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Experimental study on the spinning geometry of multi-thread fancy yarn on hollow-spindle spinning machines: Part I

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Structured Abstract

Purpose

This article aims to define the relationships between the first spinning zone of the hollow-spindle spinning system and technological parameters of manufacturing multi-thread fancy yarn.

Design/methodology/approach

A simple mathematical equation was introduced to account for the effect-thread helices. The validity of this equation was tested using visual observations on the helices of the effect thread in terms of their number, width and regularity and then compared against the theoretical values.

Findings

It was found that higher overfeed ratios increased the diameter of the helices without affecting their number, while increasing the rotational speed increased their number but reduced their diameter. The effect of these changes on the fancy yarns was that higher number of helices resulted in more fancy profiles while wider helices resulted in larger fancy profiles.

Originality/value

This research offers fancy yarn manufacturers a better understanding of the manufacturing process of fancy yarn and its practical advantage is to help them in determining the type of resultant fancy yarns by controlling the geometry of the first spinning zone.

Keywords

fancy yarn; helical geometry; hollow-spindle system; spinning zone.

1. Introduction

The hollow-spindle system is a non-traditional system for making several types of yarns. For example, these yarns could be made by combining together a strand of drafted fibres with a multi-filament. Therefore, the resulting yarns may be wrap-spun (Gong and Wright, 2002). Several studies have been reported about this system and this type of yarn (Lawrence et al., 1985, Baoyu and Oxenham, 1994, Li et al., 2002). Alternatively, this system could be used to make fancy yarns from drafted fibres (Gong and Wright, 2002). These fibres are usually supported by a spun thread. The composite structure is then fastened by a third component, usually a multi-filament, to make fancy yarns. The type of fancy yarn made varies according to several factors, such as the drafting ratio of the strand. Furthermore, this system could be combined with the ring system to make fancy yarns (Gong and Wright, 2002). More recently, studies have been reported which expanded the versatility and utility of this system. For instance, the ability of this system to make fancy yarns by using only threads was previously reported (Nergis and Candan, 2006, Nergis and Candan, 2007).

During the manufacture of multi-thread fancy yarns on such a system, it was observed that the effect thread (of the fancy yarn) formed a helical configuration around the core thread in the first spinning zone; otherwise, a multi-thread fancy yarn cannot be made. The formation of the helices is partly induced and regulated by the false-twist hook. This hook is attached to the out-let hole of the hollow spindle. Without such a hook, it was difficult to obtain regular helices. The false-twist hook has several other advantages. These includes: making wider wavy and sigmoidal sections of the fancy gimp yarns; promoting the quality of fancy gimp yarns because it reduced the number and size of non-gimp projections; reducing the variability observed in the area of non-gimp profiles; reducing the value of the Shape Factor of Fancy (Gimp) Yarns; and improving the tensile properties of the gimp yarns when considering the first break and the longer elongation for the effect thread (Alshukur and Fotheringham, 2014). Further studies were conducted recently on the fancy yarns made on this system (Alshukur and Fotheringham, 2015, Alshukur and Sun, 2016).

The first spinning zone is located between the supply rollers of the threads and the in-let hole of the hollow spindle. The supply rollers were the first drafting rollers on hollow-spindle spinning machines. It is now confirmed that the failure of the effect thread to make a helical structure around the core thread results in inability of making a final fancy yarn. It was thought that the nature of the helices formed correlates with the structure and quality of the ultimate multi-thread fancy yarn as modelled mathematically recently (Alshukur and Gong, 2017). Therefore, it was necessary to study the geometry of these effect-thread helices.

2. Mathematical Background

The helix triangle for a single helix of the effect thread is presented in Figure 1 (a). Such a helix may be obtained at a suitable value of rotational speed (RS) of the hollow spindle. If the rotational speed is raised sufficiently, more helices form, for the same length of the effect thread, as indicated in Figure 1 (b). Meanwhile, the radius of the helix becomes narrower. For a single helix, if the length of the effect thread is L_e, while the length of the core thread is L_c, the radius of this helix R is calculated depending on Pythagoras equation:

$$L_e = \sqrt{(2\pi R)^2 + L_c^2} \quad (1)$$

Suppose the manufacturing process is in a steady-state situation. If n helices of radius r were formed, while L_e and L_c both remain constant, the new helices will be equal in dimensions. The lengths of the effect thread and the core thread for each new helix become l_e and l_c respectively. Moreover, L_e= n l_e and L_c= n l_c. The length l_e is also given by Pythagoras equation as:

$$l_e = \sqrt{(2\pi r)^2 + l_c^2} \text{ or } (\frac{L_e}{n})^2 = (2\pi r)^2 + (\frac{L_c}{n})^2 \quad (2)$$

