Optimization of Break Draft, Pin Spacer and Rubber Cots Hardness to Enhance the Quality of Ring Spun Yarn Using Factorial Design

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ABSTRACT

The aim of the present work is to optimize the drafting parameters for ring spinning by using full factorial (2^3) experimental design. Three drafting parameters of ring spinning each at two levels were chosen for this study. These technological parameters were break draft, size of pin spacer and hardness of rubber cots. It was found from statistical analysis that pin spacer size has a significant effect on yarn unevenness (U %), imperfection index (IPI), hairiness (H) and yarn strength (CLSP) compared to the other two chosen factors. These yarn quality parameters were improved by increasing the spacer size. The increase in spacer size reduces the cohesive forces among the fibers during drafting. The pin between the cradle and the top front roller transfer the individual fibers from the drafted fiber assembly to the spinning triangle without any stretching or accumulation. This yields a more integrated structure and the quality of yarn is improved.

Keywords: Optimization, Ring spinning, Pin Spacer, Cotton yarn properties, Full Factorial Design

INTRODUCTION

Ring spinning is one of the most effective spinning techniques for yarn manufacturing. It provides excellent yarn properties compared to other spinning systems. However, it is limited by relatively low traveler speed, high balloon tension, low spindle speed and spinning triangle. These limitations are responsible for lower production rates than rotor, air jet and friction spinning systems [1-3]. In spite of low production, ring spinning provides a yarn structure that yields excellent mechanical properties [4].

The operation of the ring spinning system can be divided into drafting, twisting and winding steps. The drafting step plays an important role in the quality of yarn. Various studies were conducted regarding drafting parameters of spinning systems to improve the yarn quality [5-7]. The drafting parameters of ring spinning that affect the quality of yarn are drafting angle and spinning triangle (both relate to spinning geometry) [8-10], draft amount, draft (break and main draft) distribution [11], drafting roller setting (front and back zone gauge) [12,13], top rubber coated roller hardness (front and back) [14], cradle length, cradle arm pressure [13,1], aprons hardness (top and bottom), spacer size and spacer type (nose type and pin type). Each mentioned parameter contributes to the quality of spun yarn [16]. The quality of yarn is measured in terms of yarn evenness, yarn imperfections (thick, thin and neps), yarn hairiness and yarn tensile properties [17]. Few studies have been conducted on various spinning system parameters to optimize the yarn quality by using statistical analysis [18-27].

The aim of this work is to optimize the technological parameters of ring spun yarn by using full factorial design. For this purpose, three technological parameters of the drafting step of the ring spinning system were selected. These are break draft, hardness of the top front roller and size of the pin spacer. The main function of any type of spacer is to provide space between top and bottom aprons for fiber assembly at main drafting zone as shown in *Figure 1(b).* Spacers used in ring spinning are the nose spacer and the pin spacer (also known as the rod spacer) as shown in *Figure 1(a).* The pin spacer not only performs its basic function, but also introduces a rod between the cradle and top front roller as shown in *Figure 1(c)* to provide additional support to the drafted fiber assembly. This yields yarn with a high degree of structural integrity. Each spacer type is further categorized by size. Determining the proper spacer size to yield the desired yarn linear density is a challenge for spinners. Thus, pin spacer size is chosen as a factor in this study. As best can be determined, this is the first study in which the pin spacer parameter is optimized in the ring spinning process.

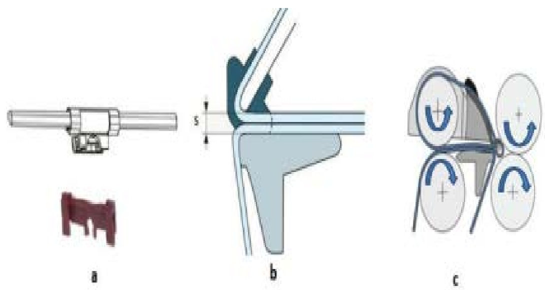

FIGURE 1. a) Pin and nose type spacer b) Space provided by spacer c) Function of pin spacer during drafting.

MATERIALS AND METHODS

Materials

Pakistani cotton was used to produce 20tex carded yarn. The cotton was tested under standard atmospheric conditions (20±2 °C and 65% RH) on a High Volume Instrument (HVI). Average properties are tabulated in the *Table I*.

Method

A standard spinning setup was used to produce 20 tex cotton yarn. For this purpose, conditioned cotton was processed in the blow room and carding section. The blow room and carding sections (Rieter setup) consisted of UniFloc (A-11), UniClean (B-11), UniMix (B-70), UniFlex (B-60) and C-51 carding machines.

TABLE I. Properties of Cotton fibers.

