nd type of fancy yarn
1	-	-	-	40	30	16000	14000
2	+	-	-	80	30	16000	14000
3	-	+	-	40	50	16000	14000
4	+	+	-	80	50	16000	14000
5	-	-	+	40	30	24000	20000
6	+	-	+	80	30	24000	20000
7	-	+	+	40	50	24000	20000
8	+	+	+	80	50	24000	20000
9	-	0	0	40	40	20000	17000
10	+	0	0	80	40	20000	17000
11	0	-	0	60	30	20000	17000
12	0	+	0	60	50	20000	17000
13	0	0	-	60	40	16000	14000
14	0	0	+	60	40	24000	20000

scheme of the machine used. The number of factor value combinations is small.

The manufacturing parameters of fancy yarns chosen in this study are given in ***Table 1***, in which the code and real independent variables of manufacturing fancy yarns are shown. The parameters of manufacturing chosen, such as the speed of supply of the effect yarn, the delivery speed of the fancy yarn and the rotational rate of the hollow spindle have a crucial influence on the distribution of the effect overt the length of the yarn researched.

Therefore fancy yarns were produced at 14 different factor value combinations, and 28 variants of fancy yarns were manufactured with different effects, such as loops, boucle, knobs as well as a spiral structure and combined effects.

Overfeed η shows how many times the effect component outmeasures the core component. In the manufacturing process overfeed η varied from 0.80 to 2.67 for both types of fancy yarns. Fancy yarn twist K varied from 320 m^{-1} to 800 m^{-1} for the 1st type of fancy yarn and from 280 m^{-1} to 667 m^{-1} for the 2nd type of fancy yarn. A minimal overfeed spiral effect was formed in the majority of places.

Test methods

The following geometrical and structural indices of fancy yarns were analysed, forecasted and designed: the linear density of the fancy yarn T, the height of the effects h, the width of the effects s, distances between effects a, and the number of effects per unit length z. As fancy yarns are produced with the twisting machine "Jantra PrKV-12", there are no possibilities of setting the structural indices of the machine. Hence, they are all counted in the experimental space.

The yarns were tested on standard test equipment using standard test methods. The linear density of the fancy yarns was tested according Standard ISO 2060 [11]. Structural indices h, s and a were measured as presented in ***Figure 1***. The structural indices of the fancy yarns were tested with the microscope Metric 7.0 PE-Live and displayed on a computer. The effects were magnified five times, then the structure effects of the fancy yarns were measured, photographed and displayed on the computer. The number of effects per unit length of the fancy yarns was calculated using a twist tester. The number of tests for each index was 25.

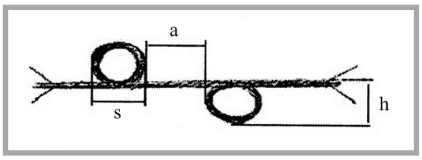

***Figure 1**. Measuring the structural indices of fancy yarns.*

Statistical analysis was done using a Microsoft Excel programme.

Results and discussions

After achieving, monitoring and calculating the geometrical and structural indices of the fancy yarns, relations were established between such indices of fancy yarns as the linear density T, the height of the effects h, the width of the effects s, distances between effects a, the number of effects per unit length z, and such parameters of manufacturing as the speed of supply of the effect yarn X_1, the delivery speed of fancy yarn X_2 and the rotational rate of the hollow spindle X_3. The general relation between the response Y (in this case T, h, s, a, z) and parameters X_1, X_2, X_3 is [10]:

$$Y = B_0 + B_1X_1 + B_2X_2 + B_3X_3 + \\ + B_{12}X_1X_2 + B_{13}X_1X_3 + B_{23}X_2X_3 + \\ + B_1X_1^2 + B_2X_2^2 + B_3X_3^2 \quad (1)$$

Here B_0 – constant term;
B_1, B_2, B_3 – coefficients of the main factor effects;
B_{12}, B_{13}, B_{23} – coefficients of the interaction effects;
B_{11}, B_{22}, B_{33} – coefficients of the quadratic effects.

The relations between these coefficients are presented in ***Table 2***. Some coefficients obtained are not significant, the values of which are shown in brackets in the table.

