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Effect of Spinning Triangle and Production Speed of Hollow-Spindle System on the Bouclé Yarn Structure

Vpliv predilnega trikotnika in proizvodne hitrosti sistema z votlim vretenom na strukturo preje buklé

Original scientific article/*Izvirni znanstveni članek*
Received/*Prispelo* 10-2020 • Accepted/*Sprejeto* 4-2021

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Abstract

This study aims to show the impact of both the width of the base of the spinning triangle and the production speeds of hollow-spindle spinning machines on the structure of ultimate multiple-thread-structure bouclé yarns and similar fancy yarns. A hollow-spindle spinning machine was used and bouclé yarns were made of a core thread, an effect thread and a (multifilament) binder. Initially, five bouclé yarns were made by setting the widths of the base of the spinning triangle at five levels, i.e. 4.5 mm, 7.5 mm, 10 mm, 13 mm and 16 mm. A further six bouclé yarns were made to show the changes that occur to the spinning triangle at various production speeds. The resulting fancy bouclé yarns were assessed by measuring the size, number and circularity ratio of bouclé profiles. It was found that at low production speeds, i.e. at start-up, that the spinning triangle was unstable, which adversely affected the structure of the final bouclé yarns. However, at production speeds higher than 17 m/min, the spinning triangle became stable, though such a stable spinning triangle had no impact on the structure of the resulting fancy bouclé yarns. The results of this study may help fancy yarn manufacturers to avoid making defective fancy yarns.

Keywords: fancy yarn, bouclé yarn, spinning triangle, hollow-spindle machine

Izvleček

Cilj te študije je bil ugotoviti, kako širina predilnega trikotnika in proizvodna hitrost predilnih strojev z votlim vretenom vplivata na strukturo večnitne preje buklé in drugih efektnih prej. Za izdelavo preje buklé je bil uporabljen predilni stroj z votlim vretenom. Preja buklé je bila izdelana iz niti v jedru, efektne niti in multifilamentne povezovalne preje. Najprej je bilo izdelanih pet prej buklé z nastavitvijo širine osnove predilnega trikotnika na pet nivojev, tj. 4,5 mm, 7,5 mm, 10 mm, 13 mm in 16 mm. Nadaljnjih šest prej buklé je bilo izdelanih zato, da bi ugotovili, kakšne spremembe nastanejo na predilnem trikotniku pri različnih proizvodnih hitrostih. Kakovost izdelanih efektnih prej buklé je bila ocenjena glede na velikost, število in razmerja kroglastih profilov buklé. Pokazalo se je, da je pri nizkih proizvodnih hitrostih, tj. ob zagonu stroja, predilni trikotnik nestabilen, kar je negativno vplivalo na strukturo izdelane preje. Pri proizvodnih hitrostih nad 17 m/min je postal predilni trikotnik stabilen, vendar to ni vplivalo na strukturo nastale efektne preje buklé. Rezultati te študije lahko pomagajo predilcem, da se izognejo napakam pri izdelavi efektnih prej.

Ključne besede: efektna preja, preja bukle (bouclé), predilni trikotnik, stroj z votlim vretenom

1 Introduction

1.1 Spinning triangle of multiple-thread-structure fancy yarns on hollow spindle-spinning machines

When using the hollow-spindle system to make fancy yarns by combining several (input) spun threads (or yarns), the final fancy yarn is said to have a multiple-thread structure. The spinning geometry of this final multiple-thread-structure fancy yarn forms part of the first spinning zone. This zone is located between the yarn supply rollers and the inlet mouth of the hollow-spindle [1, 2]. This zone is characterised by the formation of an approximately right-angle spinning triangle and effect-thread helices. An example is provided in Figure 1 for the Gemmill & Dunsmore MK#3 hollow-spindle spinning machine. This machine can make the effect component of fancy yarns using either drafted fibres (i.e. slivers or rovings) or previously spun threads as the input materials. When using a spun thread for the effect component, a spinning triangle forms when the effect thread emerges from the supply rollers to the point where it starts making a helix around the core thread. The sides of such a spinning triangle were the segments of the core thread (one side of the triangle), the effect thread (hypotenuse of triangle) and the distance between the nipping points of the upper and lower supply rollers on these two threads (i.e. the base of the triangle). Observations indicated that changing the width of the base of such a triangle may alter the size of such a spinning triangle. It is easily possible to change such a width using the grooves of the control cylinder, which is located before the upper supply roller (not shown in Figure 1). Several studies have been conducted on multiple-thread-structure fancy yarns made using the hollow-spindle system as shown below.