After rearranging such a relationship, the following has resulted:

$$(2n\pi r)^2 = L_e^2 - L_c^2 \quad (3)$$

Suppose $\eta = L_e/L_c$ is the overfeed ratio of the effect thread relative to the core thread. Suppose angle β is the helix angle, therefore, cosβ=1/η. Relationship (3) became:

$$(2n\pi r)^2 = \eta^2 L_c^2 - L_c^2 = L_c^2(\eta^2 - 1) \quad (4)$$

Therefore the radius of each helix formed is given by the relationship:

$$r = \frac{L_c\sqrt{\eta^2-1}}{2\pi n} \quad (5)$$

This simple model indicated that the radius r is also related to the overfeed ratio η of the effect thread and the length of the spinning zone L_c. It also implies that the helix angle remains the same even though the dimensions of the helices changes in response to changes in the rotational speed or any other factor. Consider the quality parameters of fancy yarn which were reported previously (Alshukur, 2013a, Alshukur, 2013b); these include the Size of Fancy Profile, the Number of Fancy profiles, and the Shape Factor of Fancy Yarn. It was believed that the radius of the helices formed may have a positive relationship with the size of fancy profile formed on the fancy yarn surface. Additionally, the number of the helices formed may correlate positively with the number of fancy profiles. The length of the core thread is assumed to be equal to the length of the first spinning zone.

3. Methods and Materials

Equation 5 was used to understand the geometry of the first spinning zone. The length of the first spinning zone is L_c=40 mm. Although trials and efforts were made to obtain real values of the radius r in order to test equation 5, difficulties have arisen. There was a limited possibility to count the number of helices formed when the rotational speed was more than 9000 rpm. It was also not possible to measure the actual value of radius for several reasons. Firstly, the limited space available in the first spinning zone. Secondly, it was impractical to fix a measuring apparatus on the machine. Finally, the theoretical model assumes a steady-state, but in reality because of the vibration observed, it was not. The approach used in this paper, therefore, was to report observations about the helices in the first spinning zone and compare it with the theory. Following this, a comparison between the numbers of helices and the number of fancy profiles has followed. This approach was completed by comparing the size of fancy profile with the theoretical value of radius. Our approach was practical and gave indication of the accuracy of the model. The experimental work of Part I of this study was reported in three experiments to establish the impact of the factors on the helices without taking into account the material type. However, the effect of material type on the helices and the fancy yarn structure will be accounted for in Part II of this study.

3.1. Experiment I: Testing the Influence of the Overfeed Ratio on the Spinning Geometry

The effect thread was a wool plied thread and its resultant linear density was R120 tex/2. The core thread was a natural wool plied thread (R195 tex/2). The binder was a nylon multi-filament (14.5 tex/77). The overfeed ratio used were in the range η=1.2~2.2 to ensure exhaustive results. Table 1 shows the machine settings for this experiments. The rotational speed was constant, RS=5000 rpm, and number of wraps was also constant, W= RS/DS= 5000/30= 166.6 wpm.

3.2. Experiment II: Testing the Influence of the Rotational Speed on the Spinning Geometry when the Number of Wraps Changes

The supply speed SS=50 m/min and the delivery speed DS=30 m/min. Therefore, the overfeed ratio was constant, i.e. η=(50/30)=1.66, i.e. η% =166%. The number of wraps was changed incrementally with the rotational speed (RS). The effect thread was a wool plied thread (R120 tex/2). The core thread was a bleached wool plied thread (R120 tex/2). The binder thread was a nylon multi-filament (14.5 tex/77). Wide ranges of the rotational speed (RS=1000~9000 rpm) and number of wraps (W=33.3~300 wpm) were used to ensure exhaustive results. Table 2 shows the machine settings for this experiment.

3.3. Experiment III: Testing the Influence of the Rotational Speed on the Structure of Fancy Yarn when the Number of Wraps was Fixed

This experiment was concerned with the changes related to the effect-thread helices in the first spinning zone and their influence on the structure of the final fancy yarns. The number of wraps and the overfeed ratio were kept constant, 180 wpm and 165 % respectively, by altering the level of both the supply speed and the delivery speed in accordance with the rotational speed. The effect component was a 83 tex lambswool thread. The core component was a 67 tex mixed thread of angora/wool/polyamide (20%/60%/20%). The order of the trials was randomised, by making yarn 1, yarn 5, yarn 3, yarn 2 then yarn 4, to make sure that the effect of the variability of the machine on the results was minimized. Machine settings for this experiment are given in Table 3. All the fancy yarns made for this experiment were conditioned in a standard atmosphere according to the British Standard (BS EN ISO 139:2005). Following this, they were systematically sampled then tested, in accordance with the methods reported previously (Alshukur, 2013a, Alshukur, 2013b). The fancy yarn qualities measured were the size of fancy profile (mm^2) and the number of fancy profiles per unit length of the final fancy yarn. 15 specimens were used to count the number of the fancy profiles per one decimetre of the ultimate fancy yarns. Sampling pitch was 1 metre for this procedure. 16 specimens were sampled randomly to account for the size of fancy profile. Sampling pitch was 50 cm for this procedure. The size of fancy profile was measured using digital image software (AnalySIS FIVE) which was associated with a digital microscope. The fancy profiles which were measured were bouclé profiles, loops, semi-bouclé profiles, i.e. elongated loops, u-shaped profiles and sinusoidal, narrow wavy profiles.

