The Journal of The Textile Institute

ISSN: 0040-5000 (Print) 1754-2340 (Online) Journal homepage: https://www.tandfonline.com/loi/tjti20

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THE JOURNAL OF THE TEXTILE INSTITUTE
2019, VOL. 110, NO. 5, 671–679
https://doi.org/10.1080/00405000.2018.1511227

Dynamic analysis of spinning triangle geometry part 2: spinning triangle geometry and yarn quality

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ABSTRACT

This paper examines empirical relationships between the geometrical parameters of the spinning triangle and the quality parameters of ring spun yarns. For this purpose, controlled variations in the geometry of the spinning triangle were induced using two existing modifications in the ring spinning process and by varying the yarn twist level. The geometrical parameters of the spinning triangle were measured using the clear rubber roller combined with digital image processing techniques as described in the first part of this study. The yarn quality parameters measured included yarn hairiness, strength, elongation and evenness. Yarn hairiness showed more noticeable sensitivity towards the physical shape of the spinning triangle than yarn tenacity, while yarn evenness and elongation were not significantly influenced by changes in spinning triangle geometry.

ARTICLE HISTORY
Received 11 February 2018
Accepted 8 August 2018

KEYWORDS
Spinning triangle; ring spinning; image processing; yarn quality; yarn hairiness

Introduction

The quest to improve yarn quality in order to produce aesthetically superior and durable clothes has led to various developments in the classical ring spinning process especially in the last two decades (Lawrence, 2010; Xia & Xu, 2013). Some of these modifications, such as compact spinning and offset spinning, can significantly improve yarn quality, particularly in terms of yarn hairiness (Lawrence, 2010; Wang & Chang, 2003). Other proposed modifications such as introduction of a contact surface, mingling chamber in the drafting zone and grooved bottom rollers did not achieve consistent and marked improvements in yarn quality and remained experimental endeavours (Alamdar-Yazdi, 2011; Aslam, Lamb, & Wang, 2013; Murugan, Vigneswaran, & Ghosh, 2011; Xia, Xu, Zhang, Qiu, & Feng, 2012). Interestingly, almost all modifications made to the classical ring spinning process to improve yarn quality also affected the physical geometry of the spinning triangle, irrespective of their commercial performance. For example, compact spinning narrowed the width of the spinning triangle, and offset spinning changed its angles. These modifications indicate the strong relationship between the physical geometry of the spinning triangle and the quality of the yarns produced.

Surprisingly, even the qualitative relationship between the spinning triangle and yarn quality has not been established although both spinning triangle and yarn quality are well-researched areas. One reason of this knowledge gap is inability to physically observe and measure the geometry of the spinning triangle as most of studies in this area focused on developing various models to understand the behaviour of the spinning triangle (Mahdiyeh & Esfandiyar, 2014). These models usually assume an idealised spinning triangle so that the spinning stress distribution at the spinning triangle zone could be computed. It is important to understand that the spinning triangle acts as a control point for delivering fibres into a yarn. The angles and positions of the fibres at which they enter into a yarn will affect their subsequent arrangement within the yarn structure, which then influences its physical properties (or quality parameters). As the geometry of the spinning triangle is an overall representation of angles and positions of the fibres inside it, a comprehensive understanding of these in relationship to yarn quality is essential to produce superior quality yarns.

In order to explore relationships between the physical geometry of the spinning triangle and yarn quality parameters, a simple three step approach was followed. The spinning triangle geometry could be varied in a controlled manner, followed by measurement of variations in its geometrical parameters and analysing the effects of those controlled variations on resultant yarn quality. As the spinning triangle is a fragile transition zone constrained between the nip of the drafting rollers, it is practically challenging to introduce precise controls on its geometry. Any intrusive modification at the spinning triangle zone could affect the fibre arrangement inside it leading to excessive end breakages. However, one possibility to control the spinning triangle geometry is to make use of those ring spinning modifications that are known for their influences on the physical geometry of the spinning triangle. For example, compact and diagonal offset spinning could be used to control the width and the angles of the spinning triangle, respectively (Wang & Chang, 2003). Similarly, varying the amount of yarn twist could influence the height of the

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Table 1. Full factorial design of experiment for three nominated variables and their associated levels.

S.no	Yarn twist	Compact spinning	Horizontal offsetting
1	KT	HC	NO
2	WT	HC	LO
3	WT	LC	LO
4	WT	NC	RO
5	KT	HC	LO
6	WT	LC	RO
7	KT	LC	RO
8	KT	HC	RO
9	WT	HC	RO
10	WT	LC	NO
11	WT	NC	LO
12	KT	NC	NO
13	KT	LC	LO
14	KT	LC	NO
15	KT	NC	RO
16	KT	NC	LO
17	WT	NC	NO
18	WT	HC	NO

spinning triangle (Hua, Tao, Cheng, & Xu, 2007). The variations in the spinning triangle geometry will be measured by the clear rubber roller method described in the first part of this study. Finally, the quality parameters of the yarns produced with different physical configurations of the spinning triangle will be evaluated through established yarn testing protocols. The effects of the geometrical parameters of the spinning triangle on resultant yarn quality parameters will be analysed by statistical correlation and analysis techniques.