The mathematical models obtained were tested taking into account its informativeness. These mathematical models are used to design new fancy yarns, which supply inequality:

$$F_A \rangle F_L, \quad (2)$$

Here
F_A – criterion of informativeness of mathematical models;
F_L – table criterion of informativeness.

Using criterion F, it was established that the mathematical models of the dependencies of the geometrical indices of fancy yarns, such as the linear density T, the number of effects per unit length of fancy yarns z of both types of fancy yarns, the height h and the width of the effects s of the 1st type of yarns tested, upon the independent variables of manufacturing fancy yarns, X_1, X_2, X_3, are suitable for further interpretation. The mathematical models of the distances between effects a are not informative, which is the reason why the following design is not used.

Mathematical statistical characteristics were calculated for all the geometrical and structural indices investigated. The minimum and maximum values of fancy yarn indices are determined by the values of factors X_1, X_2, X_3 in the experimental space. The statistical data of which are presented in ***Table 3***.

According to these data, one can find the limits of variation of the structural indices of the fancy yarns examined. For example, the variation coefficient of geometrical and structural indices varied as follows: the linear density of fancy yarns T – 2.5% for both variants investigated; the height of the effects h – 33.4% (1st type of fancy yarn) and – 41.28% (2nd type), the width of the effects s – close to 44.0% for both types of fancy yarns, the distances between effects

***Table 2.** Coefficients of relations obtained*

Coef-ficient	Responses					
	The height of effects h, mm	The width of effects s, mm	The linear density of fancy yarns T, tex		The number of effects per unit length z, m^{-1}	
	1st type	1st type	1st type	2nd type	1st type	2nd type
B_0	1.951	2.352	140.29	92.79	84.183	76.189
B_1	0.777	0.668	26.05	16.66	43.218	40.197
B_2	-0.148	(0.015)	-13.71	-9.52	-4.510	-18.598
B_3	-0.353	-0.580	-2,26	(0.12)-	-8.613	2.900
B_{12}	(0.002)	-0.156	-8.75	5.66	10.356	16.435
B_{13}	0.163	0.254	1.42	0.86	5.954	1.562
B_{23}	(-0.004)	(-0.012)	(0.05)	(-0.32)	11.481	(0.092)
B_{11}	-0.403	-0.401	-4.09	-2.03	-30.858	-26.934
B_{22}	(0.001)	-0.136	6.31	4.97	5.442	14.061
B_{33}	-0.143	-0.191	-0.91	-3.16	-1.683	10.061

