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Effect of process variables on properties of viscose vortex coloured spun yarn

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The vortex spinning machine has been used to develop coloured spun yarn which is commonly used in the yarn-dyed fabrics. Based on the Box and Behnkan Design, the regression analysis of response surface is used to study effects of process variables, namely nozzle pressure, yarn delivery speed and yarn count, on the properties of viscose vortex coloured spun yarn, such as yarn tenacity, elongation-at-break, evenness and diameter. The results show that different response variables are affected by different combinations of model terms. Yarn tenacity is significantly affected by yarn delivery speed, yarn count, and quadratic terms of nozzle pressure and yarn delivery speed. Yarn delivery speed has a nonlinear and marked effect on yarn elongation-at-break, while yarn count has a linear effect on yarn elongation-at-break. Yarn evenness is significantly influenced by nozzle pressure, yarn delivery speed and yarn count. There is interaction between yarn delivery speed and yarn count. Yarn hairiness H value is significantly affected by nozzle pressure and yarn delivery speed. Compared with yarn delivery speed, yarn count and nozzle pressure have a significant effect on yarn diameter.

Keywords: Coloured spun yarn, Regression analysis, Viscose yarn, Vortex spinning, Yarn properties

1 Introduction

Coloured spun yarn with special yarn formation process is made of mixture of two and more types of different coloured fibres. Fibres are dyed firstly, and then are blended with other fibres with different colours to spin yarn, reversing the process of the traditional yarn formation[1]. The resulted yarn is made into fabric, without dyeing processing, which can shorten the processing period of fabric. The resulted fabric has the effect of three dimensional mixed colours, showing twilight and beautiful vision, which can meet the individual, diversified, fashionable and low-carbon economic requirements of modern consumers. Coloured spun yarn is spun mainly by traditional ring spinner with lower production efficiency. However this can be improved by the vortex spinning machine with highest yarn delivery speed, as it is one of new spinning technologies. It can also make the coloured spun yarn diversify. Murata vortex spinner (MVS), No. 861, having an inspector function of foreign fibres cannot produce coloured spun yarn with high percentage coloured fibres. Therefore, some key sensors, such as the residual yarn sensor must be replaced by newly designed sensors in order to distinguish the coloured yarn. Previous studies focused on the development of gray yarn produced by vortex spinner, which can be summarized as (i) analyzing the formation mechanism of vortex spun yarn[2-7], (ii) discussion of the influence of yarn process parameters on the structure and properties of vortex spun yarn[8-10], and the comparisons of yarn properties produced by different spinning systems[11-13], and (iii) the investigation of the fabric characteristics produced by different yarns including open-end rotor spun, compact spun, conventional ring spun, and vortex spun yarns[13-15].

There has been little research on the development of coloured yarn by vortex spinner. This study is therefore undertaken to investigate the effects of process variables on properties of viscose vortex coloured spun yarn, which is widely used in the area of knit fabric and woolen sweater.

2 Materials and Methods

2.1 Materials and Yarn Samples Preparation

MVS spinning system adopts high whirled air jet stream to twist the open-end trailing fibres in twisting chamber, and then to make them into yarn. Three passages of drawing process were implemented in this experiment for the purpose of improving fibre alignment and sliver evenness. The MVS coloured yarns were spun from the blend materials of coloured and grey viscose with 60% of coloured viscose ratio on Murata Vortex Spinner No. 861. Reactive dyes of

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3BSH, 3RN and RK10 (mass percentage being 0.73, 1.22 and 4 respectively) were used to produce coloured viscose fibres with BK-07 colour code. The fibre properties used to produce the yarns are given in Table 1.

