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Influence of Technological Parameters on the Periodical Effects of Fancy Yarns

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Abstract
The effects of fancy yarn formation in one process can be controlled by the choice of the main factors connected to this process, like the speed of fancy yarn production, the speed of supply of the effect component, and the speed of the hollow spindles. The object of this study was fancy yarn of complex structure that had two linen yarns as 'effect' components. Analysis of the results indicated that the variables investigated influence the number of effects per unit length of fancy yarn and are significant because they determine the character and kind of fancy yarn effect. Periodical fancy effects were also investigated, such as open loop, arc, loop/knot, plain knot, extended knot made of dense coils, snarl, and long knot made of dense coils, including their intercombinations. The mathematical models obtained were investigated from an informative point of view. It was concluded that the mathematical model, which expresses the relationship between the number of effects of open loop - arc in the unit of fancy yarn length and the technological parameters of fancy yarn manufacturing, is informative and, therefore, interpreted further. The model obtained enables to forecast the geometry of the effects of fancy yarns, and it also allows to design new fancy yarns with the desired structure.

Key words: *fancy yarns, technological parameters, effects, forecasting, mathematical model.*

Introduction

In the past few years, extensive studies have been carried out by researchers to establish process-structure-property relationship models so as to investigate properties and to design the new yarns with the characteristics desired [1 - 3]. Yarns with various effects are very important textile products of spinning and twisting processes [1].

Nowadays, interest in fancy yarns creation, production, and applications is increasing. Such yarns, because of their decorative effect in knitted and woven fabrics, have considerable commercial significance. Fancy yarns, because of the abundance of effects [4], noticeably enhance the aesthetic effect of the textile materials in which they are used.

The decision of a designer to use fancy yarns means that it is no longer necessary to design a complex decorative structure for a textile article in order to create a decorative fabric. If the structural effects of fancy yarns are very strongly expressed, the aesthetic effect will be felt even in cases where the fabric structure is of the simplest. Hence, plain fabric can combine the elegance and simplicity of a plain structure with the decorative effect of the complex structure of fancy yarn. The impact of fancy yarn in the fabric can also be heightened by careful planning of the contrast between fancy and plain yarns [5]. The decorative level of fancy yarn also depends on geometrical and structural parameters, like the linear density of fancy yarns, the length of the effect component, the length of the segments of the effect component yarn, used for effect (such as loops, knots, etc.) creation, the number of periodical effects in a unit of fancy yarn length. Without the afore-mentioned parameters, the kind and character of the effect, especially such dimensions as length, height, the width of the effect, and fancy yarn geometry, on the whole are most significant for the designing of fabrics with fancy yarns [2, 6, 7]. Therefore, we can say that fancy yarns are materials of sophisticated structure, which influences their features of the fabric.

It is also possible to make an appearance that resembles fancy effects in woven or knitted fabric. The skilled programming of a jacquard-controlled weaving loom made it possible to mimic the looks of a bizarre style fancy effect in the weft using ordinary straight filament or spun yarns. In addition, textile designers and marketing departments have a particular interest in something new and innovative. Furthermore, any new fancy structure will offer the chance of creating new methods of marketing and even an entirely new market. However, it is in regions where there was none before. It should be emphasised that factors such as an increasing demand for customer choice and increasingly rapid technical and technological advances which are the most dominant here.

The parameters of rotor spun fancy yarns with slub effects were modelled and investigated [8]. Such structural parameters of the effect as slub length and amplitude were analysed. The relation between the slub multiple and slub length was established. The parameters affecting the slub length are the rotor diameter, normal yarn count, slub multiple, and performance of the servomotor. An increase in rotor diameter and slub multiple increases the length of the slub effect.

To understand the structure of fancy yarns, it is important to consider the different forming conditions the effects are created in, as well as to determine the effect size and evenness [9]. It was found that the control of the feed speed of the effect component and the tension of core component during forming has a direct impact on the structure of fancy yarn with a loop effect.