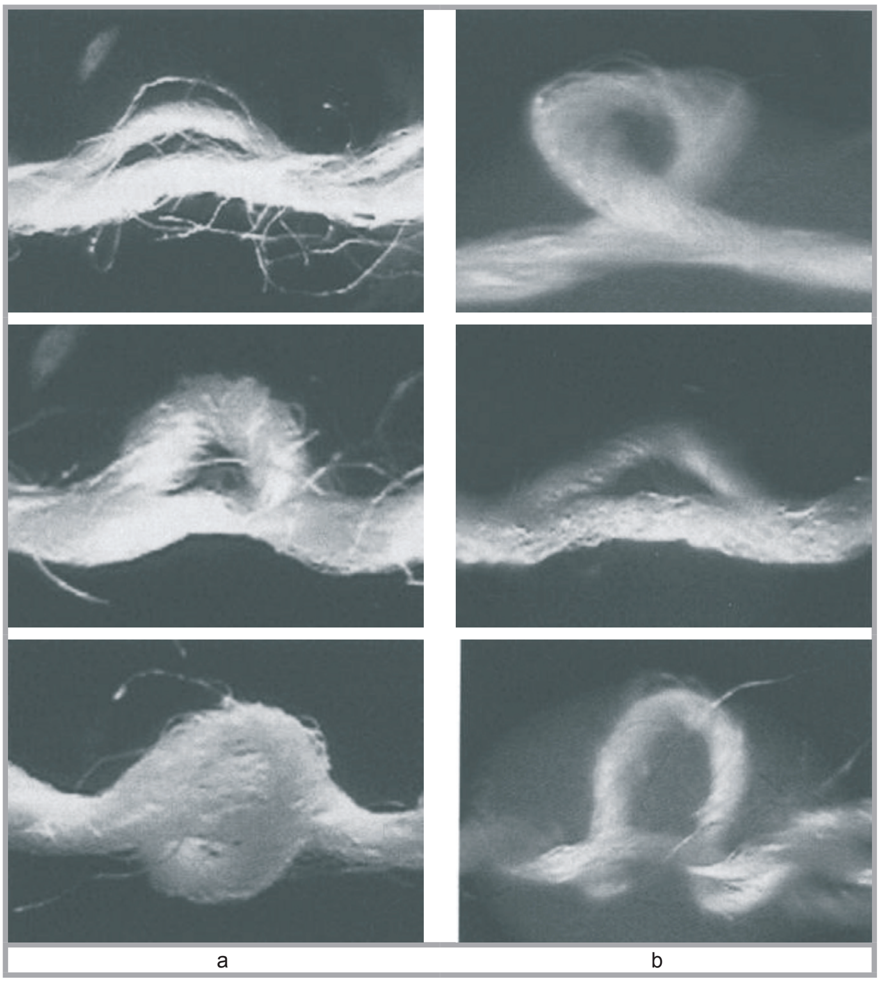

***Figure 2**. Effects of fancy yarns: a – of the 1st type of fancy yarn, b – of the 2nd type of fancy yarn, when the overfeed is 1.2-1.3*

***Table 3.** Minimum and maximum values of fancy yarn indices defined by the values of factors X_1, X_2, X_3 in the experimental space; * – fancy yarn variants 5 and 7 of the 1st type of fancy yarn (see Table 1) and variants 3, 7 and 9 of the 2nd type of fancy yarns are with waves and have a spiral structure, for which there is no possibility of measuring the sizes of the effects of these yarn variants.*

Type	Indices of fancy yarns	Coded values of factors			Calculated value, min/max*
		X_1	X_2	X_3	
1st	The linear density of fancy yarns *T*, tex	–	+	+	108.0 ± 0.6 / 191.7 ± 1.3
		+	–	+	
2nd		–	+	–	71.1 ± 0.3 / 127.7 ± 0.8
		+	–	+	
1st	The height of effects *h*, mm	–	0	0	0.65 ± 0.01 / 3.87 ± 1.23
		+	–	–	
2nd		–	–	–	0.71 ± 0.01 / 4.74 ± 1.96
		+	–	–	
1st	The width of effects *s*, mm	0	0	+	0.92 ± 0.01 / 4.92 ± 2.12
		+	–	–	
2nd		0	0	+	0.91 ± 0.01 / 4.76 ± 2.11
		+	–	–	
1st	Distances between effects *a*, mm	+	–	–	6.61 ± 0.2 / 19.1 ± 2.87
		–	–	–	
2nd		+	+	+	6.24 ± 0.2 /16.45 ± 2.66
		–	–	–	
1st	The number of the effects per unit length *z*, m^{-1}	–	0	0	1 ± 0.2 / 115 ± 2.4
		+	–	–	
2nd		–	0	0	1 ± 0.5 / 125 ± 2.6
		+	–	–	

a – 15.04% (1st type of fancy yarn) and 16.17% (2nd type), the number of effects per unit length *z* – 16.2% for both types of fancy yarns.

Overfeed is a very important factor which influences the structure of fancy yarns, as well as the sizes and distribution of effects in the yarn. Fancy yarn variants 3, 7, 9 (see ***Table 1***) with waves and a spiral structure are produced with the smallest overfeed. Core and effect components switch round together on these yarns. These tendencies are the same for both types of fancy yarns investigated. When the fancy yarn's twist *K* is 500 m^{-1} (1st type of fancy yarn) or 425 m^{-1} (2nd type of fancy yarn) and the overfeed η=1, the core and effect components are mostly twisted. In this case the linear density of fancy yarns is smallest: 108.0 ÷ 112.2 tex (1st type of yarn) and 71.1 ÷ 73.5 tex (2nd type).