Based on the Box and Behnkan experimental design, experimental yarn samples under different process conditions were spun in order to determine the role of yarn formation process, such as nozzle pressure, yarn delivery speed and yarn count on the properties of vortex coloured spun yarns made by coloured and grey viscose fibres. MVS coloured viscose yarns were spun by Zhejiang Huafu Melange Yarn Spinning Co., Ltd., China. The actual values of nozzle pressure, yarn delivery speed and yarn count corresponding to coded levels are given in Table 2. Table 3 shows experimental plans for MVS machine variables used for vortex coloured spun yarn samples. The other fixed process parameters of spinning vortex coloured yarn samples are shown in Table 4.

Table 1—Fibre properties

Viscose fibre	Length mm	Fineness dtex	Breaking strength cN/tex	Elongation-at-break, %	Initial modulus cN/dtex
Grey	38	2.03	22.4	23.69	39.96
Coloured	38	2.12	21.3	23.28	39.25

Table 2—Actual values corresponding to coded levels

Coded level	Actual value		
	Nozzle pressure Mpa (x_1)	Yarn delivery speed, m/min (x_2)	Yarn count Ne (x_3)
-1	0.45	320	20
0	0.50	350	30
1	0.55	380	40

Table 3—Experimental plans for MVS machine variables used for vortex coloured spun yarn samples

Combination No.	Nozzle pressure (x_1)	Yarn delivery speed (x_2)	Yarn count (x_3)
1	-1	-1	0
2	1	-1	0
3	-1	1	0
4	1	1	0
5	-1	0	-1
6	1	0	-1
7	-1	0	1
8	1	0	1
9	0	-1	-1
10	0	1	-1
11	0	-1	1
12	0	1	1
13	0	0	0
14	0	0	0
15	0	0	0

2.2 Test Methods

All yarn samples were placed for 48 h in an atmosphere of 20±2 ℃ and 65±2% RH in order to adjust humidity balance. All the tests were conducted at the same conditions.

Yarn tensile properties were tested by a Desktop Dual Column Electronic Universal Materials Testing Machine (H-10K- L, America Tinius Olsen). Tensile test parameters were set as the specimen test length of 500mm, extension rate of 200 mm/min and pre-tension of 0.5cN/tex. The resulted yarn tenacity value was taken as the mean of 30 tests.

Yarns evenness and hairiness H values were examined by a capacitive evenness tester (YG133B/M-H, China Suzhou Changfeng Textile Electromechanical Technology Co., Ltd) with yarn speed of 400m/min and a testing time of 1 min. Yarn hairiness count was tested in a yarn hairiness tester (YG171B-2, China Nantong Sansi Electromechanical Science & Technology Co., Ltd.) with the testing speed of 30m/min and a test length of 10m. The value of evenness and hairiness for each yarn sample is the mean of 10 test results.

Yarn diameter was measured by a scanning electron microscope (SNE-3000M, Korea SEC Co., Ltd.). Two hundred tests per sample were performed and their mean value was used to represent the diameter of this yarn sample.

3 Results and Discussion

3.1 Statistical Analysis

Based on the polynomial regression analysis, the experimental data was fitted by a quadratic polynomial[16]. The relationship between the response variable and the independent variable can be

Table 4—Process parameters of spinning vortex coloured spun yarn samples

Process parameter	Value
Sliver weight, g/5m	19
Condenser width, mm	4
Distance between front roller and hollow spindle, mm	20
Hollow spindle inner diameter, mm	1.1
Needle holder	130d, L8-8.8
Feed ratio/take up ratio	1.00/0.99
Roller settings, mm×mm	41-43
Colour code /ratio of coloured fibre, %	BK-07/60

described by the following second-order polynomial following equation:

$$Y = \alpha_0 + \sum_{i=1}^{k} \alpha_i x_i + \sum_{i=1}^{j-1} \sum_{j=1}^{k} \alpha_{ij} x_i x_j + \sum_{i=1}^{k} \alpha_{ii} x_i^2 \quad \ldots (1)$$

where Y is the forecast response value; α_0, α_i, α_{ii} and α_{ij}, the coefficients of interception, linear terms, quadratic terms and interaction terms respectively. The code level of independent variable (x_i) can be calculated using the equation:

$$x_i = (X_i - X_0)/\triangle X \quad \ldots (2)$$

where X_i is the actual value of independent variable i; X_0, the actual value of independent variable i at the central point; and $\triangle X$, is the step change of X_i corresponding to a unit variation of the dimensionless value.

