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

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Structured Abstract

Purpose

This study aims to define the relationships between the structure of multi-thread fancy yarns and the combination of the rotational speed and thickness and stiffness of the effect component.

Design/methodology/approach

To do so, two groups of fancy yarns were made using stiff and soft effect threads and at six different machine settings.

Findings

It was found that a stiff effect thread was suitable to make fancy yarns at low rotational speeds, while the thickness of the effect threads was more important than its stiffness at low number of wraps. Additionally, even when using the same number of wraps and the overfeed ratio, a bouclé yarn, a gimp yarn, a wavy yarn or a loop yarn may results if the thickness and stiffness of the effect thread and the rotational speed were all controlled properly.

Originality/value

This study helps fancy yarn spinners to determine the type of final fancy yarns by controlling the geometry of the first spinning zone.

Key words:

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

1. Introduction

The desire to make distinctive, fashionable fancy yarns created the momentum for inventors to invent new methods for making fancy yarns, such as using the rotor-spinning system to create fancy yarns (Kwasniak and Peterson, 1997, Pouresfandiari, 2003). It also gave momentum to researchers to conduct studies on the technologies, already available in the market and can be used to make fancy yarns. Those researchers helped providing a better understanding of those technologies and published new findings about the influence of the technological factors of the machines on the related fancy yarns. Some of those studies were conducted on the hollow-spindle system to study one factor at a time (Alshukur and Sun, 2016, Alshukur and Fotheringham, 2014, Baoyu and Oxenham, 1994, Lawrence et al., 1985), two factors or combination of factors at one time (Petrulyte and Petrulis, 2014, Ragaisiene, 2009a, Ragaisiene, 2009b, Alshukur and Fotheringham, 2015); others were conducted on the ring system (Grabowska, 2010, Grabowska et al., 2006) or the combined system (Nergis and Candan, 2007).

Due to the high number of fancy yarns available commercially and the absence of standards to assess them objectively, the quality and the structure of fancy yarns were the subject of a study published recently (Alshukur, 2013a). This study established new and universal methods and concepts, called the quality parameters of fancy yarns, to quantify and assess the structure and quality of several types of fancy yarns objectively. Those fancy yarns can be loop yarns, bouclé yarns, button yarns, knop yarns, slub yarns, eccentric yarns, cloud yarns, stripe yarns, snarl yarns, tape yarns, gimp yarns, nepp yarns and all derivatives of such fancy yarns. Those quality parameters of fancy yarn were the Size (or Area) of Fancy Profile, the Number of Fancy Profiles, the Circularity Ratio of Fancy Profile, the Shape Factor of Fancy Yarn and the Relative Shape Index of Fancy Yarn (Alshukur, 2013a). Those concepts were applied on several types of fancy yarns and on several studies (Alshukur, 2013b, Alshukur and Fotheringham, 2014, Alshukur and Fotheringham, 2015, Alshukur and Sun, 2016).

Recently, a new study was published to provide an analytical understanding to the structure of several types of multi-thread fancy yarns (Alshukur and Gong, 2017). Due to its importance, however, providing analytical understanding to fancy yarn manufacture and the technologies used to make them (Pouresfandiari, 2003, Matsumoto et al., August 2002) is more useful than merely statistical studies. So, this study was conducted to study the spinning zone of hollow-spindle machines analytically. In Part I of this article, the influence of the overfeed ratio and the rotational speed on the spinning geometry of the multi-thread fancy yarn, the formation of helices from the effect thread and the influence of the rotational speed on the structure of those fancy yarns were revealed. To complete this research, Part II of this article was conducted to understand the influence of the rotational speed and thickness and stiffness of the effect thread on the fancy yarn structure.

2. Machine Settings, Materials and Methods

In this experiment (IV), the supply speed (SS) = 50 m/min while the delivery speed

(DS) =30 m/min, so the overfeed ratio η=50/30=1.66 (i.e. η%=166%). The values of the rotational speed (RS) increased incrementally from 3000 to 8000 rpm as shown in Table 1. So, the number of wraps (W) changed, according to the changes made to RS, from 100 to 266 wpm. Two groups of fancy yarns were made to show the influence of stiffness and thickness of the effect thread on the results. For those two groups, the core thread was a 67 tex spun thread of mixed fibres, i.e. wool/angora/polyamide (60%/20%/20%). The binder thread was a nylon multi-filament (14.5 tex/77).