When the overfeed η is 1.2 - 1.3, different effects of fancy yarns (spiral effects, arcs, and open or closed loops in some places) are formed (see ***Figure 2***). These structural effects were determined for fancy yarn variants 1, 5 (only for the 2nd type of fancy yarn) and 12 (see ***Table 1***). In this case the linear density of the fancy yarns examined varied from 126.8 tex to 133.8 tex for the 1st type of fancy yarn and from 77.8 tex to 88.7 tex for the 2nd type. When the overfeed η is 1.33 and the fancy yarn's twist *K* is 533 m^{-1} (1st type of yarn) and 467 m^{-1} (2nd type), the height of the effects *h* of the fancy yarn varied from 0.79 mm to 2.12 mm (1st type of yarn), and 0.71 ÷ 2.29 mm (2nd type). The number of effects per unit length *z* varied from 50 m^{-1} to 95 m^{-1} and the width of the effects *s* was similar for both types of fancy yarns - 0.91 ÷ 2.69 mm. In this case the distances between effects *a* has a maximum value for both types of fancy yarns, i. e. 10.81 ÷ 19.1 mm (1st type of yarn) and 8.32 ÷ 16.45 mm (2nd type).

As we can see from the photo graphics presented in ***Figures 3.a*** and ***3.b***, if the overfeed has an average value of η = 1.5 ÷ 1.6 and the fancy yarn's twist *K* was varied from 320 m^{-1} to 600 m^{-1} (1st type of yarns), and 280 ÷ 500 m^{-1} (2nd type). Fancy yarn bosses as well as open and closed loops are formed, and in some places knots occur. These effects are determined for variants 4, 8, 13 and 14 (see ***Table 1***). In this case the linear density of the 1st type of fancy yarn is 139.2 ÷ 149.1 tex and 89.4 ÷ 95.0 tex for the 2nd type; the height of the effect of the 1st type of fancy yarn rises to 3.16 mm, and to –3.85 mm for the 2nd type of fancy yarn; the width *s* of the effects being, respectively, 3.88 mm (1st type of yarn) and 4.34 mm (2nd type). The distance between effects *a* and the number of effects per unit length *z* of fancy yarn variant 4 varied the most, i. e. 6.64 ÷ 11.38 mm