Materials and methods

Yarn spinning

Three variables namely yarn twist, diagonal horizontal offsetting and fibre compacting were varied to influence the height, angles and width of the spinning triangle, respectively. Yarn twist was varied in two levels, i.e. 1108 (WT) and 1032 (KT) TPM (Z direction), respectively. The yarn twist range was narrow as per the availability of the ring spinning frame. Diagonal offsetting was varied in three levels, i.e. left offset (LO), right offset (RO) and no offset (NO). The offsetting arrangement was achieved by threading and spinning the yarns through left or right adjacent spindles. Fibre compacting using a Suessen Elite® CompactSet (Suessen, Germany) attachment with variable air suction control was used to assess three levels, i.e. high pressure compacting (HC), low pressure compacting (LC) and no compacting (NC). The low and the high compacting pressures were achieved by varying the air suction level while no compact yarns (NC) were produced in the classical ring spinning arrangement without a compact spinning attachment. A full factorial design of experiment was proposed to vary the spinning triangle geometry based on the nominated variables and their associated levels as shown in Table 1. A total of 18 yarn specimens of 12 tex linear density were produced according to the proposed design of experiment. Yarns were produced from 100% Australian combed cotton rovings (upper half mean length 31.5 mm, 4.5 Micronaire) of 724 tex linear density and 42 TPM twist level. Yarn spinning was carried out at 10,600 rpm spinning speed on an industrial scale Zinser 350 ring frame

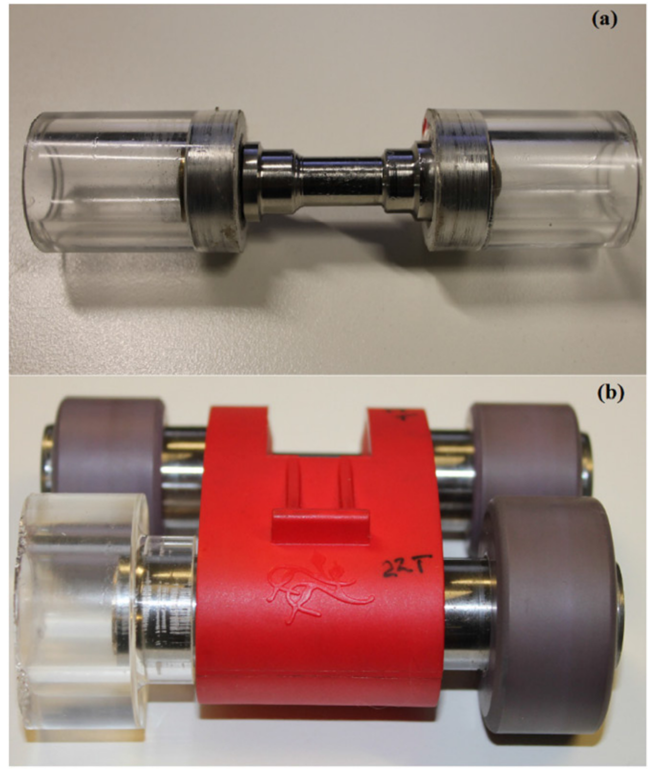

Figure 1. Clear rubber roller for (a) normal ring spinning (b) compact spinning arrangement.

(Saurer, Switzerland). A spinning ring of 45/42 mm (outside/inside) diameter with a traveller number 36 was used. The temperature and relative humidity in the spinning shed were 25 °C and 55%, respectively.

Spinning triangle measurement

The spinning triangle images were recorded using the clear rubber roller and associated image acquisition setup, as discussed in the first part of this study. Two different clear rubber rollers for regular ring spinning and compact spinning arrangements were employed for this purpose, which are shown in Figure 1. The clear rubber roller for compact spinning was made in the similar way as the clear rubber roller for ring spinning was developed. The diameter of clear compact spinning roller was 40 mm. The spinning triangle images for each experimental run were recorded in the same way as described in the first part of this study.

Yarn quality testing

The yarn specimens produced in accordance with the experimental matrix were subjected to testing to evaluate four important quality parameters, i.e. yarn hairiness, tensile strength, elongation and evenness. Uster evenness tester with OH module (hairiness), Uster Zweigle hairiness tester and Uster Tensorapid were used for this purpose. The specifications of yarn testing procedures in terms of the number of samples, sample length and other important testing parameters are given in Table 2. All yarn samples were conditioned for at least 24 h before testing in the standard lab

Table 2. Yarn testing specifications.

Equipment	Model	Sub samples	Within samples	Pre tension (cN/tex)	Test speed (m/min)	Test time (min)	Yarn length (m)
Uster tester	UT4	1	5	–	400	5	2000
Uster Zweigle hairiness tester	HL400	1	5	–	400	5	2000
Uster Tensorapid	Uster Tensorapid 4	1	50	6	5	–	25 (50 × 0.5)

Table 3. Results of geometrical parameters of the spinning triangle and quality parameters of ring spun yarns.

	Spinning triangle geometry				Yarn quality				
Yarn sample ID	Width (mm)	Height (mm)	Left angle (degrees)	Right angle (degrees)	Tenacity (cN/tex)	Elongation (%age)	Zweigle S3	Uster H	Uster CV_m (%age)
KT-HC-NO	0.84	1.20	72.86	67.64	15.35	5.8	65.8	3.41	16.29
WT-HC-LO	1.15	1.69	81.29	62.06	16.6	6.49	80	3.36	16.23
WT-LC-LO	1.20	1.71	81.45	60.87	13.09	5.29	77	3.26	16.34
WT-NC-RO	3.14	3.23	49.37	80.71	14.73	5.74	395	4.11	16.53
KT-HC-LO	0.96	1.67	81.87	66.54	16.02	5.87	61	3.17	16.16
WT-LC-RO	1.24	1.42	56.65	77.06	13.69	5.74	107	3.05	16.4
KT-LC-RO	1.10	1.62	63.95	78.61	14.23	5.58	218	3.4	17.67
KT-HC-RO	0.97	1.70	66.00	82.58	15.63	5.64	157	3.46	16.28
WT-HC-RO	1.08	1.53	61.46	80.31	16.38	6.33	68	3.27	19.53
WT-LC-NO	1.16	1.22	68.93	59.40	14.26	5.26	63	3.52	16.01
WT-NC-LO	2.88	2.81	77.22	47.28	13.06	5.3	407	3.99	16.67
KT-NC-NO	2.88	4.43	77.19	66.74	14.87	5.65	426	4.18	15.97
KT-LC-LO	1.06	1.74	81.98	64.95	15.22	5.83	91	3.33	17.26
KT-LC-NO	0.93	1.22	71.87	65.60	12.9	4.99	140	3.58	17.14
KT-NC-RO	3.02	3.83	55.05	83.39	14.41	5.53	431	4.23	16.49
KT-NC-LO	2.88	3.03	80.94	47.69	13.52	5.33	443	4.09	16.55
WT-NC-NO	3.07	4.24	73.96	66.55	14.03	5.65	409	3.96	15.96
WT-HC-NO	0.98	1.11	69.81	61.82	14.2	5.55	115	3.37	17.7

Note. Superior yarn quality parameters are shaded in green colour while inferior yarn quality parameters are shaded in red colour.