The tenacity, elongation-at-break, evenness, hairiness and diameter of viscose vortex coloured spun yarn are shown in Table 5. S3 value is the cumulative sum of hairiness count for 3 mm and over 3mm hairiness. The experimental data of viscose vortex coloured spun yarn properties were input into a computer statistical program to obtain the response surface equations using forward step regression procedure. The statistical software (version Minitab 16) was employed for the regression analysis. Table 6 shows estimated coefficients (Coded) and p-values of model terms for different response variables. A minus sign of terms indicates that the value of response variable decreases by increasing the factor value and vice versa. The model term is significant if its p-value is less than 0.05,

Table 5—Yarn property test results of viscose vortex coloured spun yarn samples

Combination No.	Tenacity, cN/tex (Y_1)	Elongation-at-break, % (Y_2)	Evenness, % (Y_3)	Hairiness H value (Y_4)	Hairiness S3	Yarn diameterμm (Y_5)
1	9.38 (6.07)	7.51 (12.37)	16.80	3.69	1.4	223.2475
2	9.05 (6.04)	9.76 (10.58)	17.40	3.22	1.5	198.3835
3	7.71 (7.41)	5.78 (10.73)	16.13	4.43	1.2	267.9855
4	8.13 (7.91)	6.90 (13.67)	17.02	3.77	1.5	197.179
5	10.28 (5.77)	9.79 (9.58)	12.65	3.84	0.4	330.423
6	9.94 (14.84)	8.28 (11.85)	12.98	3.61	0.4	304.725
7	8.19 (11.03)	4.17 (17.52)	18.32	4.09	1.7	245.428
8	8.46 (8.23)	4.72 (17.00)	19.99	3.64	0.6	184.7461
9	10.50 (5.23)	10.28 (6.56)	12.94	3.56	1.0	311.905
10	9.28 (6.36)	8.89 (10.47)	12.73	4.10	0.3	331.243
11	8.90 (10.95)	7.34 (23.90)	20.09	3.41	0.7	190.799
12	7.27 (20.97)	3.73 (19.18)	19.12	4.15	1.3	200.5995
13	9.21 (5.41)	6.31 (10.74)	16.89	3.84	0.7	239.893
14	9.62 (6.90)	6.25 (11.09)	16.48	3.45	0.1	214.5675
15	9.29 (8.66)	6.19 (13.45)	16.43	4.27	0.8	190.9785

Values in parentheses are CV%.

Table 6—Estimated coefficients (Coded) and p-values of model terms for different response variables

Model term	Yarn tenacity (Y_1)		Elongation-at-break (Y_2)		Yarn evenness (Y_3)		Yarn hairiness H value (Y_4)		Yarn diameter (Y_5)	
	Coeff	p-value	Coeff	p-value	Coeff	p-value	Coeff	p-value	Coeff	p-value
Constant	9.45462	0.000	6.5300	0.000	16.7357	0.000	3.80467	0.000	218.891	0.000
x_1	-0.00250	0.972	0.3013	0.279	0.4362	0.001	-0.22625	0.007	-22.756	0.002
x_2	-0.68000	0.000	-1.1987	0.001	-0.2788	0.015	0.32125	0.001	9.084	0.139
x_3	-0.89750	0.000	-2.1600	0.000	3.2775	0.000	0.02250	0.751	-57.090	0.000
x_1^2	-0.29808	0.019	-	-	-	-	-	-	-	-
x_2^2	-0.52808	0.001	0.9938	0.028	-	-	-	-	-	-
x_3^2	-	-	-	-	-0.6332	0.0001	-	-	43.593	0.000
$x_1 x_2$	0.18750	0.091	-	-	-	-	-	-	-	-
$x_1 x_3$	-	-	-	-	-	-	-	-	-	-
$x_2 x_3$	-	-	-	-	0.3350	0.032	-	-	-	-