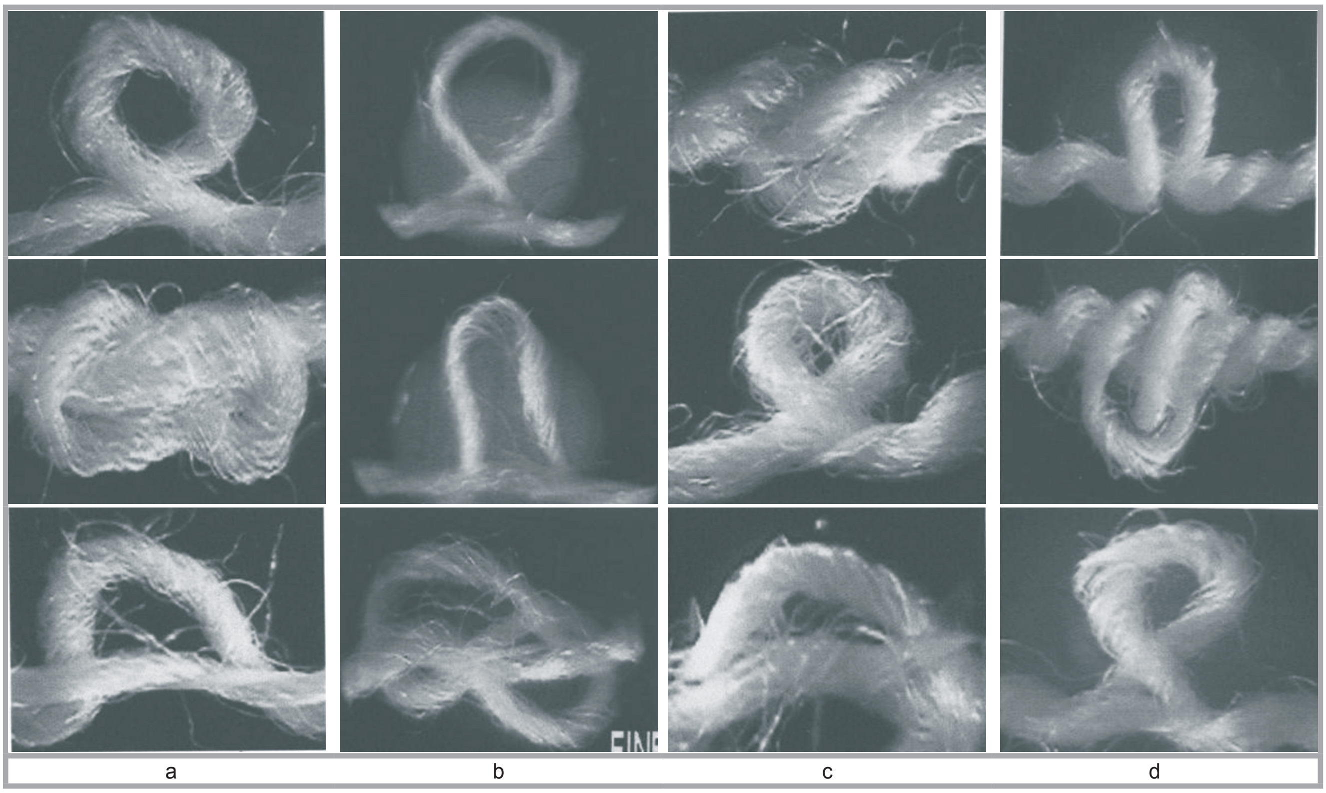

***Figure 3**. Effects of fancy yarns: a – of the 1st type of fancy yarn when the overfeed is 1.5 and the yarn twist 400 m^{-1}; b – of the 2nd type of fancy yarn when the overfeed is 1.6 and the yarn twist 280 m^{-1}; c – of the 1st type of fancy yarn when the overfeed is 2.0 and the yarn twist 500 m^{-1}; d – of the 1st type of fancy yarns when the overfeed is 2.67 and the yarn twist 800 m^{-1}*

and 80 ÷ 115 m^{-1} accordingly, only for the 1st type of fancy yarn.

When the overfeed is an average of η = 2, different effects of fancy yarns (periodically open and closed loops, knots) are formed (see ***Figure 4***). These structural effects are without arcs and are determined only for fancy yarn variants 10 and 11 (see ***Table 1***). In this case the linear density of fancy yarns is high, i. e. it reaches 160.2 tex for the 1st type and up to 109.0 tex for the 2nd type.

Figures 3.c and ***3.d*** present the effects of fancy yarns when the overfeed and fancy yarn's twist are higher (variant numbers 2 and 6, see ***Table 1***). The effects of fancy yarns in these variants are similar to those of variants 10 and 11 . When η = 2.67 and K = 667 m^{-1}, the index z of the 2nd type of fancy yarn reaches a maximum value of about 125 m^{-1}, but the distances between effects a reaches the minimum value – about 1.3 ÷ 1.5 mm. In this case, index T has a maximum value for both types of fancy yarns, i.e. 191.7 tex and 127.7 tex, respectively.

From the data presented in ***Figures 4***, it is evident that the influence of factor η is significant for indices T, h, s and z of the fancy yarns investigated. In these Figures