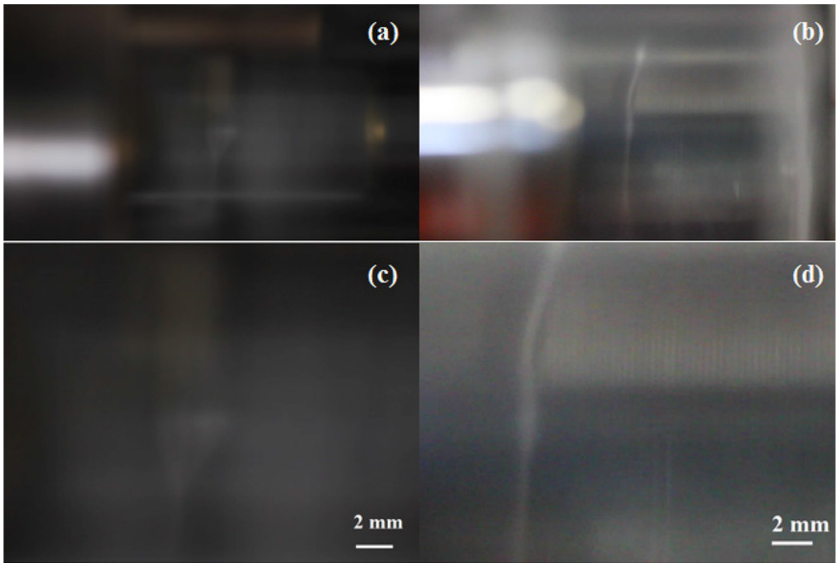

Figure 2. Spinning triangle image acquired through (a) clear rubber roller in classical spinning arrangement (b) clear compact roller in compact spinning arrangement (c) magnified image of the classical ring spinning triangle (d) magnified image of the compact spinning triangle.

conditions (i.e. 20 ± 1 °C temperature and 65 ± 2% relative humidity).

Results and discussion

The geometrical parameters of the spinning triangle and quality parameters of the yarns that were produced according to an experimental matrix and measured by digital image processing and yarn quality testing, respectively, are given in Table 3. The presented values of the geometrical parameters of the spinning triangle are an average of 7500 individual observations while the values of the yarn quality parameters are an average of total number of yarn specimens selected, as given in Table 2. The yarns have been referred to in a standard format, i.e. yarn twist- compacting level- diagonal offset. For example, the first experimental run was abbreviated as KT-HC-NO, which referred to the particular yarn produced with knitting twist (KT), high compacting pressure (HC) and no horizontal offset (NO).

It can be observed from the results in Table 3 that different parameters from both data sets (i.e. spinning triangle geometry and yarn quality) showed a good range of variation and contrast in their values. For example, the width of

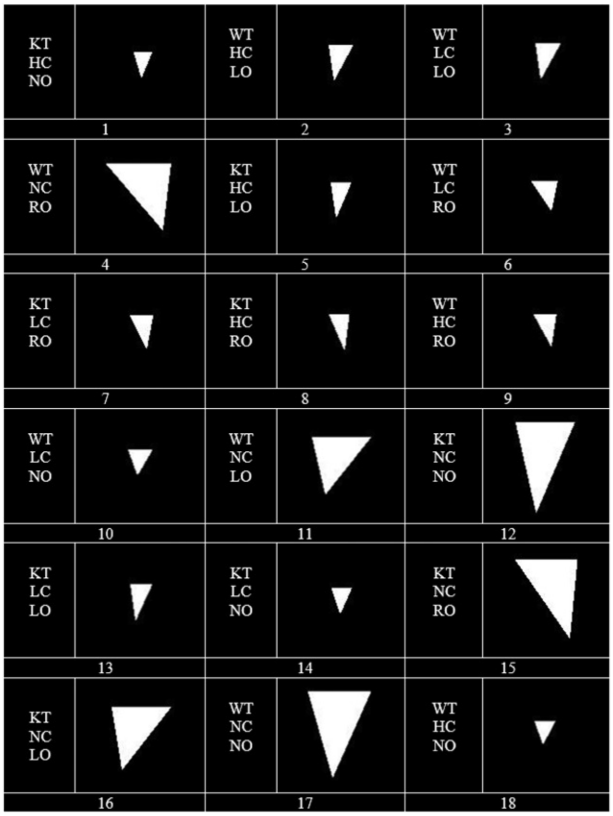

Figure 3. Scaled visual representation of the simulated spinning triangle geometries.