The findings of [10] show that the twist of chenille fancy yarn affects both the yarn shape and degree of pile packing. Because of low twist, chenille yarns tend to flatten, while the higher twist chenille yarn maintains its roundness. There is no doubt that the structure of chenille fancy yarn is an important factor for other characteristics like pile loss, and abrasion resistance [10]. Furthermore, chenille yarn material, yarn twist, and pile length have a significant effect on the abrasion resistance of not only chenille yarns but fabrics also [11].

Experimental design. Materials and methods

A second order composite design was chosen because of its obvious advantages:

Table 1. Design and factor level combinations.

No.	Composite design					
	Factor level combinations					
	Coded level			Actual values		
	X_1	X_2	X_3	P, m/s (m/min)	SH, s^{-1} (min^{-1})	S, m/s (m/min)
1.	-1	-1	-1	0.50 (30)	266.67 (16000)	1.50 (90)
2.	+1	-1	-1	1.17 (70)	266.67 (16000)	1.50 (90)
3.	-1	+1	-1	0.50 (30)	400.00 (24000)	1.50 (90)
4.	+1	+1	-1	1.17 (70)	400.00 (24000)	1.50 (90)
5.	-1	-1	+1	0.50 (30)	266.67 (16000)	1.83 (110)
6.	+1	-1	+1	1.17 (70)	266.67 (16000)	1.83 (110)
7.	-1	+1	+1	0.50 (30)	400.00 (24000)	1.83 (110)
8.	+1	+1	+1	1.17 (70)	400.00 (24000)	1.83 (110)
9.	-1	0	0	0.50 (30)	333.33 (20000)	1.67 (100)
10.	+1	0	0	1.17 (70)	333.33 (20000)	1.67 (100)
11.	0	-1	0	0.83 (50)	266.67 (16000)	1.67 (100)
12.	0	+1	0	0.83 (50)	400.00 (24000)	1.67 (100)
13.	0	0	-1	0.83 (50)	333.33 (20000)	1.50 (90)
14.	0	0	+1	0.83 (50)	333.33 (20000)	1.83 (110)

P – the speed of fancy yarn production, X_1;
SH – the speed of the hollow spindle, X_2;
S – the speed of supply of the effect component, X_3

- It was possible to investigate the corner points (points on the corners of the cube), so we were able to study a large part of the experimental space; it is important that the corner points correspond with the maximum values of the chosen factors as they decide the productivity of the equipment as well as process possibilities,
- the number of factor value combinations is small.

The design and factor-level combinations for the fancy yarn twisting are shown in ***Table 1***.

The experiments were performed on a Jantra (Bulgaria) machine for fancy yarns with the help of a complex model created for the experiments. This machine was equipped with hollow spindles of the FAG type (Germany). The effect component – in this case two linen spun yarns, causing various effects, is locked into position by the interaction of other components – the core and the binder. This is done by passing the core and effect components down the centre of the hollow spindle with a package containing binder yarn. The binder yarn balloons off to wrap around the intermediate effect product when it enters the hollow shaft. As the hollow spindle rotates, the binder component is wrapped around the other ones. The analysis of experiment results allowed to establish the relationships between the variables mentioned before and the number of various periodical effects in a unit of fancy yarn length. Such structural fancy effects like opened loop, arc, loop/knot, plain knot, extended knot made of dense coils, snarl, long knot made of dense coils and various other intercombinations were investigated. The object of the subsequent study was fancy yarn constructed from four components. The core component – twisted cotton yarn of 18.5 tex × 2, the effect component – two linen spun yarns of 56 tex and 56 tex, and the binder component – 5 tex filament polyamide yarn (PA 6, f 12, Chernigov, Ukraine). Such a complex structure and variety of effects of fancy yarns was constructed with the purpose of using them in woven and knitted fabrics. In course counts they can be used to produce distinctly and strongly textured knitwear and fabrics using simpler effect constructions, while in finer counts they may produce elusive texture effects in garments.

