THE OPTIMIZATION OF EXPERIMENTAL PARAMETERS FOR JET-RING SPINNING

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Abstract: *The application of air-jet nozzle in ring spinning system has been turned up in the last decade, and the greatest advantage reported is the reducing of hairiness. In this paper, an attempt has been made to optimize the utility of a single air-jet nozzle in ring spinning system. Some parameters, such as air pressure, the distance between front roller nip line and air-jet nozzle inlet, and the number of orifices were adjusted to get a better quality yarn. In order to confirm the role of these parameters, the properties of ring and jet-ring spun yarns were compared. All the samples were characterized in terms of count, twist, irregularity, hairiness and strength. The results showed that the air pressure and the distance have a significant influence on irregularity; all the experimental parameters have a significant influence on hairiness. By multi-objective programming method, a set of optimal experimental parameters was found, and the properties of jet-ring spun yarn were improved significantly.*

Key words: *Ring spinning; Air-jet nozzle; Irregularity; Hairiness; Optimization*

1 INTRODUCTION

Ring spinning has been a widely used method of yarn production, but is disadvantaged due to several limitations, one of which is the poor integration of many fibers that protrude from the yarn surface causing yarn hairiness [1-2]. Yarn hairiness has been shown to negatively affect the properties of the resultant fabric, particularly in terms of pilling propensity [3-5]. Generally, the hairiness of yarn can be reduced either by sizing or singeing in the short staple field and by Solo-spun or two-folding in the long staple field [6], but either higher costs or time consumption. Another method for reducing yarn hairiness is jet-ring spinning system that applied air-jet nozzle into ring spinning system, which was proved to be an effective method [7-11].

Jet-ring spinning was first reported by Wang et al [7]. In their work, an upward swirling flow of air against the yarn movement was introduced, and the result showed that the yarn hairiness was significantly reduced [7]. Subsequently, Cheng et al [8] studied the effect of some experimental parameters on yarn hairiness, and stated the relationships between yarn hairiness and twist level, spindle speed and air pressure. But their work showed that the evenness and imperfection of jet-ring spun yarns are worse than ring spun yarn, and they thought the distance between front roller nip line and air-jet nozzle inlet hardly affects the yarn hairiness [8]. Ramachandralu et al [9-11] presented that the air vortex in the direction same as the yarn twist gives better hairiness reduction. And he introduced twin air-jet nozzle into ring spinning system. The results demonstrated that the qualities of yarns were improved in 0.25 bar air pressure of first 'S' nozzle and 0.5 bar air pressure of second 'Z' nozzle. Zeng et al [10] presented their report about the properties of jet-ring spun yarns by adjusting air pressure and orifice angle of the air-jet nozzle, the results showed that hairiness will be reduced in a higher air pressure and a smaller orifice angle, but unfortunately, the evenness of yarn deteriorated.

In this work, our objectives are:

1. to assess the effect of some experimental parameters, which are air pressure, the distance between front roller nip line and air-jet nozzle inlet, and the number of orifices, on the jet-ring spun yarn properties,

2. to find the optimal experimental conditions by multi-objective programming method.

We use Box-Behnken experimental design to examine the effects of different spinning parameters on yarn properties. In order to evaluate the performance of Jet-ring spinning, we tested both conventional ring and jet-ring spun yarns and compared with them in evenness, imperfection, hairiness, and tensile properties.

2 MATERIALS AND METHODS

A cotton roving was provided by Velveta Company. The yarns were produced in a spinning system which combined ring spinning with a single air-jet nozzle. In order to determine the role of air pressure, the distance between the front roller nip line and nozzle inlet, and the number of orifices in obtaining optimum yarn characteristics, three levels of air pressure, 0.25, 0.5, 0.75 bar, three kinds of distance, 1, 2, 3 cm, and also three different orifice's number, 2, 3 and 4 were selected. The nozzle schematic diagram was showed as Figure 1, the direction of nozzle inlet face toward the front roller. And the parameters of jet nozzle were: chamber diameter is 3.5 mm, orifice diameter is 0.7 mm, orifices angle is 450.