Cotton Parameter	Mean ± SD
Spinning Consistency Index	150 ± 7.66
Fineness (mtex)	157 ± 1.50
Maturity Index	0.88 ± 0.04
Length (mm)	28.2 ± 1.0
Uniformity Index	83.77 ± 1.0
Short Fiber Index	8.15 ± 0.9
Strength (cN/tex)	32.11 ± 0.9
Elongation % (%)	7.58 ± 7.0
Moisture (%)	6.36 ± 0.4
Reflectance (Rd)	75.3 ± 0.8
Yellowness (+b)	8.6 ± 0.04

The carding machine was set to remove 4.2% dropping and 7.5% fly from the feed batt and slivers of 4.96k tex (70 grains/yard) were obtained at a delivery speed of 165 meters/min. Eight card slivers were fed to the breaker drawing machine, and drawn sliver of 4.67 ktex (66 grains/yard) was produced at a delivery rate of 500 meters/min. Then, eight ends of breaker drawn sliver were fed to the finisher drawing machine to get a 4.60 ktex (65 grains/yard) sliver at a delivery rate of 450 meter/min. The finisher drawn slivers were fed to the roving machine to obtain a roving of 738tex (Ne 0.80) at a flyer speed of 900 rpm, and twist level of 33.68 twist/meter. These roves were spun into 20 tex (Ne 30) cotton yarns at a spindle speed of 20,700 to a twist level of 972 twist/meter (24.70 twists/inch). The three drafting parameters of the ring spinning system (break draft, pin spacer size and hardness of rubber cots) were set to two levels for the experiment at hand. Coded levels and actual values of these factors are given in *Table II*.

TABLE II. Experimental factors and their levels.

Factor with Symbol	Coded Values and actual values	
	-1	1
Break Draft, X_1	1.34	1.39
Pin Spacer Size (mm), X_2	2.0	2.50
R. Cots Hardness (shore), X_3	63	68

The yarn samples were prepared according to the factor and level combinations as determined by full factorial experimental design. Full factorial design is one of the most advanced experimental designs employed to understand the quantitative relationships between multiple input variables and response variables. Quality parameters such as mass irregularity, yarn faults in terms of imperfection Index and yarn hairiness were measured using a Uster Tester-4. The yarn linear density was measured with a Uster auto sorter. The lea strength of yarn was measured using a Mesdan tensile tester under standard atmospheric conditions (20±2°C and 65% RH). The nominal linear density and lea strength were used to determine the tensile strength in terms of the Count Lea Strength Product (CLSP).

RESULTS AND DISCUSSION

The results of measurements of yarn irregularity, imperfection index, hairiness and tensile behavior of 20tex carded ring spun yarn using the full factorial experimental design are given in *Table III.*

TABLE III. Full Factorial experiment design with Yarn Properties.

Factors			**Physical Properties of Yarn ± CV %**					
X_1	**X_2**	**X_3**	**U**	**CVm**	**CV 10m**	**H**	**IPI**	**CLSP**
-1	-1	-1	12.84	15.45	2.66	6.11	700	2265
			1.3	1.2	13	2.5	20.3	3.64
1	-1	-1	12.79	15.72	2.67	6.24	668	2174
			2.1	1.9	14.6	0.8	14.2	3.55
-1	1	-1	11.79	14.15	2.55	5.55	471	2410
			1.2	1.3	13	1.2	15.1	3.65
1	1	-1	12.15	15.55	2.53	5.6	450	2421
			1.1	1	14.7	1.9	12.9	2.86
-1	-1	1	13.01	15.49	2.8	6.1	723	2278
			1.2	1.3	13.6	2	18.6	2.42
1	-1	1	13.41	16.25	2.74	6.18	881	2193
			1.6	1.5	16.6	1.5	16.2	3.55
-1	1	1	11.94	15.34	2.69	5.73	372	2341
			2.2	2.1	15.8	2.6	23.1	3.6
1	1	1	12.16	15.27	2.67	5.65	491	2349
			1.8	1.7	16.4	2.2	17.6	3.56

TABLE IV. Regression Coefficient for different response variables using coded values of input variables.