1.2 Literature survey

The structure of multiple-thread fancy yarns made by either wrapping or twisting was studied using several approaches. These include the mathematical modelling of the structure, the statistical or empirical modelling of the structural features of these yarns, technological studies of the parameters of the machines and their impact on the structure, engineering studies of the properties of the input yarns and their impact on the structure, engineering studies of the formation conditions of the structure and forces affecting the formation process, etc. In one analytical study based on mathematical equations, the structure and formation of several types of multiple-thread-structure fancy yarns were modelled analytically [3]. In such a purely theoretical study, no practical results were presented to test the accuracy of the theoretical equations. Further, the fancy yarns described in such a study were made by twisting, not wrapping, and using routes and technologies different from the hollow-spindle spinning system.

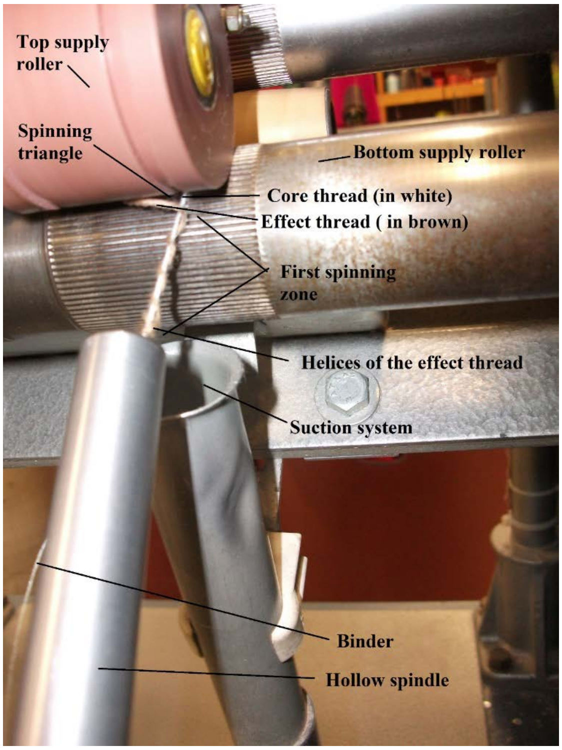


Figure 1: Spinning Triangle on the Gemmill & Dunsmore hollow-spindle spinning when making multiple-thread-structure fancy yarns

When using the hollow-spindle spinning or hollow-spindle twisting systems, the spinning geometry was shown to have an impact on the structure of multiple-thread final fancy yarns. A recent experimental investigation using the hollow-spindle system showed that the tension of the core thread can change the spinning geometry of fancy yarns [4], particularly within the first spinning zone. Consequently, it was used to regulate the style of the ultimate multiple-thread-structure fancy yarns by selecting suitable values for it. The practical benefit of such a study is that it showed it was possible to make good-quality multiple-thread-structure fancy bouclé yarns using a differential overfeed ratio of as low as +50% of only *one* effect thread in comparison with the core thread [4]. Following this, two other studies were also conducted to provide a deeper understanding of the formation of the effect-thread helices within the first spinning zone of hollow-spindle spinning machines [1, 2]. In these two studies, it was shown that the shape and size of the effect-thread helices can change the structure of the ultimate multiple-thread-structure fancy yarns. These two studies also showed that the spinning geometry was also controlled by several factors, such as the overfeed ratio of the effect thread, the weight and stiffness of input effect thread and the dynamic forces affecting the segment of the effect thread within the first spinning zone [1, 2]. Dynamically, the diameter of the helices is controlled by external forces, such gravitational force, air drag, centrifugal force and centripetal force. It is also controlled by internal forces, such as tension and the bending force of the effect thread [1]. Mathematically, it was shown that the overfeed ratio and the number of helices can define the radius of the helices in the steady-state rotation or configuration of the effect-thread helices [2].

In another study, a universal, analytical model of the structure and geometry of several types of multiple-thread-structure fancy yarns was presented [5]. In other studies, another form of mathematical modelling of the geometry of bouclé yarns was used to build a mathematical model of the strength of such types of fancy yarn. In the same study, however, the structure was called loop yarn when the structural profiles were sinusoidal in shape, though these were similar to any typical bouclé yarn structural profiles [6, 7]. In another study, the *Structural ratio of multi-thread fancy yarn* was presented using a simple mathematical equation to account for the interaction of the number of wraps and the overfeed ratio, and to show how such an interaction may help in deciding the structure and type of fancy yarn [8]. Depending on the value of this ratio, the final fancy yarn can be bouclé yarns, gimp yarns, overfed fancy yarns or wavy yarns.