indicating statistical significance at 95% confidence level. The final response surface models in terms of coded factors for yarn tenacity (Y_1), elongation-at-break (Y_2), yarn evenness (Y_3), yarn hairiness (Y_4) and yarn diameter (Y_5), are shown in following equations:

$$Y_1 = 9.45462 - 0.00250x_1 - 0.68000x_2 - 0.89750x_3 - 0.29808x_1^2 - 0.52808x_2^2 + 0.18750x_1x_2 \quad \dots (3)$$

$$Y_2 = 6.5300 + 0.3013x_1 - 1.1987x_2 - 2.1600x_3 + 0.9938x_2^2 \quad \dots (4)$$

$$Y_3 = 16.7357 + 0.4362x_1 - 0.2788x_2 + 3.2775x_3 - 0.6332x_3^2 + 0.3350x_2x_3 \quad \dots (5)$$

$$Y_4 = 3.80467 - 0.22625x_1 + 0.32125x_2 + 0.0225x_3 \quad \dots (6)$$

$$Y_5 = 218.891 - 22.756x_1 + 9.084x_2 - 57.090x_3 + 43.593x_3^2 \quad \dots (7)$$

The squared multiple correlation coefficients for response surface models developed were used to evaluate the quality of these models. The R^2 values for Eqs (3) - (7) are 0.9743, 0.9056, 0.9931, 0.7462 and 0.9269 respectively.

3.2 Yarn Tenacity

Effect of process variables on the tenacity of viscose vortex coloured spun yarn are shown in Fig. 1. Nozzle pressure and yarn delivery speed has a nonlinear and marked effect on yarn tenacity, as illustrated by Eq. (3) and Table 6. The yarn tenacity increases with the augment of the nozzle pressure firstly, and then it decreases with the increase in nozzle pressure. However, the influence of yarn delivery speed on the yarn tenacity takes on different variation trends. When the nozzle pressure is lower, the increase in yarn delivery speed will result in the decrease of the yarn tenacity, as shown in Fig. 1. It may be accounted for by the fact that open-end trialing trailing fibres in nozzle block do not wrap the yarn trail well for the smaller nozzle pressure and the reduced twisting time at higher yarn delivery speed, which makes the yarn structure loose. The better wrapping effect of the wrapping fibres holds the fibre bundle tightly together and thus improves the yarn tenacity. However, when the nozzle pressure is higher, the yarn tenacity initially increases and then decreases with the increase in yarn delivery speed (Fig. 1). As the whirled airflow enough makes the open-end trailing fibres in nozzle block twist and wrap the yarn trail for higher nozzle pressure, the twisting time is shortened for increasing yarn delivery speed. When the twisting time is too short due to too high yarn delivery speed, the open-end trailing fibres cannot be wrapped well around yarn body by whirled airflow, resulting in decrease in yarn tenacity. Yarn count significantly affects coloured yarn tenacity, which can be verified by lower p-value of term x_3 (Table 6). The yarn with lower yarn count has higher yarn tenacity. On the one hand, the reason may be that more open-end trailing fibres will be formed for the coarser fibre bundle and the proportion of wrapper fibres for coarser yarn is higher than fine yarn. The other hand, the reason may be that wrapper fibres hold the fibre bundle more tightly. It can be accounted for by the fact that the twisting force of whirled airflow in nozzle block will become higher away from the center of the nozzle block[2].