Terms	**U**		**CVm**		**CV10m**		**IPI**		**H**		**CLSP**	
	Coeff.	**p-val.**	**Coeff.**	**p-val.**	**Coeff.**	**p-val.**	**Coeff.**	**p-val.**	**Coeff.**	**p-val.**	**Coeff.**	**p-val.**
Constant	12.5	0.004*	15.403	0.010*	2.6638	0.010*	594.9	0.007*	5.895	0.001*	2303.9	0.000*
X1	0.12	0.36	0.295	0.441	-0.011	0.441	27.9	0.137	0.0225	0.266	-19.63	0.036
X2	-0.5	0.093*	-0.325	0.411	-0.054	0.411	-148.5	0.026*	-0.2625	0.024*	76.38	0.009*
X3	0.12	0.354	0.185	0.588	0.0613	0.588	22.27	0.17	0.02	0.295	-13.63	0.052
X1*X2	0.03	0.763	0.037	0.903	0.0013	0.903	-3.43	0.674	-0.03	0.205	24.38	0.029
X1*X3	0.04	0.692	-0.123	0.705	-0.009	0.705	41.22	0.094	-0.0225	0.266	0.38	0.795
X2*X3	-0.08	0.479	0.042	0.891	0.0088	0.891	-36.8	0.105	0.0375	0.166	-21.62	0.033

TABLE V. Regression equation for response variable.

No	Yarn Properties	Regression Equation	R^2 (%)
1	U %	12.5112 + 0.1163 X1 - 0.5012 X2 + 0.1188 X3 - 0.0788 X2*X3	97.35
2	CVm %	15.403 + 0.295 X1 - 0.325 X2 + 0.185 X3 + 0.037 X1*X2 - 0.123 X1*X3	79.74
3	CV 10m %	2.66375 - 0.01125 X1 - 0.05375 X2 + 0.06125 X3 + 0.00875 X2*X3	97.79
4	Hairiness	5.8950 + 0.0225 X1 - 0.2625 X2 + 0.0200 X3 - 0.0300 X1*X2 - 0.0225 X1*X3 + 0.0375 X2*X3	99.86
5	IPI	594.90 + 27.90 X1 - 148.47 X2 + 22.27 X3 + 41.23 X1*X3 - 36.80 X2*X3	99.81
6	CLSP	2303.88 - 19.625 X1 + 76.375 X2 - 13.625 X3 + 24.375 X1*X2 - 21.625 X2*X3	99.98

The experimental design and statistical analyses were performed using Minitab17® (trial version) statistical software package. The regression coefficient and *p*-value of the response variables are given in *Table IV*. The regression coefficient indicates the change in the mean response per unit increase in the factor. Higher regression coefficient of a given response indicates that the response has been significantly affected by the factor. The sign (+,-) of the regression coefficient indicates that response increases or decreases as a result of changing a factor. A factor having a *p*-value less or equal to 0.05 is considered a statistically significant term with a 95% confidence level.

It is observed from *Table IV* that yarn unevenness, yarn imperfection index and yarn hairiness all have negative regression coefficients as a function of the pin spacer (X_2). This means that these terms decrease with an increase in size of the pin spacer (X_2). Yarn strength (CLSP) increases with increasing the size of the pin spacer (X_2). The *p*-values of these regression coefficients are also lower compared to the remaining terms. The regression equations for all response variables with R^2 values are given in *Table V*. The R^2 values indicate the percent variation in the response variables resulting from the factors included in the regression equations.

The correlation (Pearson correlation and p-value) between the response variables is given in *Table VI*. The result shows that U% is statistically significant and has a positive relation with yarn hairiness and imperfection index. This indicates that an increase in yarn unevenness increases the yarn hairiness and imperfection index. Yarn hairiness and yarn strength (CLSP) are also statistically significant and have a negative interaction, meaning that spun yarn with low hairiness has more strength. This may be attributed to a more integrated yarn structure. The fibers are better bound in the yarn structure during the spinning process, increasing the strength of the spun yarn.

TABLE VI. Correlation between response variables.

	U%	**CVm**	**CV10m**	**H**	**IPI**
CVm	0.77				
	0.025				
CV10m	0.691	0.537			
	0.058	0.17			
H	0.909	0.68	0.686		
	0.002*	0.063	0.06		
IPI	0.968	0.617	0.61	0.865	
	0.000*	0.104	0.109	0.006*	
CLSP	-0.849	-0.689	-0.677	-0.957	-0.816
	0.008	0.059	0.065	0.000*	0.014

Cell Contents: Pearson correlation, P-Value

Yarn Unevenness

Yarn unevenness is a measure of variation in weight per unit length of the yarn or the variation in thickness of the yarn. Uster measures the yarn unevenness by a capacitive method. Yarn unevenness is measured by a Uster Tester in terms of U% and coefficient of variation of unevenness in terms of CVm %, CV3m % and CV10m % [1, 3]. The results of yarn unevenness and coefficient of variation of unevenness are given in *Table IV*. The impact of break daft, spacer size and rubber cots hardness on yarn unevenness is given in *Figure 2*.