4. Results and Discussion

4.1. Results of Experiment I

Images of the first spinning zone corresponding to the machine settings of Experiment I are given in Figure 2 and comments and observations related to these images are given in Table 1. This table indicates that when the number of wraps (of the binder) were constant, the number of helices was either 3 or 4 regardless of the value of the overfeed ratio. So, the overfeed ratio did not affect the number of the helices. It only affected the radius of these helices. Further, height overfeed ratios resulted in the formation of loops in the first spinning zone. The size of those loops increased with increasing the overfeed ratio. Those loops led to the formation of defects on the bouclé yarn structure such as large loops or large, unstable fancy profiles. In this experiment, η=1.6 was the minimum overfeed ratio which made helices with a loop from the threads used. Overfeed ratios higher than η=1.6 created irregular fancy profiles on the resultant fancy yarn. The variations in the number of the helices may have resulted due to the variations in the input materials and the variation of the machine.

4.2. Results of Experiment II

Images of the first spinning zone related to this experiment are given in Figure 3 and comments and observations related to those images are given Table 2. Taking into account the threads used, it was found that RS= 5000 rpm was the minimum rotational speed which was suitable to make a fancy yarn. It corresponded to machine settings number 5. Table 2 confirms that the overfeed ratio did not contribute to the number of the helices when both the rotational speed and the number of wraps were changed. However, the number of the helices was found to increase with the rotational speed while the diameters of the helices became narrower. Further, regular helices were formed when RS≥6000 rpm because the diameter of the helices became relatively narrow.

4.3. Results of Experiment III

Table 3 shows comments and observations about the first spinning zone when the rotational speed increased while both the number of wraps and the overfeed ratio were kept constant. This table indicates that the number of the helices was increasing with the rotational speed while their radius was decreasing. The final fancy yarns are shown in Figure 4 which shows that those yarns made were different from each other. The size of the fancy profiles was excessively large for yarns 1, 2 and 3 which were made at low rotational speeds. Further, the fancy profiles became higher in number and smaller in size as the yarns were observed from fancy yarn 1 to fancy yarn 5.

The fancy yarns were tested and the results given in Table 4. This table indicates that the average size of fancy profile for yarns 1, 2 and 3 was in the range of 15.02 ~ 20.61 mm^2. Figure 5 shows that when RS was higher than a certain level, the fancy profiles started to become smaller, e.g. yarns 4 and 5. For these yarns the average size of fancy profile was in the range 9.97 ~ 11.68 mm^2. At the same time, the number of large fancy profiles was as low as 4.88 ~ 6.06 per dm. In contrary, the smaller fancy profiles were more in number and reached about 9.8 profiles per dm (Figure 6). The circularity ratio of fancy profile (CR) was higher for fancy yarns 4 and 5, i.e. 62.12 and 65.26 respectively. Therefore, the CR indicates they had better bouclé profiles (Alshukur, 2013a, Alshukur, 2013b). The relationships of Figure 5 and Figure 6 represented regression models as follows:

$$\text{Size of fancy profile (mm2)} = 28.7 - 0.00140\ RS \qquad (6)$$

Number of fancy profiles (per dm) = 2.69 + 0.000509 RS (7)

The results of the statistical studies of these two regression models are given in Table 5. This table indicates that both regression models were significant, at a significance level α=0.05 as seen from the p-values of Analysis of Variance (ANOVA). Additionally, since all p-values of t-test were smaller than α=0.05, all terms included in the models were significant at α=0.05. The accuracy of the fitted lines of the models was high since the values of Coefficient of Determination R^2 were high, i.e. 86.5 % and 95.5 % respectively. However, since the value of adjusted R^2 was higher for the second regression model then the first regression model, i.e. 94.1 % ≥ 82.0% respectively, it indicated that the second model was more accurate than the first one.

In this experiment, all the fancy yarns had identical values of structural parameters, i.e. thread thickness, number of wraps and the overfeed ratio, yet they were different in appearance, texture and quality as shown in Figure 4. Understanding those differences started from understanding the spinning geometry in the first spinning zone where the effect thread formed several helices around the core thread. A wide diameter of the helices resulted in large fancy profiles. Additionally, a few helices resulted in a lower number of fancy profiles. In contrast, when the helical configuration had narrow diameter and more helices, a higher number of smaller fancy profiles has resulted.

The number of the effect-thread helices, in the first spinning zone, was low in the case of yarns 1, 2, and 3, due to the low values of the rotational speed. Additionally, due to the fixed overfeed ratio, the diameters of such helices were wider than that in the cases of higher rotational speeds for yarns 4 and 5. Table 3 gives the theoretically calculated radii of the helices, assuming stable helices. When the rotational speed was increased and became sufficiently high, the values of radii became lower. Additionally, because of the fixed overfeed ratio, the number of helices formed was higher than the case of yarns 1, 2 and 3.