Other studies concerned the contribution of technological factors of the hollow-spindle system to the structure of multiple-thread fancy yarns. Examples of these studies are those that dealt with the impact of the supply speed of the effect thread, the rotational speed of the hollow-spindle and the delivery speed of the ultimate fancy yarns [9–14]. These studies were based on the design of experiment method using either the Box-Behnken design or second-order composite models. The differences between these studies lie in the type of material used and types of fancy profile that resulted [9–14]. The researchers studied these overfed fancy yarns in terms of linear density, breaking tenacity, height of the effect projections, width of the effect projections, distance between the effect projections and the number of effect projects per unit length. In these studies, the effect threads that were studied were loop/knot and plain knot, plain knot-knot effect profiles, closed loop, opened loop, loop-knot, opened loop-plain knots, knot made from various loops and combinations thereof [9–14]. The impact of other factors was also reported, including the bending stiffness of effect threads [15, 16], the combined effect of the overfeed ratio and the number of wraps [8] and false twist [17].

Other forms of investigation were also based on the design of experiment method using factorial designs [18-21]. The multiple-thread-structure fancy yarns were gimp fancy yarns, derivatives thereof and generic overfed fancy yarns. The properties studied were the linear density of ultimate fancy yarns [18], their aesthetics and structural properties [19] and their tensile properties [20, 21]. This group of technological factors included the supply speed of effect thread, the delivery speed of ultimate fancy yarn, the rotational speed of the hollow spindle, the use of false-twist, the nature of the effect component (i.e. number of threads, linear density, type of spinning method and any special treatments), the nature of the core component and the nature of the (multifilament) binder. Significant results were obtained, as summarised in Table 1 [18–21].

Using the combined hollow-spindle system and ring-spindle system in one machine, two similar studies were conducted on multiple-thread-structure bouclé yarns and fancy knitted fabrics made from them [22, 23]. The factors of these two studies were the overfeed ratio of the effect thread, the number of wraps of the binder and the direction of wraps. The bouclé yarns were assessed by counting the number of bouclé profiles per unit length and by measuring their height. The fancy knitted fabrics made of these bouclé yarns were studied in terms of areal density, fabric thickness and abrasion resistance. The knitted fabrics were single jersey and (1×1) rib in the first study [22], and 2×1 and 2×2 rib fabrics in the second study [23]. The overfeed ratio had two levels, i.e. 100% and 200%, while the number of wraps had three levels, i.e. 400, 450 and

Table 1: Summary of results reported on multiple-thread-structure fancy gimp yarns using a fractional factorial design

Factor and levels	Advantages gimp yarn structure	Disadvantages to gimp yarn structure
Core component: two single threads versus a single thread	Thicker gimp yarns; higher value of the maximum load and load at the first peak; better extension at the first peak; higher number of the core ruptures; lower number of irregular non-gimp fancy projections with smaller sizes	Not applicable
Binder component: heavy textured multifilament versus lighter non-textured multifilament	Higher values for load at the first peak and extension at the first peak, lower number of non-gimp profiles with smaller sizes	Lower number of core ruptures
Effect component: heavy and stiff bamboo yarn versus lighter, softer cotton yarn	Thicker gimp yarns; higher value of load at the first peak; smaller number of non-gimp profiles with smaller sizes; and higher number of core ruptures	Lower value of the maximum load; less extension at the first peak
Supply speed: high versus low	Thicker gimp yarns	Not applicable
Rotational speed: high versus low	Reduced number of non-gimp profiles by increasing the number of wraps; slightly increase in the number of core ruptures	Not applicable
Delivery speed: high versus low	Not applicable	Thinner gimp yarns
False-twist: using versus not using it	Not applicable	Slight increases in the number of non-gimp profiles
Number of wraps: high versus low	Increase in the number of core breaks; reduced number of non-gimp profiles by increasing the rotations of the spindle	Decrease in the maximum load; slight increases in the size of abnormal distortions
Overfeed ratio: high versus low	Increase in the number of the core ruptures	Reduced number of core breaks; increases in the number of non-gimp profiles and their average size

500 wraps per metre. All these factors were found to have an influence on the results, but clear interaction plots for the effect of these factors were not provided and the experimental design was not a standard experimental design for either of the two studies [22, 23].

The spinning triangle was not studied in any of these published studies. However, since the spinning triangle on traditional ring spinning machines is important to the structure of typical spun yarns and controlling its dimensions has led to the invention of compact ring spinning, a similar investigation is required for the spinning triangle on the hollow-spindle system. Such an investigation may be completed in two cases. In the first case, which is beyond the scope of this study, the effect element of fancy yarns should be made by spinning drafted fibres, i.e. sliver or roving. In the second case, the effect element of fancy yarns is made by combining previously made yarns. In this second case, since the spinning triangle forms part of the first spinning zone, studying it may help increase current knowledge of the spinning geometry of this category of fancy yarns. Based on all of that, this study was conducted to complete the experimental investigations that were reported for the most part in three studies [1, 2, 4]. The topic of this study was the distance between the core thread and the effect thread at the beginning of the first spinning zone, also known as the width of the base of the spinning triangle. Further, since the motion of the effect thread changes at different levels of production speeds, in particular at the start-up of the hollow-spindle machines or at low production speeds, the spinning triangle may change. Therefore, the impact of running the hollow-spindle system at different levels of production speed on the structure of the ultimate fancy yarns was also studied.