After prepared the samples, we put the samples into the conditions of 65% humidity and 25°C temperature for 24 hours for the following testing. These samples were tested in terms of count, twist, evenness, hairiness (Zweigle G567), imperfection (Uster tester 4) and tensile property (Instron 4411, pretension was 0.125 N, gauge was 50 cm, tensile speed was 100 mm/min).

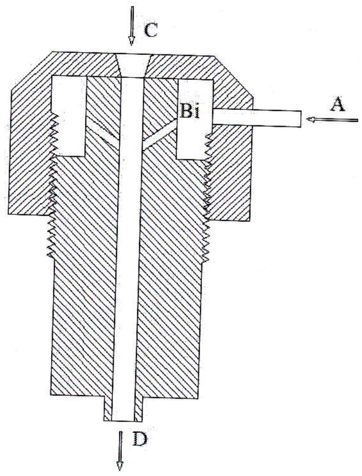


Figure 1 The schematic of air-jet nozzle. (A) the inlet of compressed air; (Bi) the orifices; (C) the nozzle inlet of air; (D) the nozzle outlet of air

Box-Behnken design

A three-level three factorial Box–Behnken experimental design (constructed using Minitab 16) was used to evaluate the effects of the selected independent variables on the response. The number of experiments required to investigate the previously noted three factors at three levels would be 27 (3^3). However, this was reduced to 15 using a Box–Behnken experimental design. The results from this limited number of experiments provided a statistical model, which can help us find the optimum experimental conditions and the relationships between experimental results and parameters. The significant variables like air pressure, the distance between front roller nip line and air-jet nozzle inlet, and the number of orifices were chosen as the critical variables and designated as X1, X2 and X3, respectively. The low, middle and high levels of each variable were designated as −1, 0 and +1, respectively, and given in Table 1. And the actual design of this experiment is given in Table 2.

Table 1 Factors and factor levels investigated in Box-Behnken experimental design

Factor	Level		
	-1	0	+1
X1: Air pressure (bar)	0.25	0.5	0.75
X2: The distance between front roller nip and nozzle inlet (cm)	1	2	3
X3: The number of orifices (n)	2	3	4

Table 2 The design of this experiment

Trial No.	Air pressure (bar)	The distance (cm)	orifices number (n)
1	+1	+1	0
2	+1	-1	0
3	-1	+1	0
4	-1	-1	0
5	0	+1	+1
6	0	+1	-1
7	0	-1	+1
8	0	-1	-1
9	+1	0	+1
10	-1	0	+1
11	+1	0	-1
12	-1	0	-1
13	0	0	0
14	0	0	0
15	0	0	0

In a system involving three significant independent variables X1, X2 and X3 the mathematical relationship of the response on these variables can be approximated by the quadratic polynomial equation:

$$Y=\alpha_0 + \alpha_1 X_1 + \alpha_2 X_2 + \alpha_3 X_3 + \alpha_{12} X_1 X_2 + \alpha_{13} X_1 X_3 + \alpha_{23} X_2 X_3 + \alpha_{11} X_1^2 + \alpha_{22} X_2^2 + \alpha_{33} X_3^2 \quad (1)$$

where Y is estimate response, α_0 is constant, α_1, α_2 and α_3 are linear coefficients, α_{12}, α_{13} and α_{23} are interaction coefficients between the three factors, α_{11}, α_{22} and α_{33} are quadratic coefficients.

In this model given in equation (1), interactions higher than second-order have been neglected. A multiple regression analysis is done to obtain the coefficients and the equation can be used to predict the response.

3 RESULT AND DISCUSSION

The yarn counts and twists were close to each other, the ring yarns count and twists were 23±0.33 tex and 730±26 tpm respectively. And the value was 23±0.39 tex and 716±15.89 respectively when the nozzle direction was down. The properties of ring spun yarn were showed in Table 3.