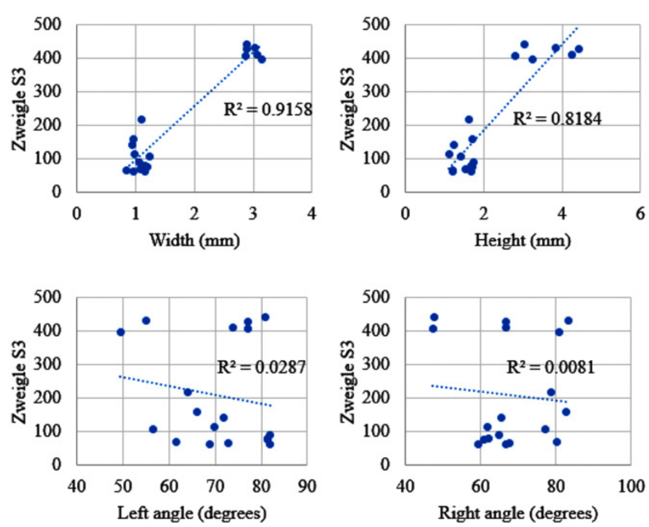

Figure 4. Scatter plots of Zweigle S3 yarn hairiness versus (a) width (b) height (c) left angle and (d) right angle of the spinning triangle.

the spinning triangle ranged from 0.84 mm to 3.14 mm while the left angle ranged from 49.37° to 81.98°. The extent of variation in the spinning triangle geometry indicated that the nominated process variables, i.e. offsetting, compacting and twist level had clearly influenced the spinning triangle geometry, as intended. Similarly, the yarn quality parameters also exhibited noticeable variations such as yarn strength ranged from 12.9 cN/tex to 16.6 cN/tex while S3 value of yarn hairiness ranged from 61 to 443. This supports the idea that mere variations in the shape or geometry of the

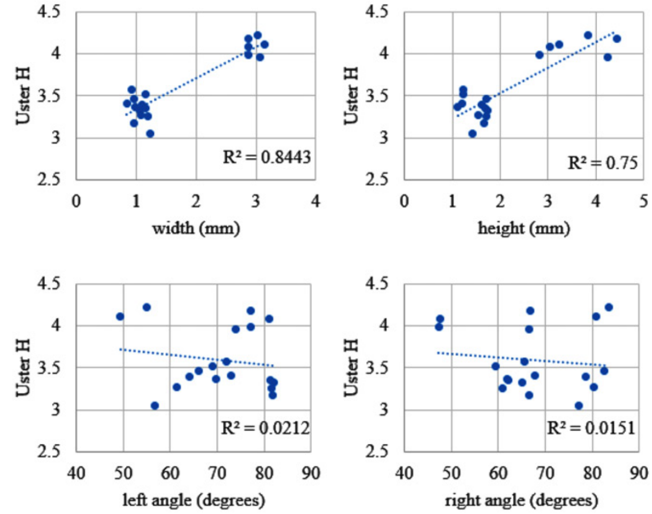

Figure 5. Scatter plots of Uster H index yarn hairiness versus (a) width (b) height (c) left angle and (d) right angle of the spinning triangle.

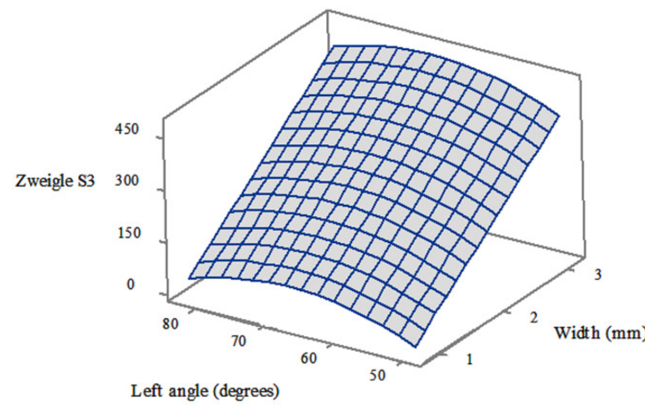

Figure 6. Surface plot of two geometrical parameters of the spinning triangle versus S3 value of yarn hairiness.

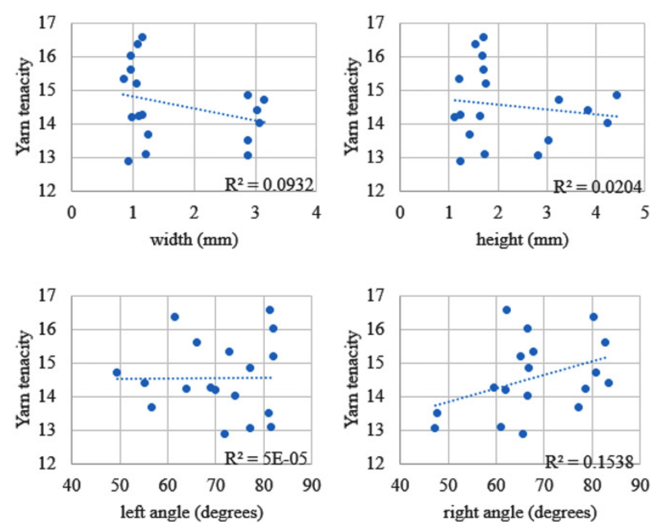

Figure 7. Scatter plots of yarn tenacity versus (a) width (b) height (c) left angle and (d) right angle of the spinning triangle.

spinning triangle could affect yarn quality (Klein, 1986; Lawrence, 2010). For each yarn quality parameter in Table 3, the high quality yarns are shaded in green while the low quality yarns are shaded in red.