3.3 Yarn Elongation-at-break

The breaking elongation change of viscose vortex coloured spun yarn affected by three process parameters is illustrated in Fig. 2 and Eq. (4). Statistical analysis shows that the yarn elongation-at-break is significantly affected by yarn delivery speed

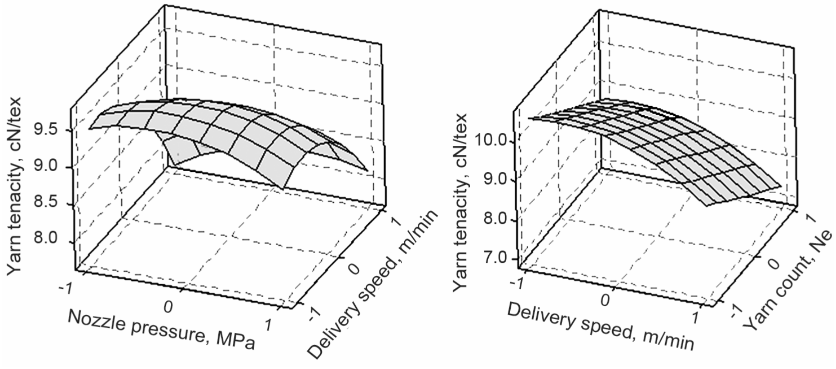

Fig. 1—Response surface plots for the effect of nozzle pressure, yarn delivery speed and yarn count on yarn tenacity

and its quadratic term as well as yarn count (Table 6). It can be seen from Fig. 2 that the breaking elongation of vortex coloured spun yarn decreases sharply at lower yarn delivery speed, and then its downward trend becomes smooth when yarn delivery speed increases constantly. Increasing yarn delivery speed will loosen the structure of resulted yarn. The loose yarn ruptures more easily while stretching it. Therefore, the yarn elongation-at-break becomes small at higher yarn delivery speed. The effect of yarn delivery speed is not linear, which can be explained by the statistically significant square value x_2^2 (p-value being 0.028) as given in Table 6. Improving the yarn count results in the linear decrease in yarn elongation-at-break, because the number of fibres in yarn cross-section decreases with the increase in yarn count. Less fibre does not resist the stress any longer and break. The coloured yarn elongation-at-break increases slightly with enhancing nozzle pressure. However, the influence of nozzle pressure on the yarn elongation-at-break is insignificant. The reason may be that the range of nozzle pressure selected by this paper is narrow.

3.4 Yarn Evenness

The variation in yarn evenness with different processing variables is shown in Fig. 3 and Eq. (5). It can be observed that yarn evenness is significantly influenced by all the three variables used in the experiment, and the quadratic term of yarn count. Moreover, there is an interaction between yarn delivery speed and yarn count, as shown in Table 6. With the increase in nozzle pressure and the decrease in yarn delivery speed, yarn evenness value increases, resulting in deteriorating yarn quality. It can be explained by the fact that the whirled airflow twists open-end trailing fibres more strongly in nozzle block, because higher nozzle pressure means the whirled airflow having higher twisting action force; lower yarn delivery speed indicates that the fibre bundle stays in nozzle block for more long time. However, the influence of nozzle pressure on yarn evenness is bigger than yarn delivery speed. Yarn count has biggest influence on yarn evenness compared to nozzle pressure and yarn delivery speed. When the nozzle pressure is 0.55MPa and yarn delivery speed is 350 m/min, the yarn evenness increases from 13.26% to 19.82%, while the yarn count varies from 20 Ne to 40 Ne. The higher the yarn count, the bigger is the yarn evenness. The reason may be that the increase in yarn count increases the total draft, resulting in the decrease in draft evenness.