The effect component used to make Group I of fancy yarns was a 83 tex lambswool thread. It had an average value of bending stiffness B=0.711 g·mm^2 and a standard deviation SD=0.318 g·mm^2. These values of bending stiffness were measured by considering the thread as a beam bending under its own weight. In Group II of fancy yarns, the effect component was a wool plied thread of linear density R118 tex/2. Its bending rigidity was B=4.20 g·mm^2 and SD=1.13 g·mm^2. The input threads were stored in standard atmospheric conditions to reduce the influence of moisture content and temperature.

The resulting fancy yarns 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, 2013b, Alshukur, 2013a). 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 structure of the fancy yarn was assessed using the size and number of fancy profiles. The fancy profiles, which were measured, were bouclé profiles, loops and semi-bouclé profiles (i.e. elongated loops, u-shaped profiles and sinusoidal, narrow wavy profiles). The size of fancy profile was measured using digital image software (AnalySIS FIVE) which was associated with a digital microscope.

3. Results and Discussion

The observations and comments about the first spinning zone are shown in Table 1. One important observation was the inability of both effect threads, the thin and the thick, to make any fancy yarn at the first machine setting. Another important observation was the inability of the thinner, softer effect thread (83 tex lambswool) to make a fancy yarn at the second machine setting. The yarns made are shown in Figure 1. This figure also shows that the wraps of the fancy yarn made at machine setting 6 were excessive, in particular for yarn II-6 which had the thick effect component. Table 2 gives the numerical results of testing all fancy yarns. Those results were shown in Figure 2, Figure 3, and Figure 4 for ease of comparison.

Figure 2 shows that the size of fancy profile decreased with increasing the rotational speed. It also decreased by increasing the thickness of the effect thread. Further, Figure 3 shows that the variation in the size of fancy profile had a negative relationship with the rotational speed as shown in Figure 3. Furthermore, excessively high variability in the area of fancy profile resulted when using the thin effect thread and RS=5000 rpm (yarn I-5). However, the difference in thickness of the input effect threads did not affect this variability at higher levels of the rotational speed. Figure 4 shows that increasing the rotational speed resulted in increasing the number of fancy profiles. So, the reduction in the size of the profiles was a result of the increase in their number when the rotational speed was increased. Figure 4 also shows that except for RS ≥ 7000 rpm, the thicker effect thread resulted in more fancy profiles than the thinner effect thread.

Those results were understood technologically as follows. The failure of the effect thread to form helices in the first spinning zone meant the inability to make a fancy yarn. Both effect threads failed to form helices at RS= 3000 rpm as they flexed and fell down due to gravity. They formed extremely large and irregular arcs. Further, the whirling of the arcs, because of the rotational motion, was not regular.

Dynamically, each thread section was subject to several forces. These forces were the gravitational force (G), air drag (A) and the centripetal force (F_c). Further, in the steady-state rotation, the centrifugal force was balanced by the centripetal force. G results from the weight of the effect thread section in the spinning zone. The rotational motion causes F_c. The value of this force depends on the mass of these thread sections, radius of the thread helix and rotational speed. Air drag is related to several factors, amongst which are mass and inertia of the thread. The impact of gravitational force and air drag at RS=3000 rpm was stronger than the centripetal force; otherwise the effect threads would not have fallen down to form large arcs. Instead, they would have formed helices. Air drag was also responsible for the uneven whirling of the arcs. Consequently, taking into account the materials used, RS = 3000 rpm was not suitable to make any type of fancy yarn. When RS=4000 rpm the thin, soft effect thread in Group I flexed more than required and collapsed due to gravity. Therefore, no helices and no fancy yarns resulted. In contrast, the effect thread of Group II was thicker and stiffer, thus its stiffness prevented it from flexing toward the ground. Instead, approximately 4 helices have formed from it; thus, a fancy yarn has formed.