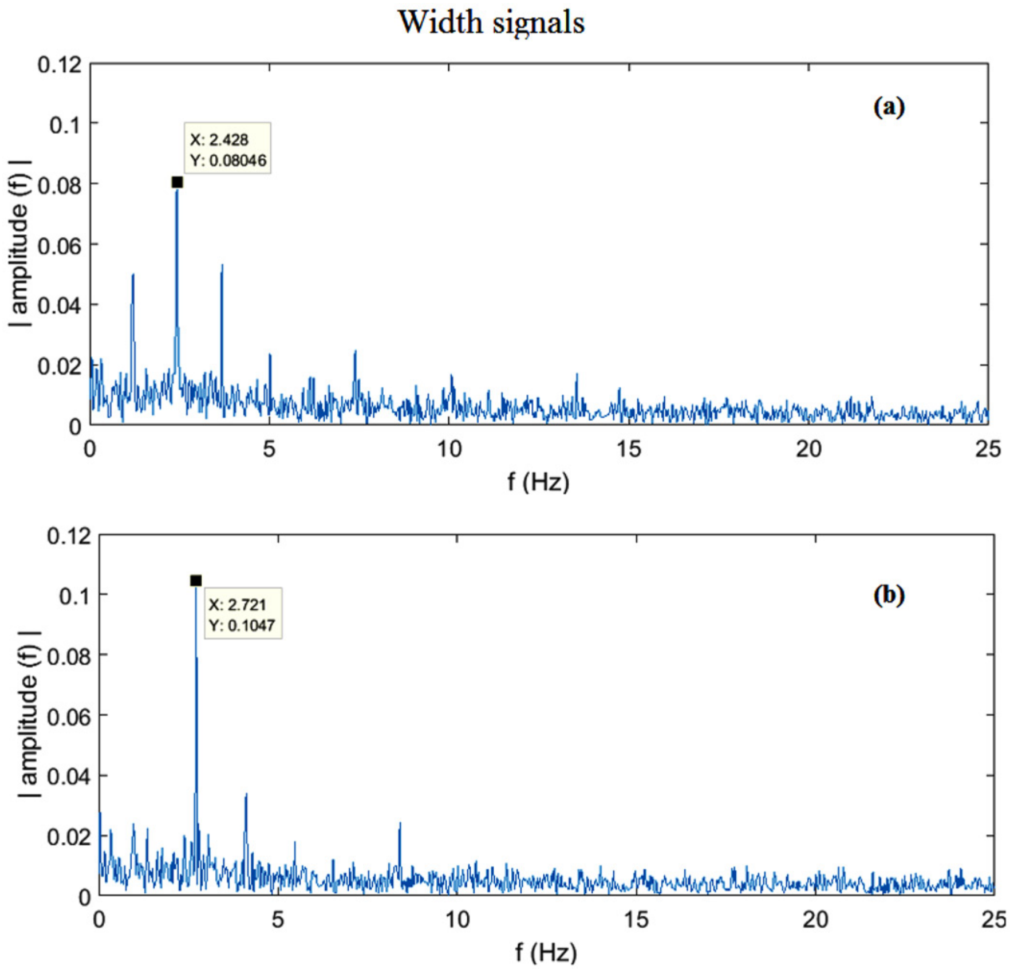

Figure 8. Fourier transformation of 30-s long signal of width of the spinning triangle for (a) WT-HC-LO yarn (b) KT-LC-NO yarn.

It is also interesting to note that not a single yarn specimen possessed overall best quality, i.e. superior value for each quality parameter. For example, WT-NC-NO showed the highest uniformity but it was not the strongest yarn among the group. Similarly, WT-HC-LO showed the highest yarn strength and elongation while KT-HC-LO exhibited the least hairiness in terms of S3 value. KT-HC-LO, which possessed the least S3 value of yarn hairiness as measured on Zweigle hairiness tester, did not exhibit the minimum hairiness in terms of H index when tested on Uster tester. This probably points towards the established discrepancy between both hairiness equipment (Haleem & Wang, 2013).

Figure 2 shows two typical images of the spinning triangle acquired using the clear rubber roller through image acquisition arrangement. An interesting point is that the compact spinning did not eliminate the spinning triangle, which is often claimed by compact spinning system manufacturers. In fact, it is not practically possible to eliminate spinning triangle as it is a transition zone where a two dimensional fibrous strand converts into a three dimensional yarn structure. In order to comprehend the extent of variations in the spinning triangle geometry, a visual comparison of 18 different spinning triangles is shown in Figure 3, where the spinning triangles were simulated based on their measured geometrical data. It can be noticed that the spinning triangle formed in the classical ring spinning arrangement was clearly bigger in physical dimensions than the compact spinning triangles. The fibre compacting squeezed the overall geometry of the spinning triangle by reducing its width and height. Horizontal offsetting clearly dragged the spinning triangle towards left or right directions and created a skewed and an asymmetrical triangle. Similarly, a triangle that was compacted and skewed simultaneously showed a unique 'skewed compact' shape.

Empirical relationships between the spinning triangle geometry and yarn quality

In order to establish relationships between the shape of the spinning triangle and yarn quality, the first step was to nominate those yarn quality parameters that showed significant variations by varying the geometry of the spinning triangle. Table 3 shows yarn hairiness (both in terms of S3 and H index) and yarn tenacity exhibited good ranges of variations in their values. The range of variation in yarn elongation was quite limited. Yarn evenness varied from 15.96% to 19.53% CV_m, which could be considered as a significant amount of variation. However, only one data point was at 19.53% while all other lay between 15.96% and 17.7%, which is a relatively limited range. In this case, the data point at 19.53% appears to be an outlier that might be