2 Experimental

For this investigation, two experiments were conducted, and the ultimate fancy yarns were made by combining only three input yarns. This number of input threads was suitable for this kind of investigation, though fancy yarn can be made from more input threads. In the first experiment, five fancy bouclé yarns were made (i.e. group I of fancy bouclé yarns). The input effect component was a 67 tex wool thread and the input core component was a three-ply cotton thread (R72/3 tex), while the binder (or wrapper) was a nylon multifilament (R14.5/77 tex). The multiple-thread bouclé yarns were made on a Gemmill & Dunsmore (G&D) MK#3 hollow-spindle spinning machine. The supply speed of the machine was 54 m/min, the delivery speed was 30 m/min and the rotational speed of the hollow-spindle was 5700 revolutions per minute. Subsequently, the number of wraps was W = 5700 ÷ 30=190 wraps per metre, while the theoretical overfeed ratio was η = (54 ÷ 30) ×100 = 180%, i.e. the differential overfeed ratio is +80%. These values of machine speeds ensured that the spinning triangle was stable, while the effect thread helices were also stable. The tension of the core thread while running the machine was *approximately* zero in accordance with the results of a previous study [4]. The width of base of the spinning triangle was set to 4.5, 7.5, 10, 13 and 16 mm, one at a time, according to the machine design and limited by the width of the upper (rubber) supply roller. Due to the variability of the manufacturing process itself, the vibration of the machine parts and the variation in linear density of the core and effect threads, the aforementioned values for the base width changed continuously within a ± 0.5 mm range. The false-twist hook was used in this experiment, while its influence on the structure was revealed in a previous work [17]. False-twist may result in a transient impact on the structure at the start-up of the machine if drafted fibres are used, but this is not the case when using yarns as input materials due to differences in number, size and mass of the input threads in comparison with loose fibres.

Since the formation of a stable spinning triangle is related to the levels of production speeds, a further experiment (Experiment II) was conducted to assess the impact of production speed on the fancy bouclé yarn structure. This experiment may complement a previous investigation on the effect of the production speed of hollow-spindle machines on the structure of bouclé yarns that have the effect component made from drafted fibres [24]. In one case of Experiment II, the spinning triangle was made unstable by running the machine at a low production speed. This is similar to the case of a machine starting-up or changing speeds when the machine is already running at a suitable production speed. Six new bouclé yarns were made (i.e. called group II of fancy bouclé yarns) for Experiment II. The core component was an R120/2 tex lambswool/viscose blended spun yarn. The effect component was an R120/2 tex lambswool/cashmere blended spun yarn. The false-twist hook was used in the Experiment II. The full settings of the machine are given in Table 2.

Table 2: Machine settings and structural parameters of bouclé yarns for Experiment II

Fancy yarn	Delivery speed (m/min)	Supply speed (m/min)	Rotational speed (min^{-1})	Overfeed ratio, η (%)	Number of wraps (m^{-1})
Yarn II (1)	17	34	3400	200	200
Yarn II (2)	24	48	4800		
Yarn II (3)	28	56	5600		
Yarn II (4)	32	64	6400		
Yarn II (5)	34	68	6800		
Yarn II (6)	36	72	7200		