Fancy yarns were produced in fourteen different factor value combinations prescribed by the composite design, and then they were tested. The procedure of counting the effects per unit length was done using standard apparatus – a twist tester. A stereomicroscope was used for precise determination of the kind and character of the effect. The number of effects per unit length of fancy yarn was measured every 500 mm, analysing 20 tests per package and later re-counted in number per meter.

The codes used for various factors were X_1 (P) – the speed of fancy yarn production, X_2 (SH) – the speed of the hollow spindle, X_3 (S) – the speed of supply of the effect component.

The general relation [12] between the response Y (in this case, Y – number of effects) and the different parameters (in this case, X_i and X_j are coded values of the three process parameters defined earlier) can be expressed as:

$$Y = B_0 + B_1X_1 + B_2X_2 + B_3X_3 + \\ + B_{12}X_1X_2 + B_{13}X_1X_3 + B_{23}X_2X_3 + \\ + B_{11}X_1^2 + B_{22}X_2^2 + B_{33}X_3^2$$

Regression equations were generated to observe the linear, interaction and quadratic effects of process variables of fancy yarn indices.

Discussion of the research results

Different kinds of fancy yarn effects were analysed: opened loop (OL), arc (A), loop/knot (LK), plain knot (PK), extended knot made of dense coils (EKC), snarl (SN), long knot made of dense coils (LKC) and combined effects:
opened loop – arc (OL - A),
opened loop – loop/knot (OL – LK),
opened loop – plain knot (OL – PK).

The stylised fancy effects are presented in ***Figure 1***. Microscopic pictures of various effects obtained by the stereomicroscope and photographed by digital camera are shown in ***Figure 2***. Scanned effects are presented in ***Figure 3***. The analysis of variances showed the variances of the results of OL - A, OL – LK, PK and OL – PK are uniform whenever the variances of the results of other investigated indices are not uniform. Further analysis was carried out with an analysis of such periodical effects as opened loop – arc, opened loop - loop/knot and opened loop - plain knot in fancy yarns.

The coefficients of the relations obtained are shown in ***Table 2***.

Table 2. Coefficients of relations with no significant coefficients shown in brackets.

Coefficients	Responses		
	OL – A	OL - LK	OL - PK
B_0	83.80	50.61	78.86
B_1	25.96	(-2.79)	7.56
B_2	8.56	3.89	4.91
B_3	-10.87	-5.96	-7.73
B_{12}	(2.84)	(1.81)	3.84
B_{13}	6.46	5.37	(1.40)
B_{23}	(-4.60)	(1.12)	-5.58
B_{11}	(-2.93)	14.39	7.39
B_{22}	8.58	(-3.91)	(-0.73)
B_{33}	-10.05	(-2.16)	-11.66

B_0 – constant term,
B_i – coefficients of the main factor effects,
B_{ii} – coefficients of the quadratic effects,
B_{ij} – coefficients of the interaction effects

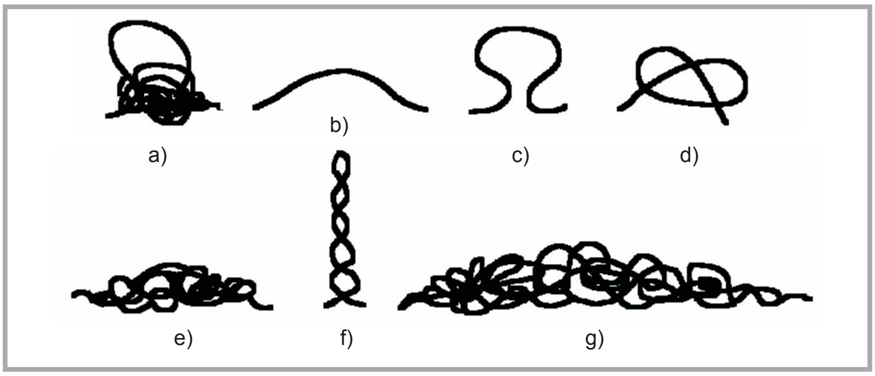

Figure 1. *Stylised fancy effects; a – loop/knot, b – arc, c – opened loop, d – plain knot, e – extended knot made of dense coils, f – snarl, g – long knot made of dense coils.*