The calculations proved that F_c was greater than G as follows. Considering an infinitesimally small section *dl* of the effect thread, having a linear mass *m*. Initially, it was required to compare its weight G (gravitational force) with the F_c. Since $dG=mgdl$ while $dF_c=mr\omega^2 dl$ and for simplicity, it was easier to compare the gravitational acceleration $g=9.80665\ m/s^2$ with the centripetal acceleration $a_c= r\omega^2$. $\omega=2\pi RS$ is the angular velocity (measured in radians per second). The radius r was calculated depending on Equation 5 of Part I of this article, and it was $r = \frac{40\sqrt{1.66^2-1}}{2\pi\times 4} = 2.11$ mm. Therefore, $a_c = 2.11(2\pi\times 4000/60)^2 = 370518\ mm/s^2 >> 9806.65\ mm/s^2$. Consequently, the gravitational force was neglected. For simplicity, air drag was also neglected at this stage of investigation.

Considering Figure 2 and Figure 4, the fancy yarns made using the thinner and softer effect thread resulted in a lower number of larger fancy profiles comparing with the thicker and stiffer effect thread. The differences in those fancy yarn qualities for the two groups of fancy yarns were related to the differences in the number of helices in the spinning zone. Such a number was always greater for the stiffer effect thread, whenever RS < 7000 rpm which made the helices touching the core thread. Since $F_c >> G$, G was neglected. The key force was thus the centripetal force. The higher the mass of the effect-thread section (in the spinning zone) the higher the centripetal force. It has been shown that the narrower helices were always associated with higher number of helices (reference to Part I of this article). Consequently, the heavier effect thread had been subjected to higher F_c which made more narrow helices, in comparison with the lighter effect thread. Such a relationship was true up to a critical level of the rotational speed (RS≈7000 rpm for this experiment) where it started to change. At this level, there was a cross over in the visual trends, in particular the trends of number of fancy profiles (Figure 4). The reasons for the change in the trends were thought to be as follow: the overfeed ratio was relatively low, i.e. $\eta=166$ % and it was insufficient to make relatively wider helices at the high levels of RS. The helices at these high levels of RS were touching the core thread, thus could no longer be any narrower. When the effect helices became touching the core thread, the thinner effect thread made helices having a narrower radius, even when the number of helices was similar to that of the stiffer and thicker effect thread. Consequently, relatively smaller fancy profiles resulted from a thinner effect thread at high rotational speeds.

It was shown that the number of helices was not stable for the thicker, stiffer effect thread. These changes may have been related to local variability of bending stiffness of this thread. This thread was a two-plied thread and its cross-section had distinctive length and width. The value of bending stiffness changes according to the direction of bending (i.e. the length or width of the cross-section). The value of bending stiffness is high if it is measured in the length of the cross-section. However, it is lower when considering the width of the same cross-section. These changes are related to the differences in the value of the second moment of inertia (I) of the cross-section. While making the fancy yarns, on a hollow spindle machine, the plied effect thread randomly changes the spatial direction of its cross-section. This thread bends more in the direction of width of its cross-section, thus it may form more helices. The opposite happens when the effect thread bends in the direction of length of its cross-section, thus it may form lower number of helices.

The variation in the size of fancy profile decreased when RS was increasing (Figure 3). At RS≥6000 rpm, the variability in the size of any profile was approximately similar to both groups of fancy yarns. These changes were related to the changes made to W. Since W was allowed to change with RS in this experiment, high W corresponded to high level of RS. When there were more wraps, the distance between the wraps became shorter. This may reduce the space margin available for the bases of fancy profiles to form. Consequently, lower variation in the Size of Fancy Profile has resulted.

4. Conclusions

Based on the materials, machine settings, and the results of the previous experiment, it was concluded that:

- stiffer effect threads were suitable to make multi-thread fancy yarns at lower rotational speed of 3000 rpm when a softer thread was incapable of doing so.
- when the number of wraps was not excessive, the thickness of the effect thread was more important than its stiffness to define the type of the effect profiles. For example, a thin effect thread resulted in a lower number of large fancy projections.
- when the number of wraps became excessively high, the contributions of the thickness and stiffness of the effect threads, to the structure of multi-thread fancy yarn, became negligible.
- types of the fancy yarn made was related to characteristics of the effect-thread helices as follow:
  - when the helices were touching to the core thread, a spiral yarn has resulted.
  - when the helices were slightly apart from the core thread and not touching it, and the distance between them was less than a diameter of the effect thread, a gimp yarn has resulted.
  - when the helices were not touching to the core thread, and the distance between them was more than a diameter of the effect thread, a bouclé yarn has resulted.