The ultimate multiple-thread structure fancy yarns were first preconditioned and then conditioned according to BSI ISO Standard 139:2005. They were then assessed according to the parameters and procedures given in previous studies for the objective assessment of such unique yarns [25, 26]. These parameters include the size of fancy profile, the number of fancy profiles and the circularity ratio of fancy profile. The size of fancy profile refers to the average area of an ultimate, fitted polygon drawn to match the circumference of the 2D projection of the fancy profile on a plane (if it is seen under a microscope). The number of fancy profiles refers to the number of the main fancy profiles of the effect component in a unit length (usually one meter) of the fancy yarn. The circularity ratio of fancy profile is a term that describes the circularity or the roundness of the representative projection of fancy profile on a plane. Fifteen specimens were sampled systematically to count the number of fancy bouclé (including semi-bouclé) profiles per dm. The sampling distance for this procedure was two metres. A manual winding reel (supplied by Doodbrand & Co. Ltd., England) was used to prepare the yarns for this purpose. A further fifteen specimens were also sampled systematically to measure the size (or area) and the circularity ratio of the fancy bouclé profiles. For these last two parameters, the sampling distance between each two bouclé profiles selected was 60 cm. The selected fifteen bouclé profiles were prepared before taking a digital image of each of them. The preparation was accomplished by placing the selected profiles, one at a time, underneath a suitable transparent plate made from glass. Doing so ensured that the fancy profiles lay in a plane if they were not already so. The plate and profile underneath it were all placed under a microscope with a magnifying power of 4×. The microscope was connected to an Olympus digital camera. Following this, a digital photo was taken of each fancy profile. A digital image analysis software package called 'analySIS FIVE®' was used to draw an ultimate, fitted polygon around the projection of fancy profile when viewed from above. This digital image analysis software was used to analyse the images and to measure both the size and the circularity ratio of the profile.

3 Results and discussion

The yarns made for the first experiment are shown in Figure 2. The fancy profiles that are marked with green colour were profiles that were selected to measure their size (mm) and circularity ratio (%). Subjectively, one may say that these bouclé yarns were *similar* in structure because they all had *similar* bouclé profiles and *regular* sigmoidal segments. These observations were confirmed objectively by the results of numerical testing procedures, as shown in Table 3. According to the p-values of ANOVA testing, no statistical differences were found amongst the yarns in terms of the size, the number and the circularity ratio of profiles. This means that the width of a stable spinning triangle had no effect on the structure of multiple-thread bouclé yarns. The similarities in the number, size and the circularity ratio of the fancy bouclé profiles mean that the effect-thread helices in the first spinning zone were similar in number and diameter [1, 2]. This also indicates that the influential factors controlling the diameter of effect-thread helices, as given previously [1, 2], exceeded any impact of the width of the spinning triangle base.

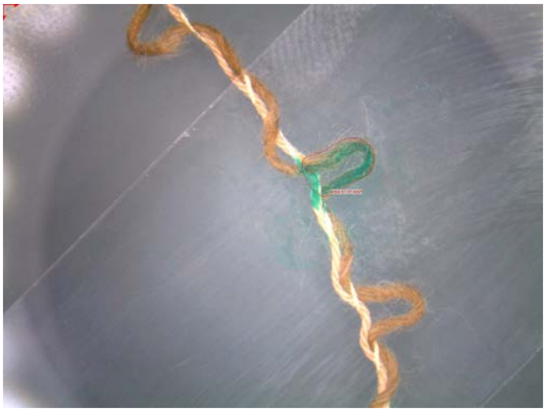
Table 3: Numerical results of Experiment I

Bouclé yarn	Width of spinning triangle (mm)	Size of bouclé profile (mm^2)		Number of bouclé profile (dm^{-1})		Circularity ratio of bouclé profile (%)	
		Average	SD [a)]	Average	SD [a)]	Average	SD [a)]
Yarn I (1)	4. 5	13.39	3.80	7.3	0.90	57	17
Yarn I (2)	7.5	14.65	4.19	7.2	1.20	53	17
Yarn I (3)	10	12.85	6.72	7.8	1.60	55	20
Yarn I (4)	13	13.59	4.15	7.3	0.90	56	18
Yarn I (5)	16	14.40	6.59	6.5	1.40	56	18

[a)] Standard deviation

Yarn I (1)

Yarn I (2)



Yarn I (3)

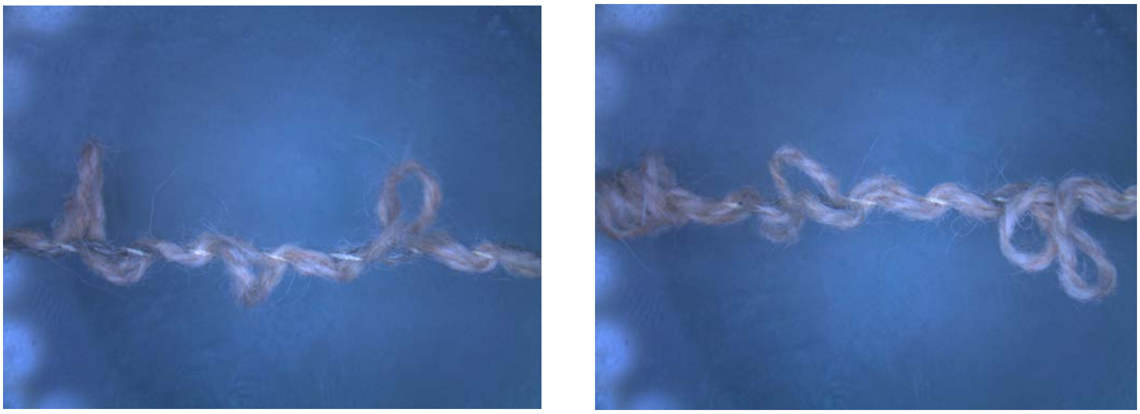
Yarn I (4)