The stability of the effect-thread helices determined the consistency of the final fancy yarn structure. Any deformation in the helical configuration had an impact on the fancy profiles. When a loop was formed, it was fixed into the fancy yarn structure and appeared as a closed, large loop (or ring) on the fancy yarn surface as seen in yarns 1, 2, and 3. Such a loop is not intended or needed to form when making bouclé yarns because loops are the fancy profiles of loop yarns instead of bouclé yarns. The main reasons for the helices deformation may have been (1) the vibration in the machine parts, (2) deformation in the supply rollers, (3) the variability in pressure imposed on these rollers, (4) the variability of the effect-thread characteristics, in particular the linear density, the bending stiffness, the short-term faults, the shape of the cross-section, etc. A periodical alteration to the number of helices was observed when making fancy yarns. During such changes in the number of helices, a loop or loops may form for yarn 1, 2 and 3. Those loops found a place over the surface of the resultant fancy yarn as loop. Ballooning of the core thread of yarn 5 was mainly due to the sufficiently high rotational speed. Such ballooning had a positive influence on the fancy yarn structure, but it made it difficult to count the number of helices of the effect thread.

Conclusions

Based on the materials, machine settings, results, analysis and discussion of the experiments of this study, it was concluded that studying the first spinning zone on hollow-spindle spinning machines was important for the following reasons:

- The effect thread must form a helical configuration around the core thread, otherwise, a multi-thread fancy yarn cannot be produced.
- It was possible to account for the effect-thread helices by a mathematical model.
- Increasing the overfeed ratio of the effect thread, while fixing the rotational speed and the number of wraps, increased the diameter of the effect thread helices without changing their number.
- Increasing the rotational speed of the hollow spindle of the machine, with or without increasing the number of wraps and the overfeed ratio, increased the number of the effect-thread helices and made them narrower in diameter.
- The number of the helices formed and their radius had a relationship with the size and number of fancy profiles formed on the fancy yarn. More helices produced more fancy profiles and wide helices produced large fancy profiles.
- Any fault occurring in the effect-thread helices had negative consequences on the structure of the final fancy yarn.
- The formation of loops in the first spinning zone resulted in abnormally large fancy loop profiles on the final fancy yarn. The number of those defective profiles was related to the number of the loops. The size of the loops defined the size of the defects.
- When there were loops alongside the effect-thread helices in the first spinning zone, either the overfeed ratio was excessive, or the rotational speed was insufficient.

Reference

ALSHUKUR, M. 2013a. The Quality of Fancy Yarn: Part I: Methods and Concepts. *International Journal of Textile and Fashion Technology,* 3**,** 11-24.

ALSHUKUR, M. 2013b. The Quality of Fancy Yarn: Part II: Practical Experiments and Application. *International Journal of Textile and Fashion Technology,* 3**,** 25-38.

ALSHUKUR, M. & FOTHERINGHAM, A. 2014. Role of false twist in the manufacturing process of multi-thread fancy yarn on hollow spindle spinning machines. *Journal of The Textile Institute,* 105**,** 42-51.

ALSHUKUR, M. & FOTHERINGHAM, A. 2015. Quality and structural properties of gimp fancy yarns using the Design of Experiments. *Journal of The Textile Institute,* 106**,** 490-502.

ALSHUKUR, M. & GONG, R. H. 2017. Structural Modelling of Multi-thread Fancy Yarn. *International Journal of Clothing Science and Technology,* accepted.

ALSHUKUR, M. & SUN, D. 2016. Effect of core thread tension on structure and quality of multi-thread bouclé yarn. *Indian Journal of Fibre & Textile Research,* 41**,** 367-372.

BAOYU, Z. & OXENHAM, W. 1994. Influence of Production Speed on the Characteristics of Hollow Spindle Fancy Yarns. *Textile Research Journal,* 64**,** 380-387.

GONG, R. H. & WRIGHT, R. M. 2002. *Fancy yarns: Their manufacture and application,* Cambridge, The UK, Woodhead Publishing Limited.

LAWRENCE, C. A., COOKE, W. D. & SUSUTOGLU, M. 1985. Studies of Hollow Spindle Wrap Spun Yarns. *Melliand Textilberichte [Eng. Ed.],* 66**,** E350-E354.

LI, X., ZHANG, J. & LI, J. 2002. Differential-Twist wrapped Yarns Made on Hollow Spindle Spinning Machine. *Textile Research Journal,* 72**,** 181-185.

NERGIS, B. U. & CANDAN, C. 2006. Performance of Bouclé Yarns in Various Knitted Fabric Structures. *Textile Research Journal,* 76**,** 49-56.

NERGIS, B. U. & CANDAN, C. 2007. Performance of Rib Structures from Boucle Yarns. *Fibres & Textiles in Eastern Europe,* 15**,** 50.