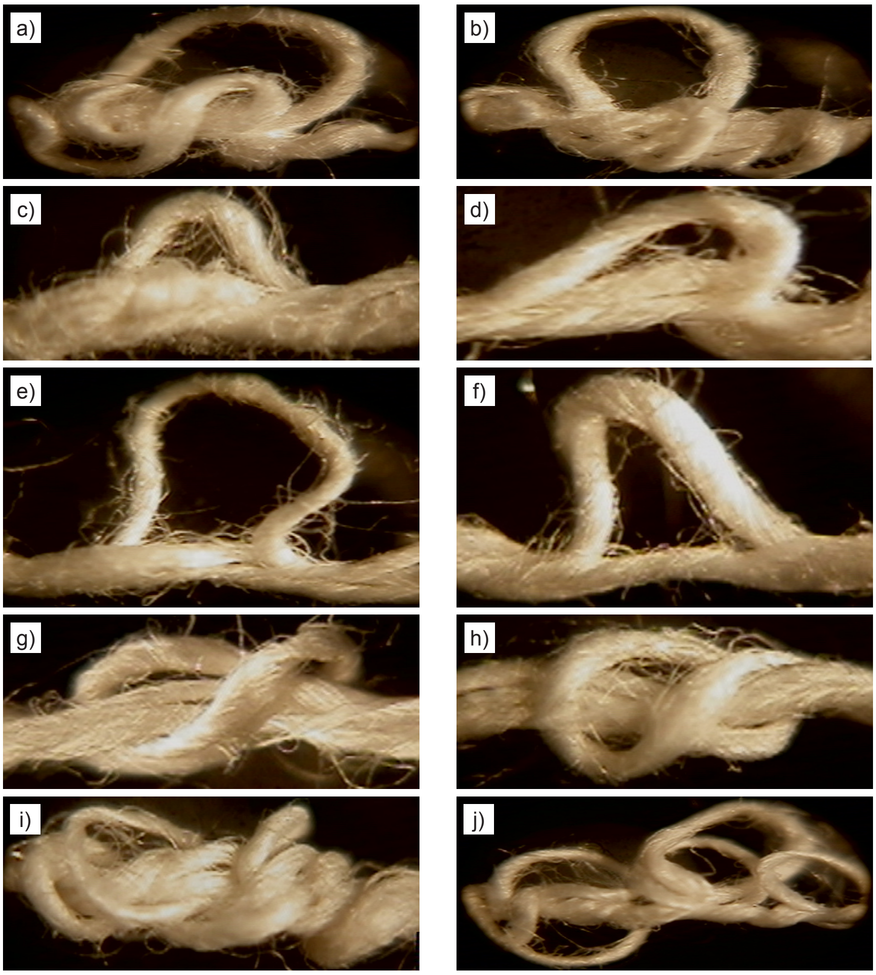

Figure 2. *Microscopic pictures of various investigated effects; a, b – loop/knot; c, d – arc; e, f – opened loop; g, h – plain knot; i, j – extended knot made of dense coils.*

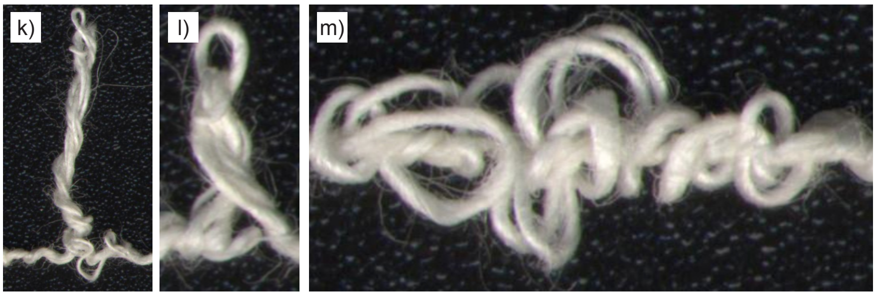

Figure 3. *Scanned pictures of investigated effects; k, l – snarl, m – long knot made of dense coils.*

The minimum and maximum experimental values of fancy yarn indices that are determined by the values of factors X_1, X_2, X_3 in the designing space are presented in ***Table 3***.