- when there was small loop formation from the effect thread in the first spinning zone, a loop yarn has resulted. However,
- when there was large loop formation in the first spinning zone, a defective bouclé yarn structure has resulted due to extremely large and circular-shaped projections. The number of the defects was related to the number of the loops while the size of the loops defined the size of the defects.

- at excessively high rotational speeds it became difficult to make a bouclé yarn, for a specific overfeed ratio, due to the changes in the effect-thread helices in the first spinning zone. There were several types of fancy yarn which resulted, i.e. gimp yarns, spiral yarns, wavy yarns or overfed fancy yarns. However, to make a bouclé yarn, a possible solution to this problem is to increase the overfeed ratio. However, increasing the overfeed ratio makes heavier fancy yarns and increases the costs. It may also affect the quality of the product negatively. Therefore, the fancy yarn manufacturer needs to strike balance between costs, quality and the specifications of the fancy yarns.

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Tables

Table 1: Machine Settings and Observations Related to this Article

DS=30m/min, SS=50 m/min				
Machine settings	**Rotational speed RS rpm**	**Number of wraps wpm**	**Group I : lambswool 83 tex B=0.711 g·mm^2**	**Group II : wool R118tex/2 B=4.20 g·mm^2**
1	3000	100	No regular formation of helices- no fancy yarns	No regular formation of helices- no fancy yarns
2	4000	133	No regular formation of helices- no fancy yarns	4 or 4.5 regular helices
3	5000	166	3 or 4 helices and formation of large loops	6 or 6.5 regular helices and slight wobbling of the core thread
4	6000	200	Wobbling of the core thread; 7 narrower helices	8 or 8.5 regular helices and slight wobbling of the core thread
5	7000	233	Wobbling of the core thread, 9 helices	Wobbling or ballooning of the core thread; helices were 9, 9.5 or 10
6	8000	266	Wobbling of the core thread; number of helices was approximated to 10	Ballooning of the core thread; number of helices was approximated to 10

Table 2: The Numerical Results of Testing the Fancy Yarns of this Article

Machine Settings	Number of helices in the first spinning zone (40 mm)		Mean (and SD) Size of Fancy Profile, mm^2		Mean (and SD) Number of Fancy Profile per (dm^{-1})	
	Group I	Group II	Group I	Group II	Group I	Group II
1	0	0	*	*	*	*
2	0	4 or 4.5	*	20.98 (8.64)	*	5.53 (1.12)
3	3 or 4	6 or 6.5	23.90 (21.91)	14.13 (5.10)	4.6 (1.35)	7.2 (1.14)
4	7	8 or 8.5	12.55 (3.49)	9.86 (4.34)	6.33 (1.34)	8.26 (1.38)
5	9	9; 9.5 or 10	10.83 (2.63)	8.70 (2.57)	8.33 (1.29)	8.4 (1.35)
6	approximated to 10	approximated to 10	8.08 (1.93)	8.45 (1.57)	9.2 (1.52)	9 (1.31)

Figures

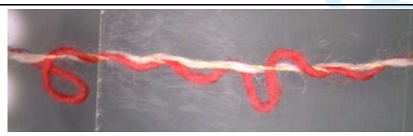
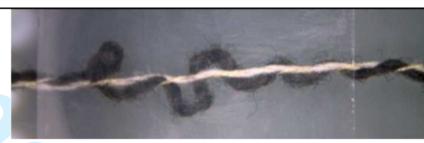
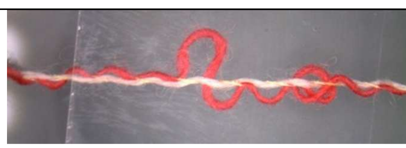
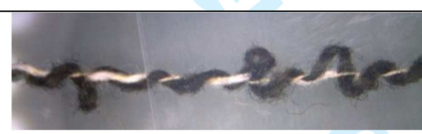
Machine setting	Group I	Group II
2		 Yarn II-2
3	 Yarn I-3	 Yarn II-3
4	 Yarn I-4	 Yarn II-4
5	 Yarn I-5	 Yarn II-5
6	 Yarn I-6	 Yarn II-6