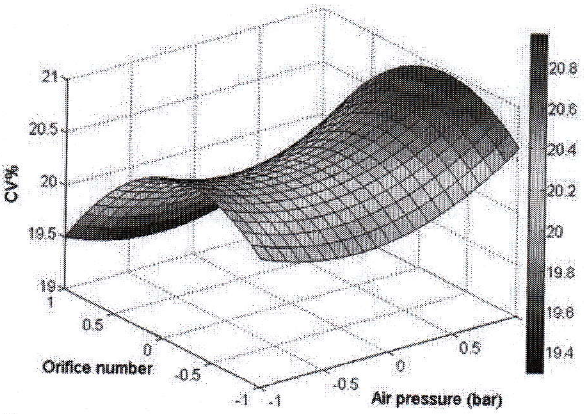
Table 3 Properties of ring spun yarn

CV (%)	-50% TP(/km)	+50% TP(/km)	+140% TP(/km)	S_{1+2} (/m)	S_3 (/m)	Te (cN/tex)	El (%)
20.35±0.19	397±86.2	1087±130	337±41.6	160.09±6.270	16.050±1.560	17.98±1.63	5.15±0.49

*CV represents the mass unevenness of yarns; H represents the total length of fibers protruding the yarn body per centimeter yarn length; S_{1+2} represents the total number of fibers within one millimeter and two millimeters protruding from yarn body; S_3 represents the total number of fibers which equals and more than three millimeters; -50% TP, +50% TP and +140% TP represent -50% thin places, +50% and +140% thick places respectively; Te represents the tenacity of yarns; El represents the elongation of the yarns.
*at the 0.05 level, each group data was significantly drawn from a normally distributed population.

3.1 Effect of experimental parameters on CV of jet-ring spun yarn

The analysis of data according to Box-Behnken method demonstrated that the air pressure and the distance between front roller nip line and air-jet nozzle inlet have an influence on the yarn's CV. A mathematical model was built to express the relationship between them. And in order to clearly describe this mathematical model a 3D surface plots was presented (Figure 2). The minimum value of CV is 19.3212% When x_1=-0.5203 and x_3=1 by optimization method.



A

$$CV = 20.3585 + 0.1887x_1 - 0.3625x_3 + 0.3627x_1^2 - 0.6748x_3^2$$

$(R^2=0.8837; p=0.0001)$

Figure 2 The mathematical model and image of CV corresponding to the experimental parameters

Although the influence of the air pressure and the distance between front roller nip line and air-jet nozzle inlet on CV is not conspicuous from the mathematical model, there are some interesting phenomena. The lower air pressure gives the lower CV value, and the CV value decrease as the increase of orifice number. The lower air pressure means that less energy and cost was needed, and the more orifice number means that uniform flow was needed. Earlier researchers reported that there was a slight deterioration in CV with jet-ring spinning, and they attributed this phenomenon to the concentration of mass in very short lengths because the surface fibers wrap around the yarn body. In our work, the results showed that in some conditions the evenness of jet-ring spun yarns were worse than ring spun yarn, but after optimization, we can find a reasonable experimental condition to improve the CV.

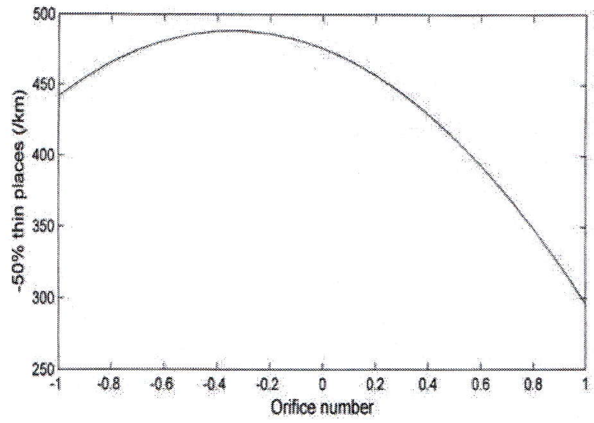
3.2 Effect of experimental parameters on imperfection of jet-ring spun yarn

The air pressure and orifice number have an obvious influence on imperfection, the mathematical models and images are shown in Figure 3. And the minimum value of -50%TP is 295/km when x_3=1, of +50%TP is 813/km when x_1=-1 and x_3=1, of +140%TP is 198/km When x_1=-1 and x_3=1.

Compared ring system with jet-ring system, the difference is the air flow. Therefore, the difference of thin places and thick places between ring and jet-ring spun yarn are the losing of fibers and the warping fibers caused by the air flow. We can find an interesting trend among these properties from the mathematical models, the higher the air pressure, the worse the imperfection, the more orifices, the better the imperfection. Suitable and uniform air flow field is beneficial to produce uniform yarn, otherwise, the losing of fibers make the thin places, and disorderly warping fibers make the thick places. And the more orifices, the better the uniform of air flow field.