The mathematical models obtained were analysed from an informative point of view. It was found that the mathematical model that expresses the relationship between the number of effects of opened loop – arc (in units of fancy yarn length) and the technological parameters of fancy yarn manufacture is informative (at a confidence probability of 0.90), and therefore it was further interpreted. It was ascertained that the models that express the relationships between the number of effects of opened loop – loop/knot per unit length of fancy yarn as well as the number of effects of opened loop – plain knot per unit length of fancy yarn and parameters P, SH, S are not informative, and hence, dissociated from the further analysis.

It was found that the influence of the technological factors is significant for the formation process of the opened loop – arc effect, but not for the quadratic effect of factor X_1, nor the two interaction effects of factors X_1, X_2 and X_2, X_3.

The regression procedure included only significant coefficients of the relations (see ***Table 2***). The sign of the coefficient of a main effect indicates the direction in which the response moves when the variable concerned changes from a lower to a higher level. As is seen from Table 2, the main effects of the speed of fancy yarn production and the speed of the hollow spindle have contribute positively to OL – A formation, while the effect of the speed of supply of the effect component has a negative contribution. A negative coefficient of the variable in a response surface equation indicates that a particular index decreases with an increase in that variable, while a positive coefficient of the variable indicates that the index increases with an increase in that variable. However, the trend is modified with the sign and magnitude of the coefficient of the squared terms and the interaction between the two variables. The quantity by which the response varies for a certain amount of change in a controlled variable is given by the amount of change in the variable multiplied by the value of the coefficient.

An analysis of the significance of the factors was done in three points of the ex-

Table 3. *Minimum and maximum experimental values of investigated fancy yarns' indices.*

Number of effects per unit length of fancy yarn	Coded value of factors			Experimental value	
	X_1 (P)	X_2 (SH)	X_3 (S)	Minimum	Maximum
OL – A	-1 +1	-1 +1	+1 -1	22.5	138.3
OL – LK	0 -1	-1 -1	0 -1	34.3	90.0
OL – PK	-1 +1	-1 +1	+1 -1	50.3	113.8

perimental space. Analysing the points of the design space where the maximum (MAX) and minimum (MIN) values of response are placed, as well as the centre point of the experiment space, it was determined that factor P changes the response by 1.5 - 3.1 times, and the S factor changes the response by 1.1 - 2.1 times, respectively, whenever the speed of the hollow spindle changes the response by 1.6 times (at MIN point) and by 1.2 times (at MAX and centre points). The investigations demonstrated that the speed of fancy yarn production and the speed of supply of the effect component are the most important factors when comparing the speed factor of the hollow spindle, except the point of design space, where the maximum value of response was obtained. Here the influence of the SH factor is a little more important when compared to the significance of factor S.

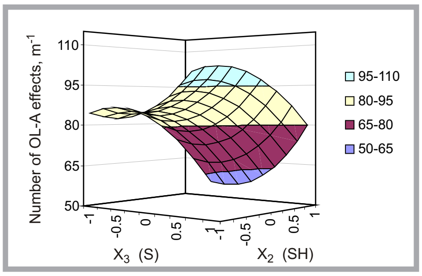

Figure 4. *Dependence of the number of effects of opened loop - arc per unit length of fancy yarn upon the speed of the hollow spindle X_2 (SH) and the speed of supply of the effect component X_3 (S) when X_1=0.*