3.5 Yarn Hairiness

Yarn hairiness H value is significantly affected by nozzle pressure and yarn delivery speed and it is less

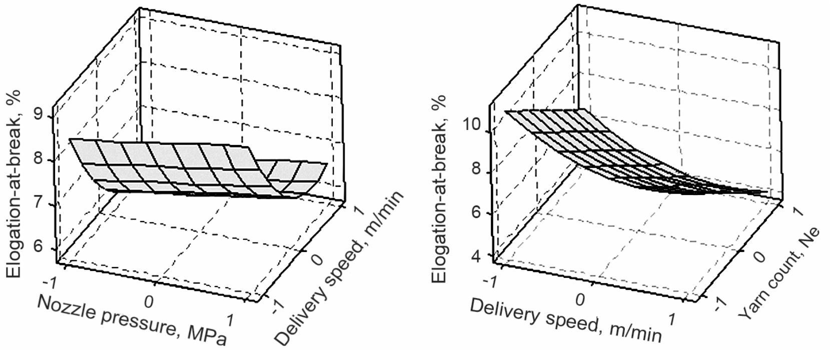

Fig. 2—Response surface plots for the effect of nozzle pressure, yarn delivery speed and yarn count on yarn elongation-at-break

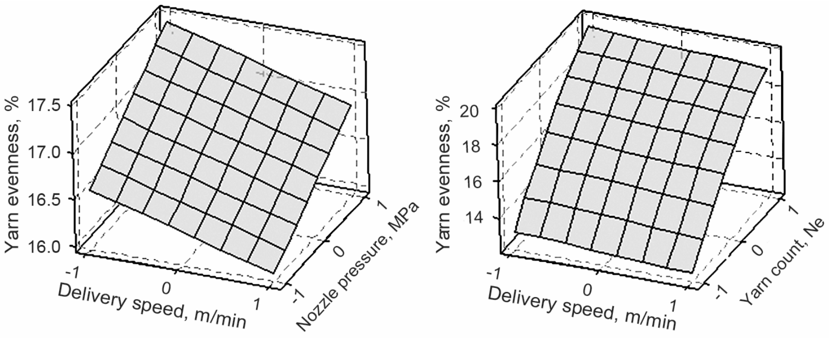

Fig. 3—Response surface plots for the effect of nozzle pressure, yarn delivery speed and yarn count on yarn evenness

affected by yarn count (Table 6). Response surface plots for the effect of nozzle pressure, yarn delivery speed and yarn count on yarn hairiness H value is shown in Fig. 4. Increasing nozzle pressure decreases the yarn hairiness H value, because the whirled airflow can make open-end trailing fibres wrap yarn body well for higher nozzle pressure. However, the yarn hairiness H value increases with the increase in yarn delivery speed. It can be explained by the fact that more open-end trailing fibres can't wrap yarn body more well when the staying time in nozzle block is shorten due to improving the yarn delivery speed. Yarn hairiness H value increases slightly as the yarn count increases. The squared multiple regression coefficient of response surface equation [Eq. (5)] for yarn hairiness H value is 0.7462. So the response surface equation can't forecast exactly yarn hairiness H value affected by yarn formation process parameters. However, coloured vortex spun yarn has very smaller hairiness, as confirmed by lower S3 values (Table 5). Therefore, the arrangement of yarn formation process may pay less attention to the influence of process variables on yarn hairiness.

3.6 Yarn Diameter

It can be observed from response surface equation [Eq. (7)] and response surface plots (Fig. 5) that all the three parameters affect the yarn diameter. The yarn count has maximum effect on the yarn diameter followed by nozzle pressure and yarn delivery speed. The analysis of variance shows that the yarn count and nozzle pressure significantly affect yarn diameter ($P<0.05$), but the effect of yarn delivery speed on yarn diameter is not significant ($P>0.05$), as shown in Table 6. Increasing nozzle pressure results in the decrease of yarn diameter, because yarn body is tightly wrapped by open-end trailing fibres at higher pressure. When yarn delivery speed is increased, it shortens the fibre bundle staying time in nozzle block, and the yarn diameter shows the slow ascending trend. In this study, narrow variation range of yarn delivery from 320m/min to 380m/min may be used to account for the fact that the effect of yarn delivery speed on yarn diameter is not significant. As yarn count varies from 20Ne to 40 Ne, the decrease in yarn diameter is rapid initially and then becomes slow. The reason is that the number of fibres inside yarn cross-section decreases with increasing the value of yarn count.