3.3 Effect of experimental parameters on hairiness of jet-ring spun yarn

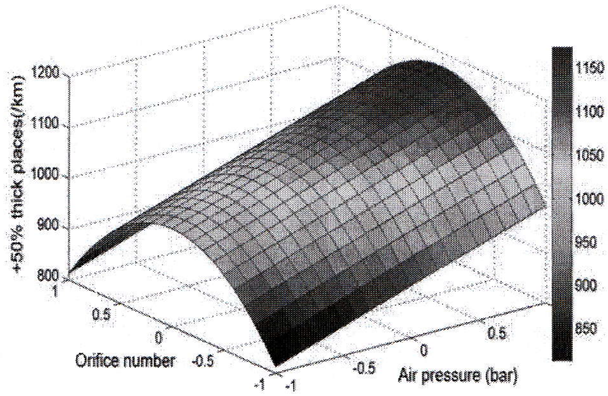
The hairiness of yarn is influenced by air pressure, distance and orifice number base on our work. Figure 4 shows the mathematical model and slice image of hairiness with the length less than 3 mm, and equation (2) expressed the relationship of hairiness with the length more than 3 mm corresponding to the experimental parameters. By the optimum method, we got the minimum value of S_{1+2} and S_3 are 112.4733/m and 2.4941/m respectively when x_1=-1, x_2=-1, x_3=1.



B

$$-50\%TP = 476.1857 - 73.325x_3 - 107.8607x_3^2$$

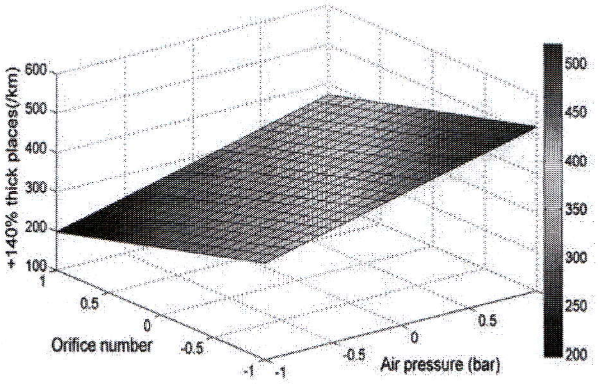
(R^2=0.7086; p=0.0000)



C

$$+50\%TP = 1083.34 + 89.6x_1 - 180.8x_3^2$$

(R^2=0.5935; p=0.0045)

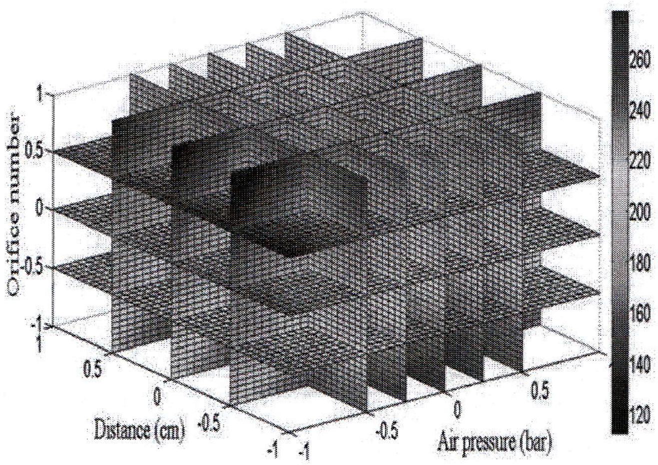


D

$$+140\%TP = 358.887 + 86.675x_1 - 74.575x_3$$

(R^2=57.23%; p=0.0061)

Figure 3 The mathematical models and images of yarn properties corresponding to the experimental parameters, (B) -50%TP corresponding to orifice number; (C) +50%TP corresponding to air pressure and orifice number; (D) +140%TP corresponding to air pressure and orifice number



E

$$S_{1-2} = 219.16 + 13.9281x_1 + 13.2144x_2 - 43.9675x_3 - 35.5767x_3^2$$

(R^2=0.9162; p=0.0000)