Tables

Table 1: Machine Settings and Results of Experiment I

Rotational speed RS=5000 rpm; Delivery speed DS=30 m/min, W=166.6 wpm				Observations of the first spinning zone
S: Supply speed; m/min	η: Overfeed ratio	n= Actual number of helices formed	r: Theoretical value of radius of helix; mm	
36	1.2	4	1.05	The helix was touching the core thread
39	1.3	4	1.32	The helix has started to separate from the core thread
42	1.4	4	1.56	Regular helices
45	1.5	4	1.78	Regular helices
48	1.6	3	2.12	A loop has formed
51	1.7	4	2.18	A loop has formed with a wider diameter than previously
54	1.8	3	3.17	Helices with a loop
57	1.9	4	2.57	A loop has formed with a wider diameter than previously
60	2	3 or 4	3.15	A loop has formed with a wider diameter than previously
63	2.1	3 or 4	3.35	A loop has formed with a wider diameter than previously
66	2.2	3 or 4	3.56	A loop has formed with a wider diameter than previously

Table 2: Machine Settings and Results of Experiment II

Settings number	Rotational speed (rpm)	Number of wraps (wpm)	Actual number of helices	Comments about the experimental situation
1	1000	33.3	0	No helices have formed because the buckling of the effect thread was not complete nor regular
2	2000	66.6	1	The helix was irregular and was affected by the gravitational force
3	3000	100	Alternating between 1 and 2	There were some irregularity and deformations in the helix at the inlet of the hollow spindle
4	4000	133.3	2	There were some irregularity and deformations in the helix at the inlet of the hollow spindle
5	5000	166.6	Alternating between 2.5, 3 and 3.5	Irregularity of the number of helices by time was observed; perhaps because of vibration of the machine parts.
6	6000	200	Alternating between 4.5 and 5.5	Regular helices have formed with narrower diameters than setting 5
7	7000	233.3	Alternating between 7 and 8	Regular helices have formed with narrower diameters than setting 6
8	8000	266.6	Alternating between 8 and 9	Regular helices have formed with narrower diameters than setting 7
9	9000	300	Alternating between 9 and 10	Regular helices have formed with narrower diameters than setting 8

Table 3: Machine Settings and Observation Related to Experiment III

Fancy yarn	Delivery speed m/min	Rotational speed rpm	Supply speed m/min	Comments about the first spinning zone	Theoretical value of helix radius mm
yarn 1	20	3600	33	The number of helices formed was 3, 3.5 and there was loop formation.	2.81 mm or 2.41 mm
yarn 2	30	5400	50	3 or 4 helices have formed with ring(s).	2.81 mm or 2.11 mm
yarn 3	45	8100	75	4 or 5 helices were formed. No ballooning of the core thread. When alteration in the number of helices happened, momentary, the helix configuration became unbalanced and a loop has formed.	2.11 mm or 1.68 mm
yarn 4	60	10800	100	There was weak wobbling of the core thread, rather than ballooning. The helices formed were 5, 6 or 7. There were several breakages of the core thread.	1.68 mm , 1.40 mm or 1.20 mm
yarn 5	75	13500	125	The number of helices was high but not clear due to ballooning of the core thread; ballooning resulted because of the high rotational speed used.	Cannot be calculated

Table 4: Results of Experiment III

Fancy yarn	Number of helices in the first spinning	Size of Fancy Profile mm²	SD of Size mm²	Circularity Ratio of Fancy Profile %	SD of Circularity %	Number of Fancy Profiles dm⁻¹	SD of Number dm⁻¹	ShF of Fancy Yarn mm²/dm
Yarn 1	3 or 3.5	24.13	10.14	53.68	15.43	4.88	1.29	117.75
Yarn 2	3 or 4	20.61	8.51	60.67	20.17	5.46	1.18	112.53
Yarn 3	4 o 5	18.96	10.24	54.48	21.83	6.06	0.96	114.89
Yarn 4	6 or 7 or 5	9.97	2.04	62.12	15.7	8.33	2.4	83.05
Yarn 5	not totally clear	11.68	5.87	65.26	16.06	9.8	1.9	114.46

Table 5: Statistical Study of Regression Models of Experiment III

	Predictor	Coefficient	t	p-value	Accuracy of the regression line	P-value of ANOVA Test
Regression Model of Size of Bouclé Profile	**Constant**	28.693	9.94	0.002	SE= 2.557 R^2 = 86.5% R^2 (adj)= 82.0%	0.022
	RS	-0.0014	-4.39	0.022		
Regression Model of Number of Bouclé Profiles	**Constant**	2.6908	4.70	0.018	SE= 0.507 R^2 = 95.5% R^2 (adj)=94.1 %	0.004
	RS	0.0005	8.02	0.004		