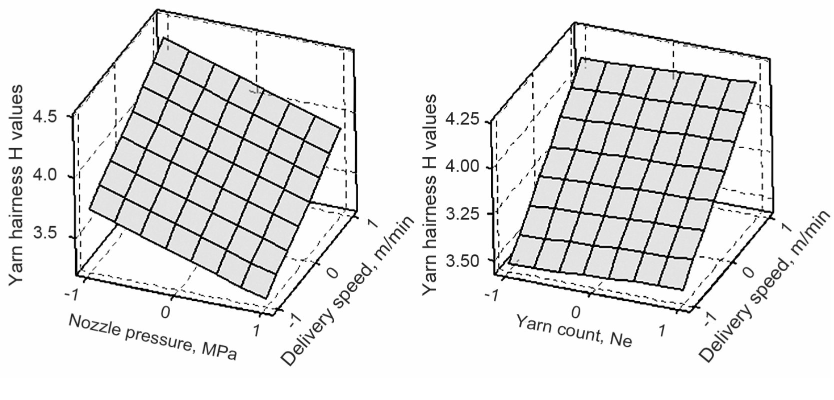

Fig. 4—Response surface plots for the effect of nozzle pressure, yarn delivery speed and yarn count on yarn hairiness H value

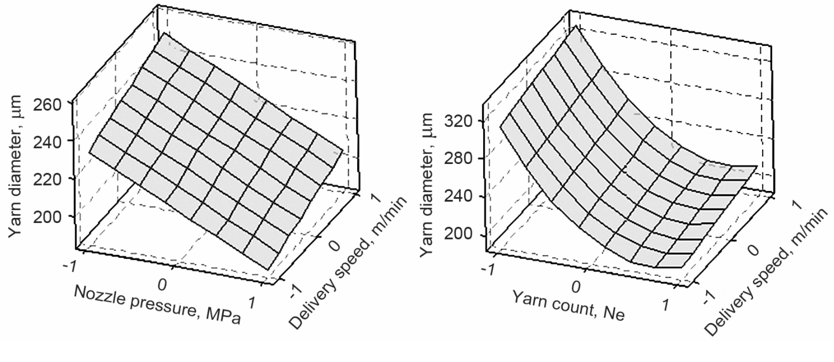

Fig. 5—Response surface plots for the effect of nozzle pressure, yarn delivery speed and yarn count on yarn diameter

4 Conclusion

The study shows that the nozzle pressure and yarn delivery speed has a nonlinear and marked effect on yarn tenacity. Yarn elongation-at-break is significantly affected by yarn delivery speed and its quadratic term as well as yarn count. Yarn evenness is significantly influenced by all the three variables used in the experiment, and there is an interaction between yarn delivery speed and yarn count. Yarn hairiness H value is affected significantly by nozzle pressure and yarn delivery speed and less affected by yarn count. Yarn count and nozzle pressure significantly affect the yarn diameter, but the effect of yarn delivery speed on yarn diameter is not significant.

It is concluded that the yarn tenacity firstly increases, and then it decreases with improving nozzle pressure. Increasing nozzle pressure results in the decrease of yarn diameter and the increase of yarn evenness. Moreover, the yarn elongation-at-break increases slightly with enhancing the nozzle pressure. The influences of yarn delivery speed on the yarn tenacity and elongation-at-break show descendant trends as a whole. Coloured vertex spun yarn has much smaller hairiness, which is significantly affected by nozzle pressure and yarn delivery speed. Increasing nozzle pressure and deceasing yarn delivery speed decrease the yarn hairiness H value. Increasing yarn delivery speed results in the decrease in yarn evenness slightly. But, improving yarn delivery speed slowly increases the yarn diameter. Increasing yarn count results in the decrease of yarn tenacity, yarn elongation-at-break and yarn diameter, but yarn evenness shows reverse trend.

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