Figure 1: Images of the Fancy Yarns for the Two Groups of Effect Threads of this Article

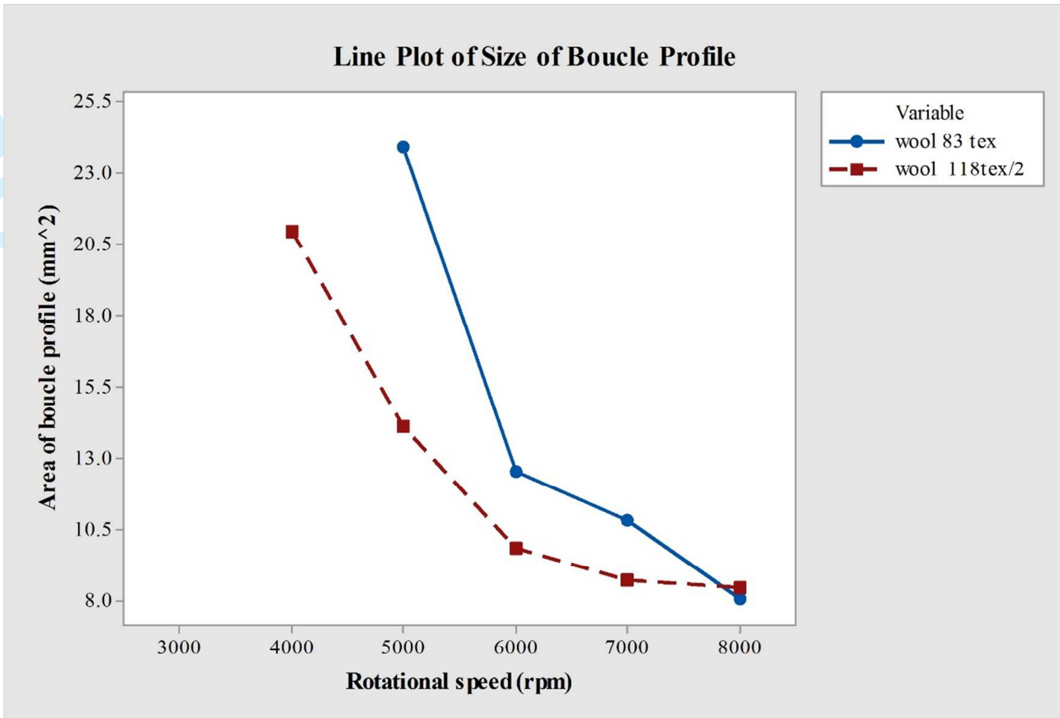


Figure 2: Influence of the Rotational Speed and Thickness of the Effect Thread on Size of Fancy Profile