Figures

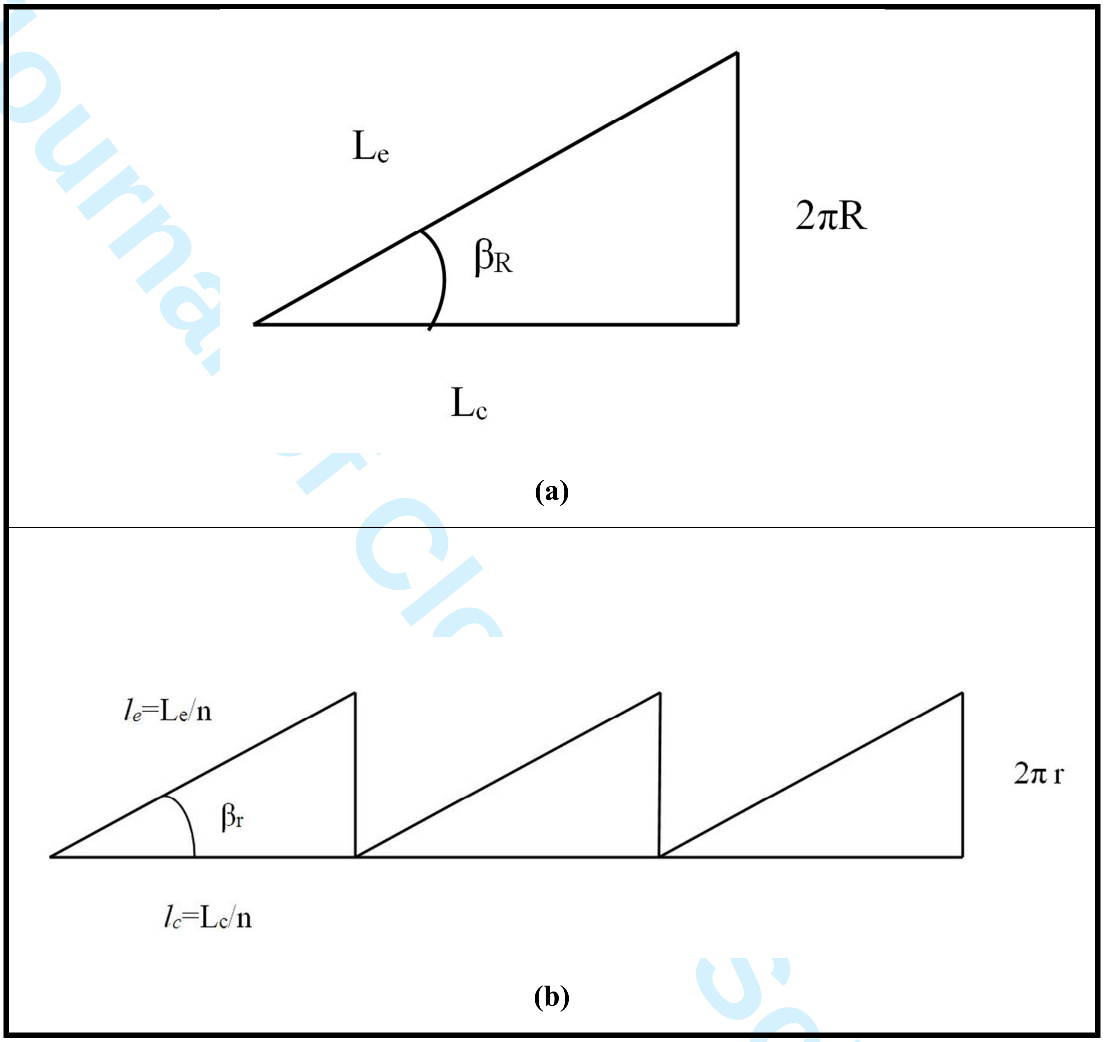

Figure 1: The Triangles of the Effect-thread Helices Formed on Hollow Spindle Machines for One Helix (a) and n Helices (b)