Yarn I (5)

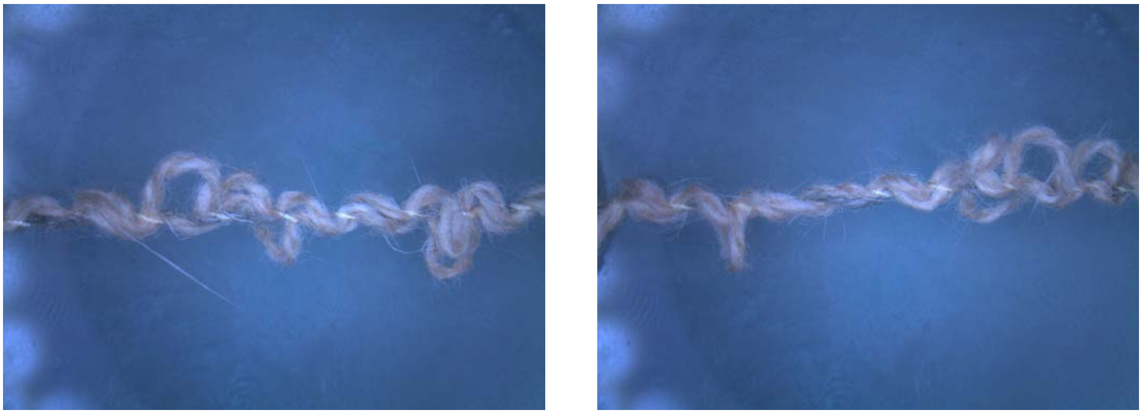
Figure 2: Images of the bouclé yarns made for Experiment I

The yarns made for Experiment II are shown in Figure 3, while the results of the numerical testing of these yarns are given in Table 4. Subjectively, one may say that the first of these yarns had a lower number of bouclé profiles in comparison with the rest of the yarns. Additionally, the other yarns do not appear to differ profoundly in terms of the number of bouclé profiles. However, due to the 3D configuration of these profiles, it is necessary to rely on numerical values for the size of the profiles. Table 4, and Figures 4 and 5 all indicate that the use of low speeds on the machine resulted in the final bouclé yarn II (1) being different from those made at higher speeds. The main difference was that profoundly larger and less bouclé profiles were obtained. Figure 4 and Figure 5 also have two regions, with an *approximately* stable region starting from a delivery speed of 24 m min-1. This region is characterised by approximately similar profiles within an acceptable level of variation that is typical for fancy yarns. This region is preceded by an initial region that has fancy bouclé yarns different in terms of size and number from the profiles of the second stable regions.

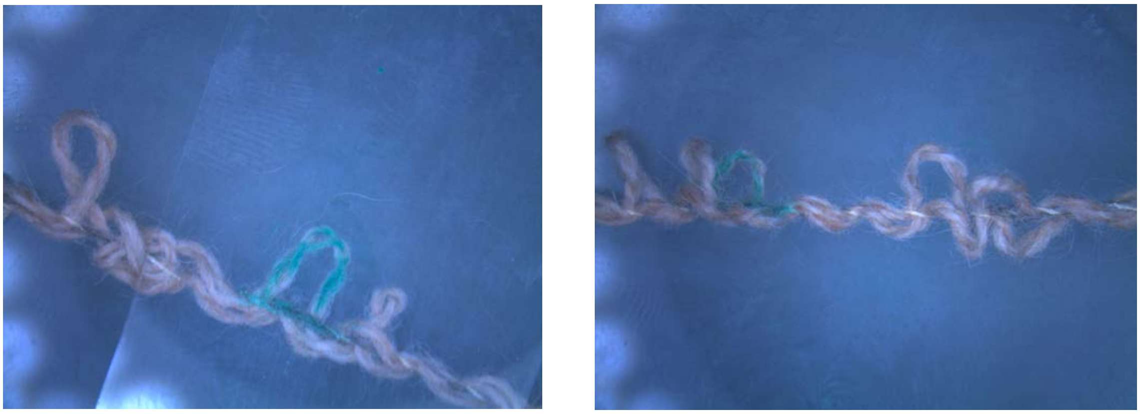
Dynamically, the effect thread segment within the spinning triangle is subjected to internal and external forces. The main internal forces are bending force and tension. The tension may initially have negative values, i.e. compression, at the start-up of the machine because the effect thread is forced forward by the supply rollers. However, once the