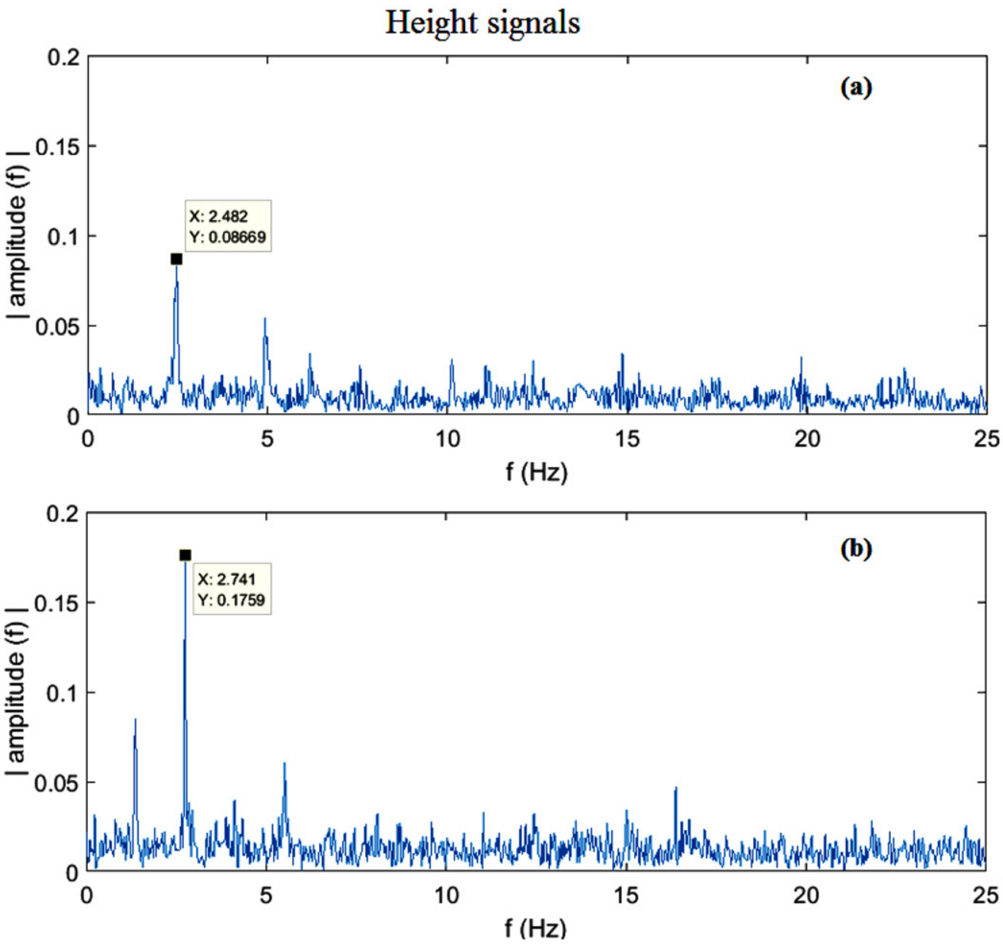

Figure 9. Fourier transformation of 30-s long signal of height of the spinning triangle for (a) WT-HC-LO yarn (b) KT-LC-NO yarn.

caused by an unknown variation in the ring spinning process such as drafting roller eccentricity. Hence, yarn hairiness and yarn strength would be considered sensitive towards the physical shape of the spinning triangle. The effect of each geometrical parameter of the spinning triangle on these two yarn quality parameters is discussed as follows.

Effects on the yarn hairiness

The scatter plots between all four geometrical parameters of the spinning triangle and yarn hairiness in terms of S3 value and H index are shown in Figures 4 and 5, respectively. Strong linear trends between yarn hairiness and the width and the height of the spinning triangle could be observed both in case of Zweigle S3 value and Uster H index. The strength of relationships is further reflected by their respective higher R^2 values. An increase in the height and the width of the spinning triangle led to an increment in yarn hairiness and vice versa. It is important to note that the height and the width of the spinning triangle were actually covariates in this case, as compact spinning reduced both the width and the height of the spinning triangle simultaneously. It was practically impossible to compact the width of the spinning triangle only without affecting its height the compacting system. The left and the right angles of the spinning triangle did not show clear trends with S3 value of yarn hairiness as well as with Uster H index in individual capacity and exhibited lower R^2 values.

An important feature of the scatter plots between both S3 value and H index versus width and height of the spinning triangle was the gap between the two clusters of the data points. The data points of the width of the spinning triangle were clustered around 1 mm or 3 mm. Similarly, the data points of the height of the spinning triangle are clustered around 1.5 mm and 3.5 mm. There were no data points between these two extreme values and there exists a possibility that the nature of the relationship between these variables could dramatically differ at unknown intermediate values. The absence of the intermediate data points was due to the inability to observe the spinning triangle geometry at a 2 mm width. The challenge is the geometry of the spinning triangle could not be precisely controlled as a physical setting on the ring spinning frame such as spindle speed or yarn twist but could only be influenced indirectly by other process parameters, i.e. fibre compacting and diagonal offsetting. Although, multiple levels of fibre compacting were selected to achieve significant differences in the spinning triangle geometry but the variation in the width of the spinning triangle was minimal. Low compacting also resulted in around 1 mm width of the spinning triangle, which was not substantially different from the spinning triangle width achieved at high pressure compacting. Hence, a linear