Figure 2: Images of the Spinning Geometry of Experiment I

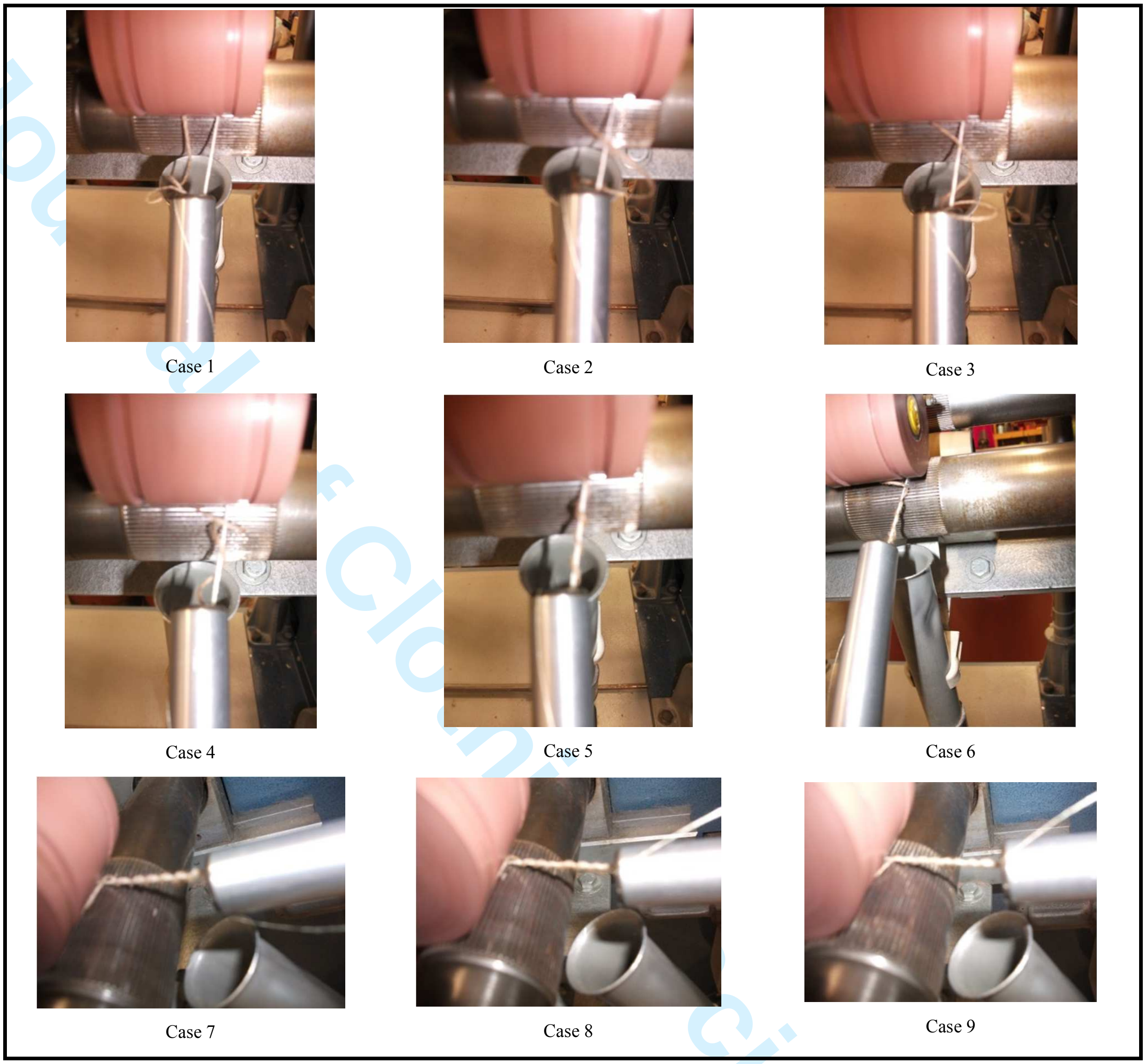

Figure 3: Images of the Spinning Geometry of Experiment II

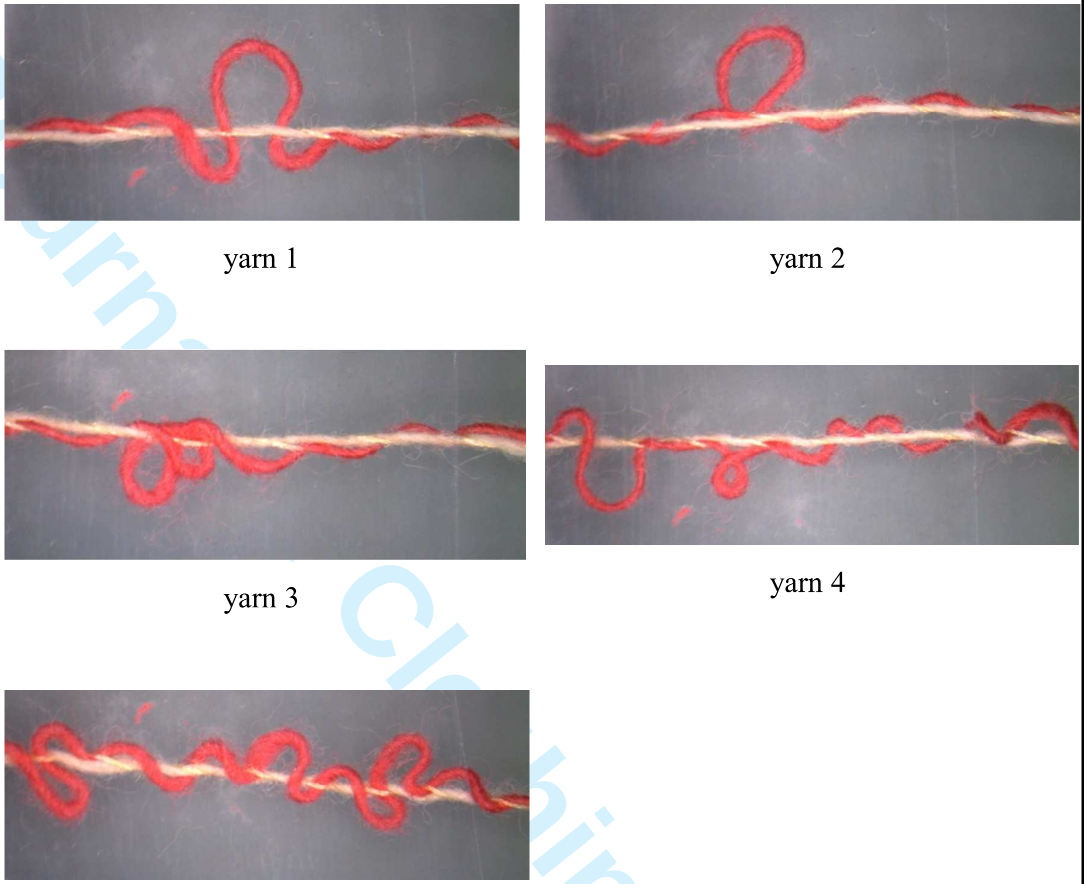

Figure 4: Images of the Fancy Yarn of Experiment III

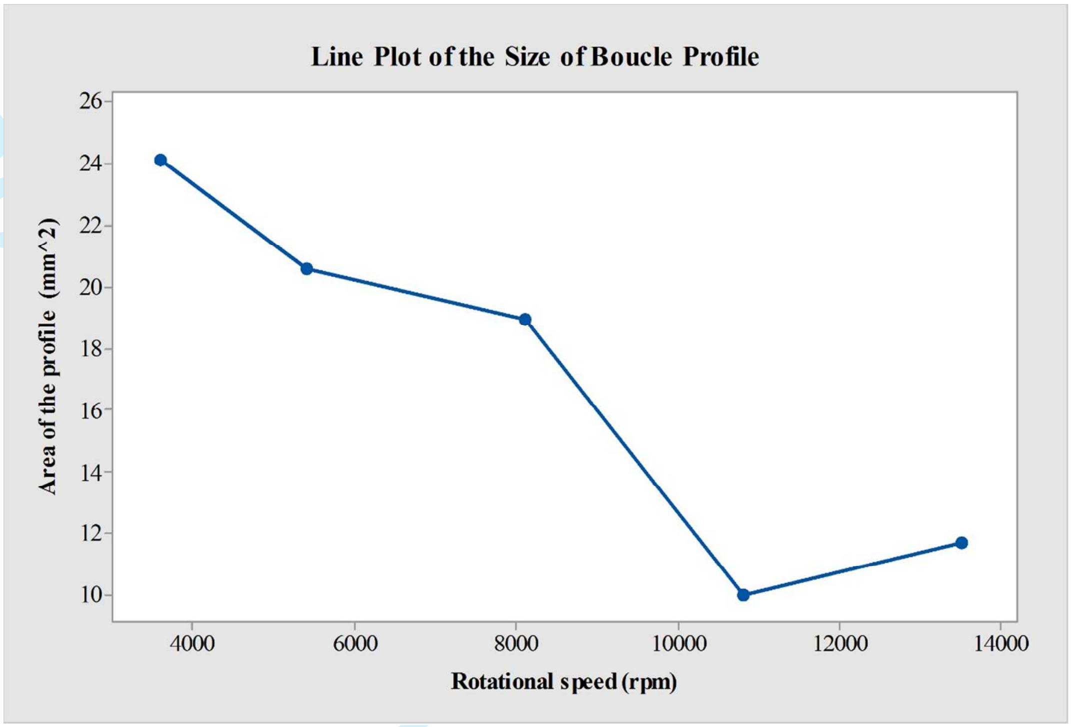