Yarn II (1) Yarn II (2)



Yarn II (3) Yarn II (4)



Yarn II (5) Yarn II (6)

Figure 3: Images of bouclé yarns made for Experiment II

Table 4: Numerical results of Experiment II

Fancy yarn	Delivery speed (m/min)	Size of bouclé profile (mm^2)		Number of bouclé profiles (1/dm)	
		Average	SD [a)]	Average	SD [a)]
Yarn II (1)	17	23.11	9.56	9.46	1.59
Yarn II (2)	24	18.45	5.73	11.87	2.50
Yarn II (3)	28	19.00	6.61	12.53	3.182
Yarn II (4)	32	20.89	6.19	12.67	2.28
Yarn II (5)	34	19.34	9.69	11.67	1.72
Yarn II (6)	36	19.90	6.66	12.53	3.638

[a)] Standard deviation

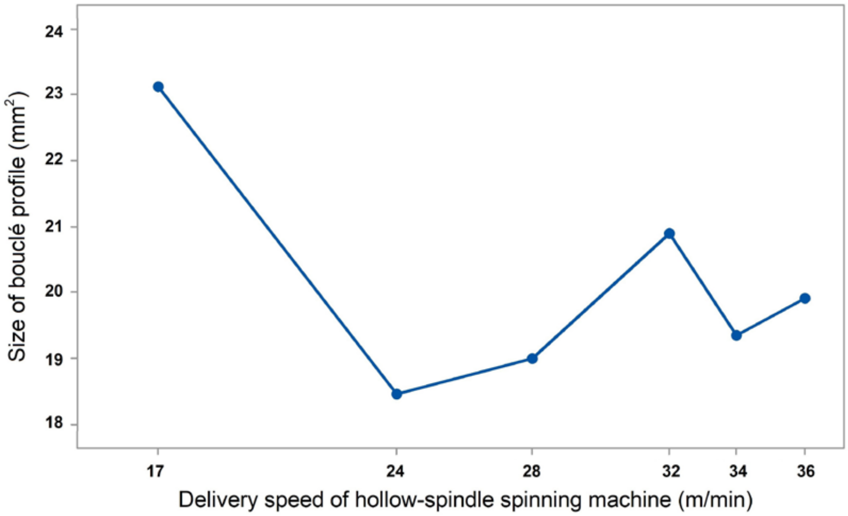


Figure 4: Relationship between the speeds of the hollow-spindle machine and the size of bouclé profiles

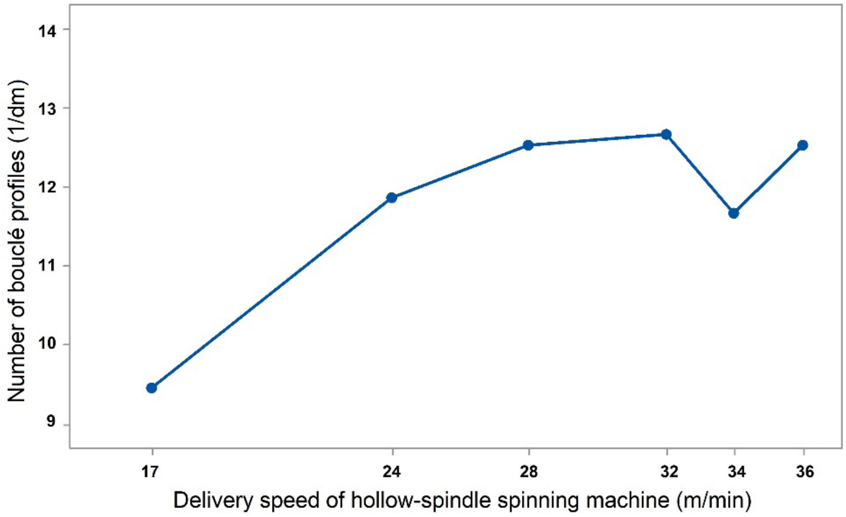


Figure 5: Relationship between the speeds of the hollow-spindle machine and the number of bouclé profiles

rotational speed and thus centrifugal and centripetal forces increase, a positive value of the tension will control the effect thread segment in all locations of the first spinning zone, including the spinning triangle. The main external forces in the spinning triangle are air drag and gravitational force. At the start-up of the machine, gravitational force (G) will be the dominating external force, and the effect-thread segments may fall downwards. As all speeds of the machine increase, air drag appears and comes into effect. Once the rotational speed reaches a specific limit, the effect thread segment starts to rotate around the core thread segment. The result of this is that a new force, called centripetal force, starts to appear and is directed outward from the centre of rotation, while centrifugal force acts in the opposite direction. Starting from this limit, the impact of air drag remains constant, and as such, it may not create substantial changes to the shape of the spinning triangle.