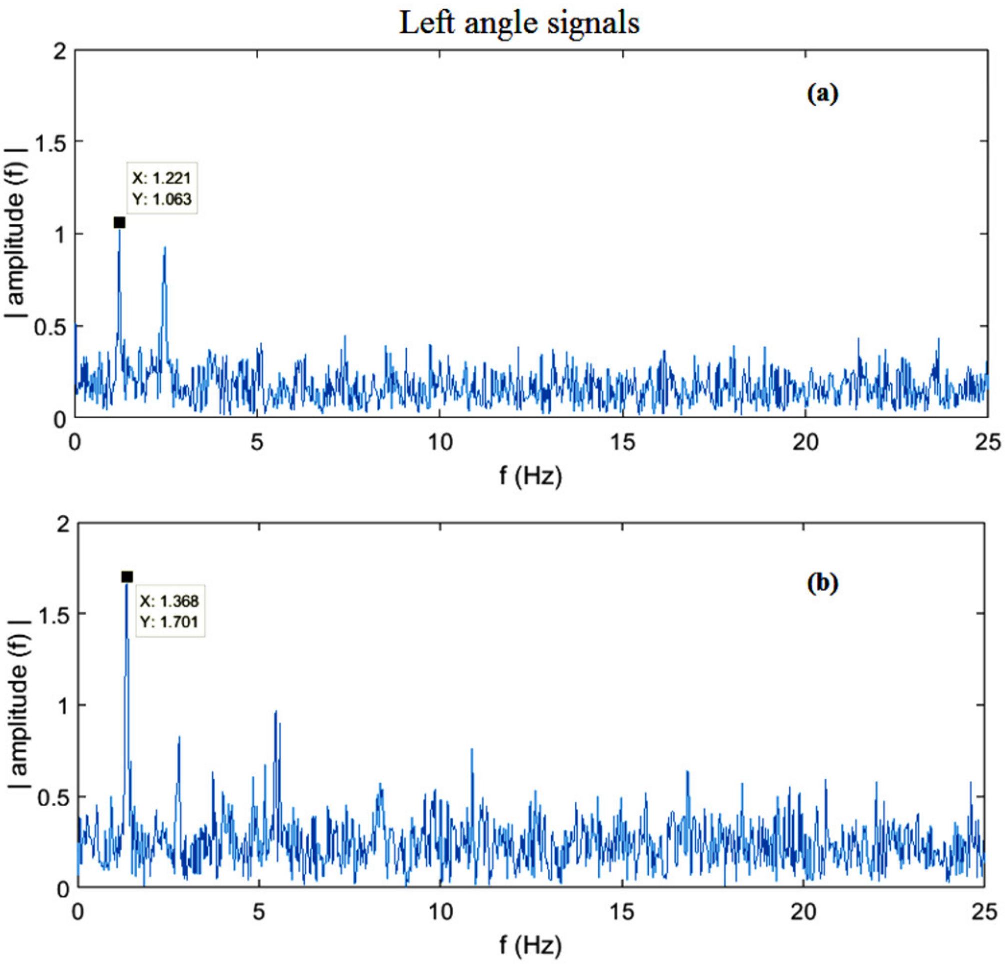

Figure 10. Fourier transformation of 30-s long signal left angle of the spinning triangle for (a) WT-HC-LO yarn (b) KT-LC-NO yarn.

relationship between yarn hairiness and spinning triangle width should be considered with some care.

A regression model for yarn hairiness as shown in Equation (1), was developed by taking the geometrical parameters of the spinning triangle as input variables or predictors and Zweigle S3 value of yarn hairiness as the output variable. The input factors were selected by developing various regression models using first order, second order and interaction terms of the geometrical parameters of the spinning triangle. The presented model showed highest value of R^2 (93.42%), which represents the amount of variation in the output variable explained by the variations in the input variable. In addition, the values of R^2 adjusted (92.01%) and R^2 predicted (90.31%), which represented the explanatory power of the model based on selected input variables and its ability to predict for new (unseen) observations, respectively, were also highest. The model was simulated in form of a surface plot to visualize the relationships between the input factors and the output variable, as shown in Figure 6.

$$\text{Zweigle S3} = -1162 + 169.9 \times \text{Width} + 32.7 \times \text{Left angle} - 0.241 \times (\text{Left angle})^2 \quad (1)$$

The surface plot shows that the width of the spinning triangle and yarn hairiness was directly proportional to each other and the relationship was almost linear in nature. The lowest yarn hairiness could be achieved at minimum width of the spinning triangle. The underlying reason for reduced hairiness at low width could be simply a superior control on the fibres at roller nip line by air suction, which kept them intact during yarn twisting. The left angle showed a non-linear relationship with yarn hairiness as its both maximum and minimum values resulted in low yarn hairiness while its mid-range values led to slightly higher yarn hairiness. It is interesting to note that the maximum and minimum values of yarn hairiness actually refer to those spinning triangles that form in the LO and the RO spinning arrangements, while mid-range values refer to a classical ring spinning triangle. This shows that both left and RO in ring spinning reduced yarn hairiness to some extent compared to regular ring spinning by exerting improved control on the fibres on one edge of the spinning triangle. It is also notable that the effect of the width of the spinning triangle on yarn hairiness was much stronger than the horizontal offsetting. The reason for this could be the fact that compact spinning controlled fibres on both edges of the spinning triangle while horizontal offsetting controlled fibres only one edge depending on the offset direction. The plot also suggests that a 'skewed-compact' spinning triangle could lead to production of least hairy yarns.