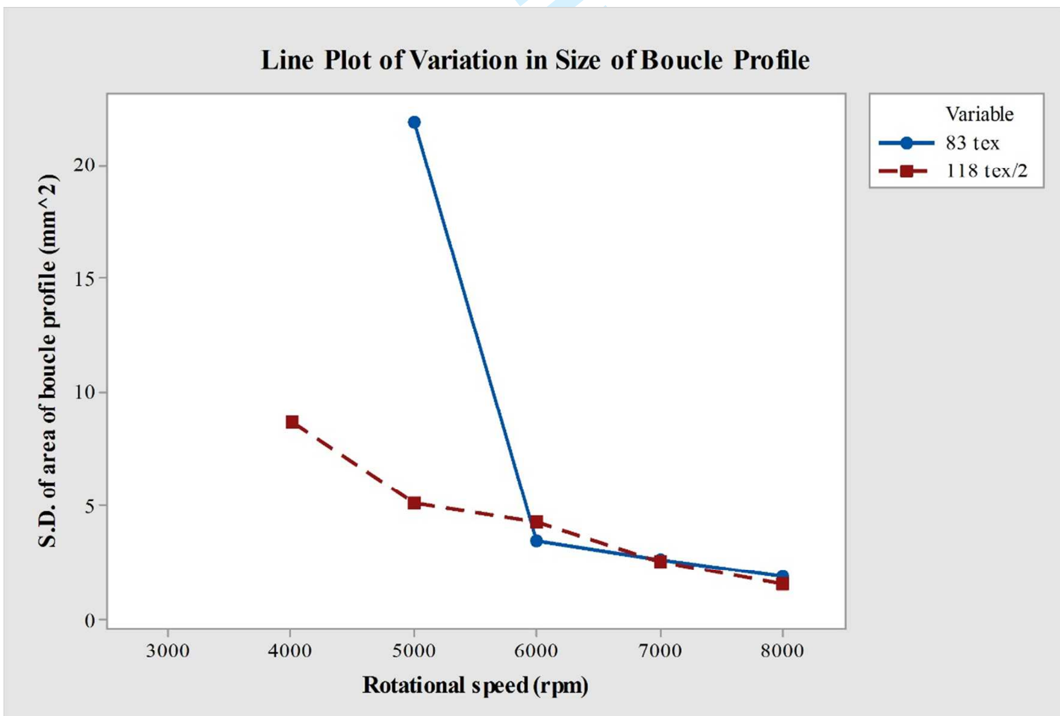


Figure 3: Influence of the Rotational Speed and Thickness of the Effect Thread on the Variation in Size of Fancy Profile

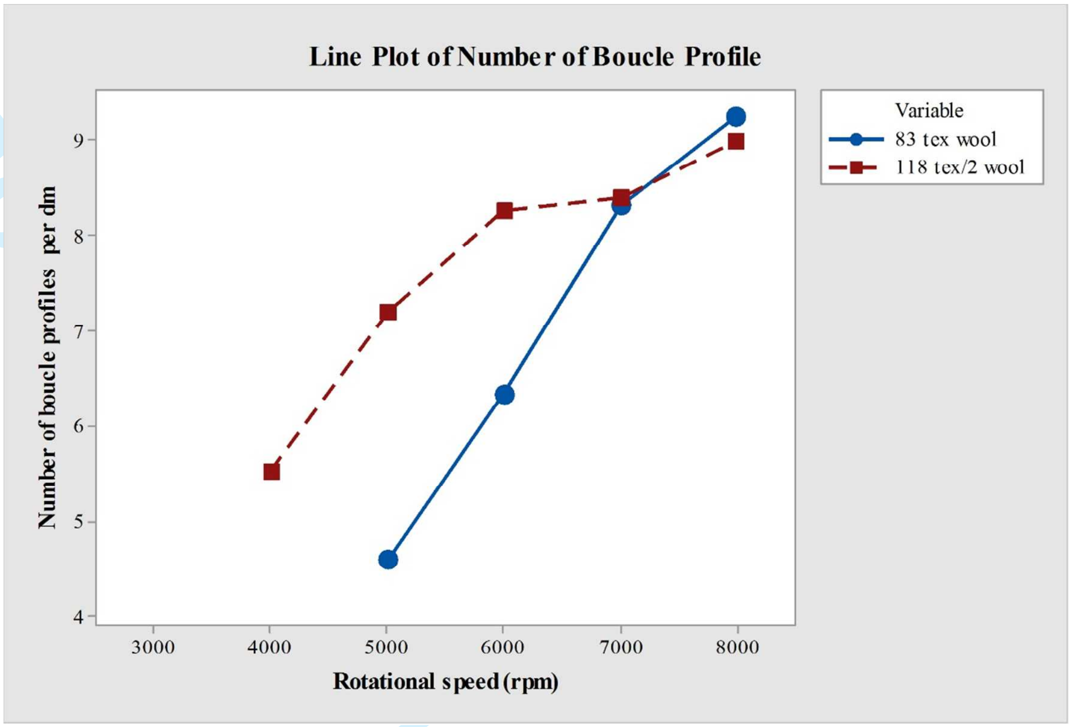


Figure 4: Influence of the Rotational Speed and Thickness of the Effect Thread on Number of Fancy Profiles