Figure 4 The mathematical model and image of yarn hairiness corresponding to the experimental parameters

$$S_3 = 21.4948 + 5.1096x_2 - 7.592x_3 - 1.7893x_1x_2 - 1.5765x_2x_3 - 3.9967x_1^2 - 2.0895x_3^2 \quad (2)$$
(R^2=0.9918; p=0.0000)

The yarns hairiness are significantly reduced when air-jet nozzle was applied, and lower air pressure, less distance and more orifice number are beneficial to reduce yarn hairiness. As to the cause of yarn hairiness, which has been attributed to the escape of fibers form the twisting action from within the spinning triangle [1, 12]. And Pillay's study demonstrated that the yarn hairiness is significantly correlated with fiber length, fineness and torsional and flexural rigidities of fibers [13]. With respect to the effect of air pressure on yarn hairiness, some researchers stated that may be more protruding fibers were wrapped into the yarn body causing by swirling air flow [7, 8]. As air pressure increases, the tangential velocity, which is responsible for wrapping the protruding surface hairs around the yarn body, increases. This leads to more wrapping fiber ends and so less hairiness. However, with increasing nozzle pressure, the recirculation zone that occurs between the inlet and the jet orifices increases. This increase is a potential source for fiber curving, so it impedes the wrapping of the protruding fiber ends [10].
The distance between front roller nip line and air-jet nozzle inlet also played a significant role in yarn hairiness, the results showed that the yarn hairiness decreases as the distance decreases. This phenomenon could be explained from several aspects, (1) the formation of yarn and hairiness were occurred in triangle zone, therefore, the yarn properties and hairiness were easy to be influenced by outer conditions; (2) the closer to the triangle zone, the more fibers warped into the yarn body; (3) some floating fibers could be blowing away.
The more orifice number, the more uniform of the air flow [14], therefore, it is important to provide the uniform air flow for improving the yarn hairiness.

3.4 Effect of experimental parameters on Yarn tensile properties

During this work, the strength and elongation properties were slightly influenced, and did not discussed because they did not to be negative effects on yarns' usage.

3.5 The optimal experimental conditions for jet-ring spun yarn

In order to get a set of reasonable experimental parameters for all of the properties of jet-ring spun yarn, we took all of the equations into account by multi-objective programming method. The best values are 19.3212, 112.4729, 2.4941, 295, 812.9 and 197.6367 corresponding to CV, S_{1+2}, S_3, -50%TP, +50%TP and +140%TP respectively. And the optimal experimental parameters from Matlab are

$$x_1 = -1, x_2 = -1, x_3 = 1$$

In our previous work, we applied the nozzle which produced the upward air flow into ring spinning system and built some mathematical models [15], but we did not give a set of reasonable experimental parameters for producing yarns. Therefore, in this work, we replenish this part by multi-objective programming. The minimum values from each mathematical model are 19.1, 115, 6.09, 186.5, 118.3 and 197.3 corresponding to CV, S_{1+2}, S_3, -50%TP, +50%TP and +140%TP respectively. But for holistic optimization, the optimal values are 19.2399, 134.4354, 6.17, 186.562, 126.844 and 200.0375 in turn. The optimal experimental parameters from Matlab are

$$x_1 = 1, x_2 = -1, x_3 = -0.169$$

3.6 Comparison of properties of ring and jet-ring spun yarns

The optimum experimental conditions for jet-ring spun yarn are 0.25 bar air pressure, 1 cm distance and 4 orifices when the nozzle produce the downward air flow, 0.75 bar air pressure, 1 cm distance and 3 orifices when the nozzle produce the upward air flow. In Table 4, we give the optimum values of jet-ring spun yarn. In Figure 5, we compared these three kinds of yarns.