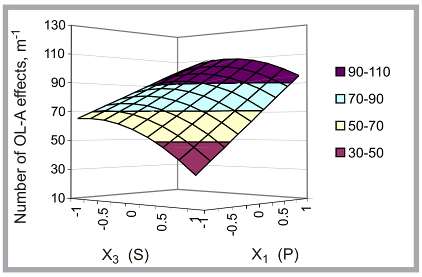

Figure 5. *Dependence of the number of effects of opened loop - arc per unit length of fancy yarn upon the speed of fancy yarn production X_1 (P) and the speed of supply of the effect component X_3 (S) when X_2=0.*

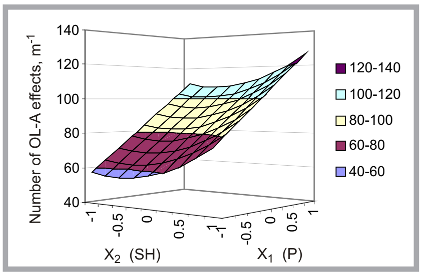

Figure 6. *Dependence of the number of effects of opened loop - arc per unit length of fancy yarn upon the speed of fancy yarn production X_1 (P) and the speed of the hollow spindle X_2 (SH) when X_3=0.*

On the basis of graphic pictures of the mathematical models, which express the link between the fancy yarn structure and the parameters of the production of the technological process of these yarns, the particular interrelationships were analysed. Three dimensional response surface maps (***Figures 4 - 6***) show the influence of the speed of fancy yarn production, the speed of the hollow spindle, the speed of supply of the effect component on the number of effects of the opened loop – arc in a unit of fancy yarn length. In these figures the third factor has a stationary point, and the factor value here is equal to zero. The border experimental values of the speed of supply of the effect component are important because they predetermine the limit values of the overfeed of the effect component. An analysis was performed with the third factor value equal to +1 or -1 (***Figures 7 - 9***).

While formulating the design it was hoped that the number of effects per unit length and the character of effects depended upon the overfeed of the effect component and the level of fancy yarn twist.

It was determined that the number of opened loop – arc effects per unit length of fancy yarn changes with the alteration of the overfeed, which is determined by the speed of supply of the effect component and the speed of fancy yarn production (see ***Figures 4 - 9***). As is evident from ***Figure 4***, when the speed of supply of the effect component increases from a coded value of -1 to -0.5 (e.g. from 1.83 m/s (110 m/min) to 0.92 m/s (55 m/min)) and X_2 changes throughout all its interval, when X_1 = 0, the response increases from 84.6 to 103.9 m^{-1}; however, a further increase in factor X_3 decreases the response up to a value of 60.8 m^{-1}. In the same interval of SH change, when X_3 changes throughout its entire interval and X_1 = 0, the response slightly decreases; later on a distinct increase in the values of response is observed. The minimum value e.g. 28.3 m^{-1} (see Figure 7) is acquired when X_1 = -1, X_2 = -0.5, X_3 = +1.

Figure 5 shows that with an increase in the values of the speed of supply of the

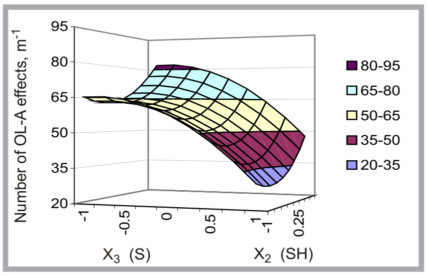

Figure 7. *Dependence of the number of effects of opened loop - arc per unit length of fancy yarn upon the speed of the hollow spindle X_2 (SH) and the speed of supply of the effect component X_3 (S) when X_1=-1.*