Figure 5: Relationship between the Size of Fancy Profile of the Fancy Yarns and the Rotational Speed in Experiment III

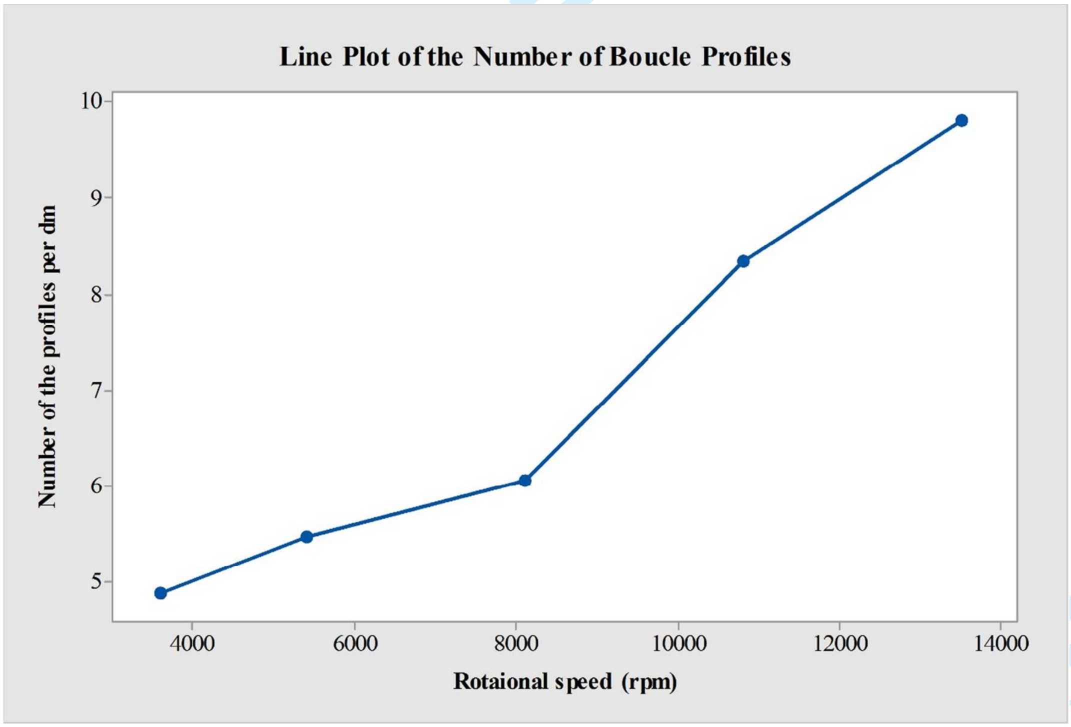

Figure 6: Relationship between the Number of Fancy Profiles of the Fancy Yarns and the Rotational Speed in Experiment III