Gravitational force is greater than centripetal force (F_c) at the start-up of the machine. This is confirmed by the following calculations based on an *infinitesimally* small segment dl of the effect thread that has a linear mass m. This yarn segment is subjected to a gravitational force of d$G = mgdl$, where g represents the gravitational acceleration, g = 9806.65 mm/s^2. Due to rotation, this yarn segment is also subjected to centripetal force d$F_c = mr\omega^2$dl, where ω represents angular velocity (measured in radians per second) and r represents the radius of the rotation of this yarn segment. Centripetal force must be greater than gravitational force for a fancy yarn to form, i.e. d$F_c >$ dG or $\mathrm{m}r\omega^2\mathrm{d}l > mg\mathrm{d}l$; thus $r\omega^2 > \mathrm{g}$. Since $\omega = 2\pi RS$, where RS represents rotational speed, therefore $(2\pi RS)^2 > \mathrm{g}$, or:

$$RS > \sqrt{\frac{60\ \mathrm{g}}{2\pi\ r}} \quad (1)$$

where the number 60 is used to convert time from seconds into minutes for the revolutions.

At the start-up of the machine, the radius of rotation r may be equal to the base of the spinning triangle. When r = 4.5 mm, which is the setting used for the first setting of Experiment I, then RS must be > 144 revolution per minute for centripetal force to be greater than gravitational force. Once centripetal force increases, air drag comes into effect. Thus, higher values of centripetal force are required to exceed such a drag. As centripetal force and centrifugal force increase in magnitude, they reach a point where they become the dominating forces and they balance out all other forces. Subsequently, both the spinning triangle and the helical configuration of the effect thread reach the steady-state case. Eventually, a *stable* spinning triangle followed by *stable* effect-thread helices are formed, and the spinning triangle smoothly merges with the top of the effect-thread helical configuration.

Since stable, *similar* helices are formed, regardless of the length of the hypotenuse of the spinning triangle, no changes will occur to their diameter or number within the first spinning zone. This means that the use of the overfeed ratio as a main element in Equation 5 in a previous study [2] remains valid. This Equation is reproduced here as follow:

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

where r represents the radius of helices, n represents their number within the first spinning zone, η represents the theoretical overfeed ratio of the effect thread and L_c represents the length of the core thread within the first spinning zone (which *approximately* equals the length of the first spinning zone).

It is thought that changes in the length of such a hypotenuse, when changing the width of the base, happen mainly at the start-up of the machine and also when changing the speeds of the machine. The case of machine start-up is also similar to the case of running the machine at low speeds. During the start-up time, once the machine reaches the set values of rotational, supply and delivery speeds, the hypotenuse will also be stable for the specific overfeed ratio used. The set values of speeds must be above a certain level to ensure the stability and regularity of both the spinning triangle and the effect thread helices. These results were explained dynamically above.

The result of Experiment II indicate that the spinning triangle was not stable at low production speed, but rather was irregular. This is because of gravity and air drag. These reasons concur with a previous investigation regarding effect-thread helices at low machine speeds, in particular the rotational speed [1, 2]. In some cases where the speeds of the machine are extremely low, the machine fails to make a spinning triangle or effect-thread helices. Consequently, it fails to make multiple-thread-structure fancy bouclé yarns. Due to the similarities in structure with other fancy yarns as described mathematically in one universal geometrical model [5], similar results may be obtained for overfed fancy yarns such as gimp fancy yarns, wavy fancy yarns, generic overfed fancy yarns and all their derivatives.

4 Conclusion

It was concluded that the width of the base of the spinning triangle of hollow-spindle spinning machines had a profound influence on the structure of multi-thread fancy bouclé yarns when such machines run at low production speeds, i.e. ≤ 17 m/min. At these low production speeds, the spinning triangle was unstable. The resulting fancy bouclé yarns thus had an unacceptably low number of profoundly large bouclé profiles, which adversely affected their quality and commercial value. This problem was solved by increasing the production speed to a higher value, i.e. ≥ 24 m/min. At these higher production speeds, the stability of the spinning triangle was improved. This helped in regulating the structure, morphology and style of the resultant multi-thread fancy bouclé yarns. Similar results may be obtained for similar multiple-thread-structure fancy yarns, such as gimp fancy yarns, wavy fancy yarns, generic overfed fancy yarns and all their derivatives. The results of this research can help fancy yarn manufacturers to improve the quality of their yarns and also to avoid the aforementioned unfavourable situations, thus saving them money, effort and time.

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