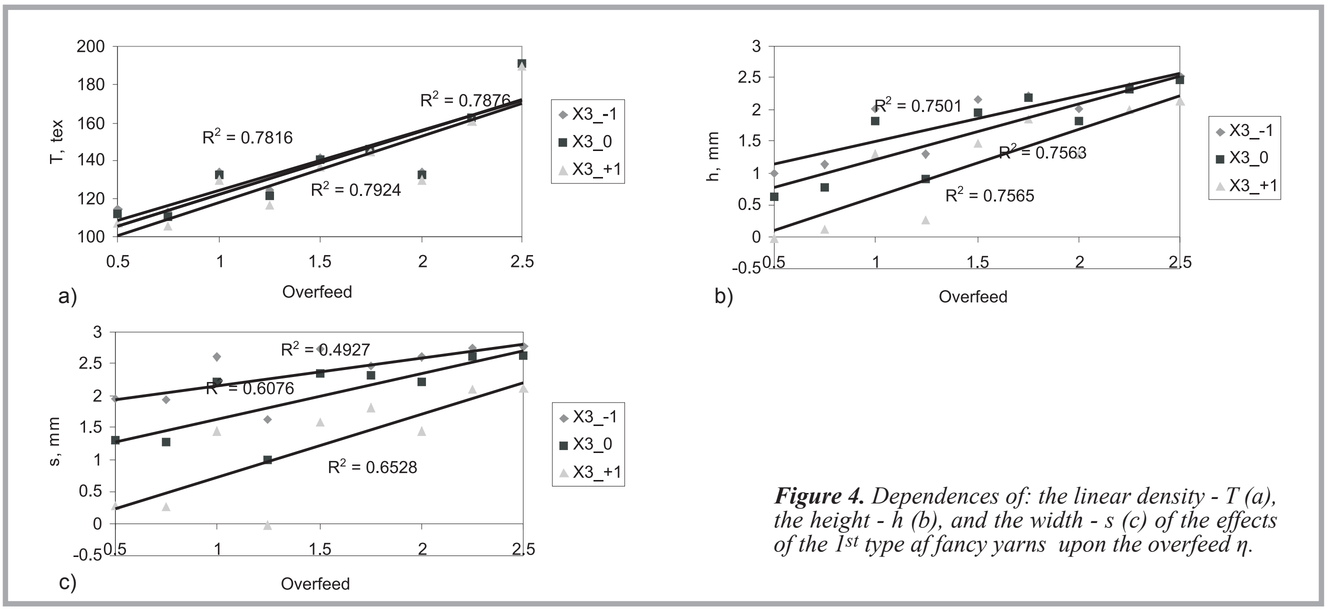

***Figure 4.** Dependences of: the linear density - T (a), the height - h (b), and the width - s (c) of the effects of the 1st type af fancy yarns upon the overfeed η.*

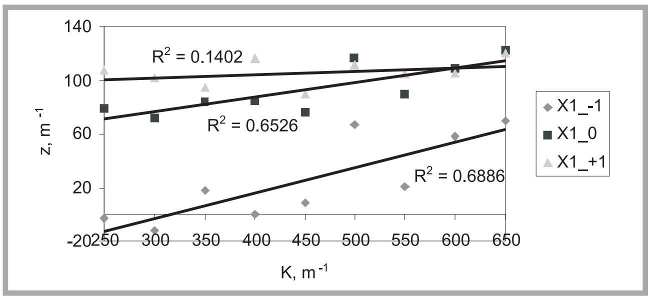

Figure 5. *Dependence of the number of effects per unit length (z) of the 2nd type of fancy yarn upon the twist K of fancy yarns.*

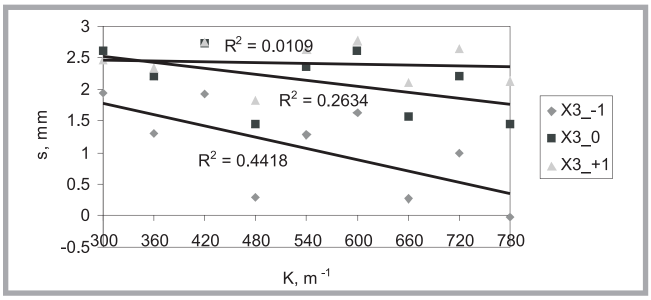

Figure 6. *Dependence of the width (s) of the effects of the 1st type of fancy yarns upon the twist K of fancy yarns.*

the rotational speed of hollow spindle X_3 has a stationary point, and the factor value is equal to -1, 0, +1.

When the overfeed increases, the indices of the fancy yarns investigated, except index *a*, also increase. These tendencies are the same for all indices of yarns studied. Dependencies of the linear density of both types of fancy yarns are similar and have the following coefficients of determination ($R^2 = 0.7724 \div 0.7924$): the height of the effects *h* and the number of effects per unit length *z*, – $R^2 = 0.7323 \div 0.7565$. As can be seen from Figure 6, the coefficients of determination are also important ($R^2 = 0.4927 \div 0.6528$). Hence, it can be stated that the width of the effects depends on the overfeed.

The influence of factor *K* on the investigated structural indices *s* and *z* of fancy yarns is presented in ***Figures 5*** and ***6***. In these Figures the speed of supply of effect yarn X_1 has a stationary point, and the factor value is equal to -1, 0, +1. When the twist of fancy yarns increases, the number of different effects also increases, but the size of these effects is the smallest.

Coefficients of determination are important ($R^2 = 0.5205 \div 0.7237$) only for the linear density of both types of fancy yarns and for the number of effects per unit length of the 2nd type of fancy yarn (see ***Figure 7***). Therefore these geometrical indices depend on the fancy yarn twist *K*. On the other hand, the coefficients of determination of dependencies *h* and *s* for the 1st type of fancy yarn and the number of effects per unit length of the 1st type of fancy yarn are low ($R^2 = 0.0094 \div 0.4418$), and therefore it can be confirmed that these dependencies on the fancy yarn twist *K* have not been established.