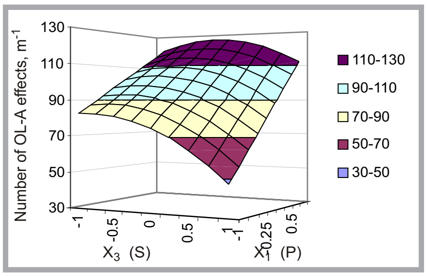

Figure 8. *Dependence of the number of effects of opened loop - arc per unit length of fancy yarn upon the speed of fancy yarn production X_1 (P) and the speed of supply of the effect component X_3 (S) when X_2=+1.*

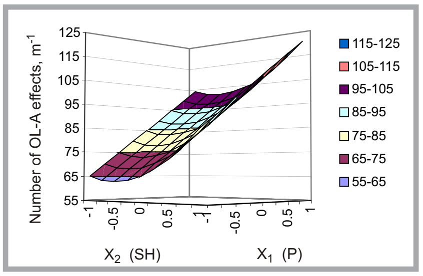

Figure 9. *Dependence of the number of effects of opened loop - arc per unit length of fancy yarn upon the speed of fancy yarn production X_1 (P) and the speed of the hollow spindle X_2 (SH) when X_3=-1.*

effect component and a decrease in the values of the speed of fancy yarn production throughout all their intervals, e.g. with an increase in the overfeed of the effect component from a minimal value of 1.29 to a maximal value of 3.67, when $X_2 = 0$, the number of opened loop – arc effects decreases from 104.1 to 30.5 m^{-1}, and such an intensive decrease in the response is clearly evident, having investigating all points of the design space. Such an alteration could be explained by the changes in the character of the effect, namely its transverse and longitudinal dimensions. As can be observed from the response surface response in ***Figure 6***, when the speed of the hollow spindle decreases from a coded value of +1 to –0.5, and factor X_1 varies throughout all its interval, when $X_3 = 0$ the response decreases by 2.3 times, e.g. from 126.9 to 55.7 m^{-1}. A less intensive decrease in the response could be observed when the factor $X_3 = -1$ (***Figure 9***). Here the number of opened loop – arc effects per unit length of fancy yarn decreases from 121.3 m^{-1} to 63.0 m^{-1}.

Nevertheless, the number of opened loop – arc effects per unit length of fancy yarn depends not only upon the overfeed of the effect component, but also upon the amount of fancy yarn twist, which is determined by the speed of the hollow spindle and the speed of fancy yarn production. A change in the response is homogenous with the decrease in the fancy yarn twist is observed when all the points in the experimental space are analysed. As is evident from ***Figure 6***, with an decrease fancy yarn twist, the response increases from 75.0 to 109.8 m^{-1}. Such an alteration could be explained by the changes in the length of the effect component for effects production. With a decrease in the level of fancy yarn twist, the binder component whirls around the effect intermediate product that is formed of the core and effect component with less force, resulting in a decrease in tight wrappings, while the unwrapped lengths increase.

An inaccuracy analysis showed that the deviation between the theoretical and experimental results of the response varies between 6.6 - 26.2 %.

Conclusions

- The regression analysis shows the influence of investigated factors - the speed of fancy yarn production, the speed of the hollow spindle, the speed of supply of the effect component, as well as their interaction effects, are significant except the coefficients of the interaction effects of the factors X_1, X_2 and X_2, X_3, as well as the coefficient of the quadratic effect of factor X_1 as far as the number of opened loop – arc effect formation is concerned.
- It was determined that the speed of fancy yarn production changes the response by 1.5 - 3.1 times, and the speed of supply of the effect component changes the response by1.1 - 2.1 times, respectively (analysing MAX, MIN and centre point of the experimental space), whenever the speed of the hollow spindle changes the response by 1.6 times (at MIN point of the design) and by 1.2 times (at MAX and centre points of the design).
- It was found that the mathematical model that expresses the relationship between the number of effects of opened loop – arc in units of fancy yarn length and the technological parameters of fancy yarn manufacture is informative. On the basis of graphical pictures of the informative mathematical model obtained, the particular interrelations were investigated. The model attained could be used to predict the response and to design new fancy yarns with the desired structure.

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