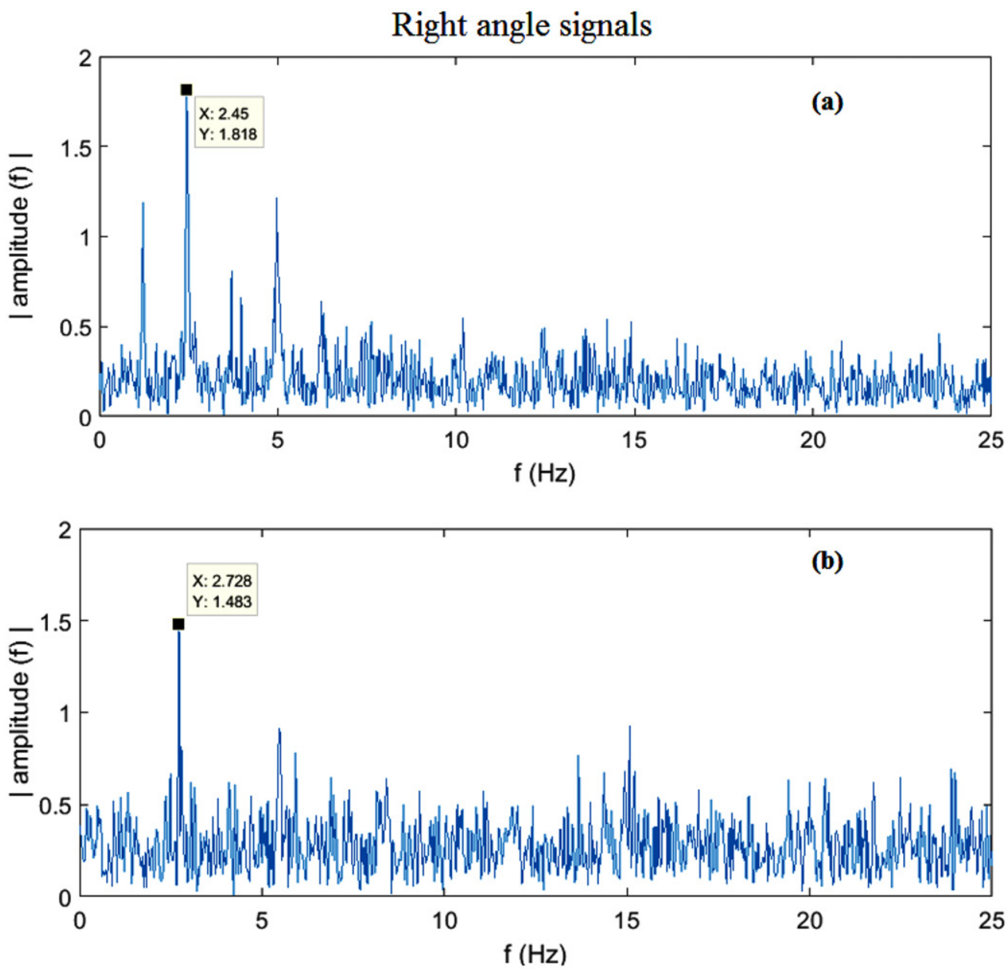

Figure 11. Fourier transformation of 30-s long signal of right angle of the spinning triangle for (a) WT-HC-LO yarn (b) KT-LC-NO yarn.

Effects on yarn tenacity

The scatter plots between the geometrical parameters of the spinning triangle and yarn tenacity are given in Figure 7. Comparing the effect of all four parameters of the spinning triangle geometry on yarn tenacity, no clear relationship or trend was noticed. The yarns that were produced with shorter spinning triangles (i.e. through compact spinning) exhibited both high and low values of tensile strength. Similarly, skewing the geometry of the spinning triangle in both left and right directions through horizontal offset method did not show any prominent relationships with yarn tenacity. The LO and RO yarns exhibited both high and low values of the yarn strength. The lack of any clear patterns and weak trends between the variables was further backed by, respectively, low R^2 values. However, it is interesting to note that the highest value of yarn strength was exhibited by WT-HC-LO yarn (i.e. 16.6 cN/tex), which refers to the 'compact-skewed' configuration of the spinning triangle. The similar 'compact-skewed' shape of the spinning triangle resulted in least hairy yarns.

The lack of statistical evidence to support the influence of the spinning triangle geometry over yarn tenacity was unexpected because the variations in the shape of the spinning triangle resulted in a reasonably broad range of yarn tenacity as given in Table 3. However, the geometrical parameters of the spinning triangle did not show any noticeable relationship with yarn tenacity. It could be deduced that some other 'phenomenon', which was actually responsible for controlling yarn strength was not reflected in terms of geometrical parameters of the spinning triangle. Instead, it acted as a hidden layer between the spinning triangle and yarn tenacity. For example, the fibre arrangement within a yarn and associated fibre migration are important factors that provide essential inter fibre cohesion to fragile yarn structure and impart strength in it. The shape of the spinning triangle controls the tension distribution among fibres (Mahdiyeh & Esfandiyar, 2014). There is a possibility that the variations in the spinning triangle geometry might have influenced the fibre arrangement within the yarns, which then affected yarn strength. The analysis of dynamic variations in the spinning triangle geometry could reveal if the delivery of fibres to the yarn was substantially different in weaker and stronger yarns. For this purpose, the dynamic data of the geometrical parameters of the spinning triangle for WT-HC-LO and KT-LC-NO yarns, which showed the maximum and minimum values of yarn strength, were analysed. The comparison of the geometrical parameters of two spinning triangles in frequency domain by taking Fourier transform of respective signals is given in Figures 8–11.

The comparison of the geometrical parameters of two spinning triangles in frequency domain showed notable differences in terms of the amplitude and the frequency of respective peaks. A shift in the peak amplitude in FT data was noticed particularly for the height signal (where peak amplitudes of stronger yarn and weaker yarns were 0.086 and 0.175, respectively) and the angles of the spinning triangle (where peak amplitudes of stronger and weaker yarns were 1.063 and 1.7, respectively). Similarly, a variation in peak frequencies was also noticed in the height and the angles of the spinning triangle. The differences in the amplitude and the frequency of variations between two spinning triangles could be the basis for differences in fibre delivery, fibre arrangement and structure in respective yarns, which eventually affected resultant yarn strength. There is a similar suggestion in literature, where a change in fibre configuration at the spinning triangle zone affected fibre arrangement within the yarn and influenced resultant yarn properties (Lima et al., 2011). However, this needs to be further confirmed by studying the structure and arrangement of the fibres within both yarns and comparing them together to reveal the link between the spinning triangle geometry and yarn strength.

Conclusions

The physical geometry of the spinning triangle was varied in this study by controlled manipulation of the spinning process variables. The geometrical parameters of the spinning triangle were measured using a combined method reported in the first part of this study. The statistical analysis between the spinning triangle geometry and the yarn properties suggested that the most sensitive yarn quality parameter with respect to the spinning triangle geometry was yarn hairiness. The S3 value of yarn hairiness showed a strong correlation with the width and the height of the spinning triangle. Lower width and diagonal offsetting of the spinning triangle led to reduced yarn hairiness. Yarn tenacity showed a considerable amount of variation (i.e. 12.9 cN/tex to 16.6 cN/tex) but there was not enough statistical evidence of any strong relationship between yarn tenacity and the spinning triangle geometry. A skewed-compact spinning triangle led to production of least hairy and stronger yarns. However, the analysis of dynamics of the spinning triangle geometry in frequency domain showed differences in terms of the frequency and the amplitude of geometrical parameters for a strong and a weak yarn, which could be the basis for difference in yarn strength. However, this requires further study on internal yarn structure. Yarn elongation and yarn evenness were least influenced by the variations in the spinning triangle geometry as they exhibited quite limited variations in their values. As potential future work, further experiments based on a wider range of yarn counts and fibre types are warranted to substantiate the findings of this study.

Disclosure statement

No potential conflict of interests was reported by the author(s).

Funding

This work was partially supported by the Australian Research Council (ARC) through a Linkage project (LP120200536).

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