Conclusions

According to the regression analysis of factors of fancy yarn manufacturing parameters, when the speed of supply of the effect component X_1, the delivery speed of fancy yarns X_2, the rotational rate of hollow spindle X_3 and their interaction are significant for their geometrical and structural indices, such as the linear density of fancy yarns T, the height of the effects *h*, the width of the effects *s*, distances between effects *a*, and the number of effects per unit length *z*. Some of the mathematical models of the dependencies of the indices of fancy yarns upon the independent variables of manufacturing fancy yarns X_1, X_2, X_3 are suitable for further interpretation.

Maximum values of geometrical and structural indices were achieved when the coded values of the factors studied were the same for both types of fancy yarns, i. e. the linear density when $X_1 = +1$, $X_2 = -1$, $X_3 = +1$, indices *h*, *s* and *z* when $X_1 = +1$, $X_2 = -1$, $X_3 = -1$, and index *a* when all factors are -1. Minimum values of the indices investigated were achieved at very different coded values.

The overfeed η and fancy yarn twist *K* are very important factors which influence the structure of yarns investigated, as well as the sizes and distribution of effects in the yarn. When the overfeed is small, fancy yarns are with waves and have a spiral structure. When the overfeed produces more arcs, open or closed loops are formed in the fancy yarn structure. When the overfeed and twist are higher, different effects of fancy yarns (periodically open and closed loops, knots) are formed.

It was estimated that the linear density *T* of the 1st type of fancy yarn researched varied from 108.0 tex to 191.7 tex, for the 2nd type – from 71.1 tex to 127.7 tex, the height of effects *h* of the 1st type of fancy yarn varied from 0.65 mm to 3.87 mm, for the 2nd type – from 0.71 mm to 4.74 mm, and the width of effects *s* of the 1st type of fancy yarn – over the 0.92 ÷ 4.92 mm range, for the 2nd type – from 0.91 mm to 4.76 mm, the distances between effects *a* of the 1st type – over the 6.61÷19.1 mm range, for the 2nd type – from 6.24 mm to 16.45 mm and the number of the effects per unit length *z* of the 1st type changed until 115 m^{-1}, for the 2nd type – till 125 m^{-1}.

Structural indices of the fancy yarns studied primarily depend on the overfeed η. With an increase in this factor, the values of these indices also rise, in which case the distances between effects decrease. The values of these indices also depend on the fancy yarn twist *K*.

References

1. *Grabowska K. E., Vasile S. et al.: Fibre and Textiles in Eastern Europe, 2006, Vol. 14, No. 57(3), pp. 38-41.*
2. *Gong R. H., Wright R. M.: Fancy yarns: their Manufacture and Application, CRC Press Cambridge: Woodhead Pub., 2002.*
3. *Ragaišienė A. Petrulytė S.: Materials Science, 2003, Vol. 9, No. 4, pp. 414-418.*
4. *Petrulytė S.: Fibre and Textiles in Eastern Europe, 2001, Vol. 9, No. 1, pp. 24-27.*
5. *Nergis B. U.: Textile Research Journal, 2002, Vol. 72, No. 8, pp. 686-688.*
6. *Grabowska K. E. Fibre and Textiles in Eastern Europe, 2000, Vol. 8, No. 28(1), pp. 26-28.*
7. *Grabowska K. E.: Fibre and Textiles in Eastern Europe, 2001, Vol. 9, No. 1, pp. 28-30.*
8. *Ragaišienė, A., Petrulytė, S. Analysis of the Properties of Yarns with Structure Effects Proceedings of International Conference (AUTEX) "The Textiles: Research in Design and Technology" Kaunas, Lithuania, September 21-22, 2000: pp. 219 – 224.*
9. *Özdemir Ö., Çeven E. K. Textile Res. J. 75 (3) 2005: pp. 219 - 222.*
10. *Krasovskij G. I., Filaretov G. F.: Planning of Experiment, Izdatelstvo BGU, Minsk (1982) (in Russian)*
11. *International standart ISO 2060. Textiles – Yarn from packages – Determination of linear density (mass per unit length) by the skein method.*

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