Table 4 Properties of jet-ring spun yarn in optimum experimental conditions

CV (%)	-50% TP(/km)	+50% TP(/km)	+140% TP(/km)	S_{1+2} (/m)	S_3 (/m)	Te (cN/tex)	El (%)
19.32	295	813	198	112.47	2.49	18.5	5.82
19.24	186	127	200	134.43	6.17	17.75	5.55

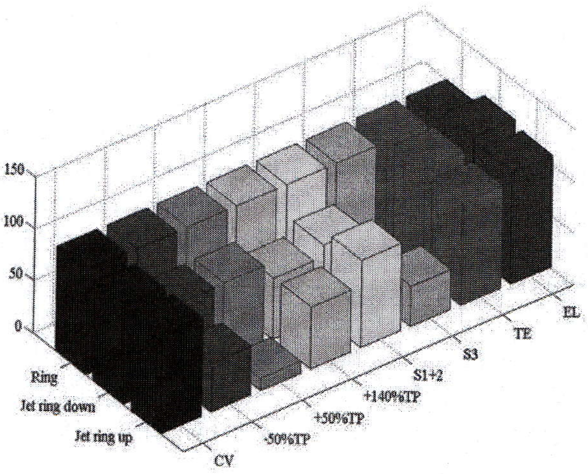


Figure 5 Comparison of ring and jet-ring spun yarns

4 CONCLUSIONS

A single air-jet nozzle is applied into ring spinning system, and a king of jet-ring spun yarn with improved quality is obtained by adjusting the air pressure, the distance between front roller and the nozzle inlet, and the orifice number of nozzle. The air pressure and the orifice number have a slight effect on yarn CV, but have a significant effect on yarn imperfection. All of the experimental parameters played important roles in yarn hairiness. And the optimal experimental conditions should be adjusted when the direction of nozzle was changed. The optimal experimental parameters are 0.25 bar air pressure, 1 cm distance and 4 orifices when the nozzle produce the downward air flow, 0.75 bar air pressure, 1 cm distance and 3 orifices when the nozzle produce the upward air flow.

5 REFERENCES

1. Wang X, Huang W., Huang X.B.: A Study on the Formation of Yarn Hairiness, J. Textile Inst. 90 Part 1, No 4, 1999, 555-569
2. Za K.: Investigation of Post-spinning Yarn Engineering, PhD Thesis, Deakin University, Australia,2003
3. Baird M.E., Hatfield P., Morris G.J.: Pilling of Fabrics a Study of Nylon and Nylon Blended Fabrics. J. Textile Inst. 47(4), 1956, 181-201
4. Timmis J.B.: How to Live with Pilling, Knitting Int. 83(9), 1976, 82-86
5. Barella A., Bardi X., Castro L.: Hairiness Modification by Yarn/Yarn and Yarn/Metal Friction, Melliand Textilber. 72(1), 1991, 3-4
6. Chang L., Wang X.: Comparing the Hairiness of Solo-Spun and Ring Spun, Textile Res. J. 73(7), 2003, 640-644
7. Wang X.G., Miao M.H., How Y.L.: Studies of JetRing spinning - Part1: Reducing Yarn Hairiness with The JetRing, Textile Research Journal 67(4), 1997, 253-258
8. Cheng K.P.S., Li C.H.L.: JetRing Spinning and Its Influence on Yarn Hairiness, Textile Res. J. 72, 2002, 1079-1087

9. Ramachandralu K., Dasaradan B.S.: Design and Fabrication of Air Jet Nozzles for Air Vortex Ring Spinning System to reduce the Hairiness of Yarn, The Journal of The Institution of Engineers (India) 84, 2003, 6-9
10. Zeng Y.C., Yu C.W.: Numerical and Experimental Study on Reducing Yarn Hairiness with the JetRing and JetWind, Text. Res. J. 74(3), 2004, 1-5
11. Ramachandralu K., Ramesh V.: Design and Development of Twin Air-jet Nozzle System for Ring Spinning, The Journal of The Institution of Engineers (India) 86, 2005, 1-5
12. Najar S.S.: An Analysis of Twist Triangle in Ring Spinning, PhD Thesis, The University of New South Wales, 1996
13. Pillay K.P.R.: A Study of the Hairiness of Cotton Yarns, Part 1: Effect of Fiber and Yarn Factors, Textile Res. J. 34, 1964, 663-674
14. Wang S., Yu X.: New Textile Yarns, ed. 1, Publishing Company of Donghua University: Shanghai, 2007, 121
15. Zhu GC, Ibrahim S., Křemenaková D.: The optimization application of air-jet nozzle in ring spinning system, In 18th International Conference STRUTEX Structure and Structural Mechanics of Textiles. 7-8th December 2011, Technical University of Liberec, Liberec, Cezch Republic