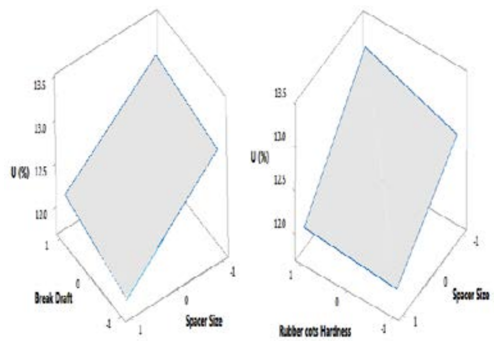

FIGURE 2. Yarn unevenness at different levels of break draft, spacer size and rubber cots hardness.

It is clear from the *Figure 2* that pin type spacer size has a significant impact on yarn unevenness. Yarn unevenness is reduced by increasing the spacer size. As spacer size increases, it provides more space between the top and bottom aprons for the drafted fiber assembly. During the attenuation of the fiber assembly, increasing space reduces the cohesive forces among fibers, attenuating the fiber assembly more smoothly and with lower distortion. As a result, the yarn produced has improved evenness. Additionally, the pin type spacer provides extra support to the drafted fiber assembly by introducing a rod (also known as a pin) between the cradle and top front rollers. This has a significant effect on the handling of the drafted fiber assembly compared to a nose type spacer, converting the complete drafted fiber assembly to the front roller without any distortion. As a result, more fibers in the drafted fiber assembly become part of the yarn body, resulting in a more integrated structure with reduced unevenness.

It is also clear from *Figure 2* yarn unevenness is increased by increasing the rubber cot hardness. The increase in rubber cot hardness increases the rubber stiffness. The stiffer rubber material handles the drafted fibers stream harshly as compared to a less stiff material, serving to increase yarn unevenness. The break draft also has a slight effect on yarn unevenness. The regression equation for unevenness is given in *Table V*. R^2 value of the regression equation for U% is 97.35%.

The coefficients of variation of unevenness (CVm % and CV10m %) of ring spun yarn with linear density of 20tex are given in the *Table III*. The impacts of break daft, spacer size and rubber cot hardness on the coefficient of variation of unevenness are given in *Figure 3* and *Figure 4*. It can be seen from the *Figure 3* and *Figure 4* that spacer size and rubber cot hardness has the same effect on the CVm (%) and CV10m (%) as on unevenness. The coefficient of variation of unevenness decreases as the spacer size increases. This may be due to the change in cohesive forces among the fibers, tending to attenuate the fiber assembly more smoothly. The CVm (%) and CV10m (%) also increase as a result of increasing the rubber cot hardness. Regression equations for coefficient of unevenness are given in *Table V*. R^2 value of the regression equation for CVm (%) and CV10m (%) are 79.74 and 97.79 percent.

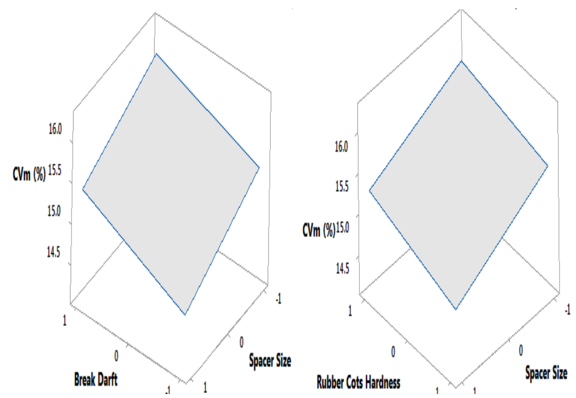

FIGURE 3. Coefficient of variation of unevenness (CVm %) at different levels of break draft, spacer size and rubber cots hardness.

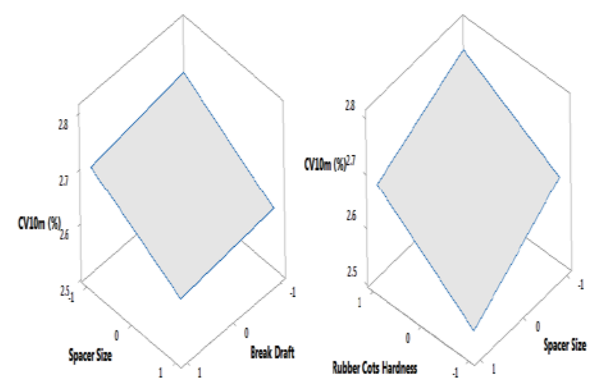

FIGURE 4. Coefficient of variation of unevenness (CVm10 %) at different levels of break draft, spacer size and rubber cots hardness.

Imperfection Index

Spun yarn faults are classified into two categories- seldom occurring yarn faults and frequently occurring yarn faults. Seldom occurring yarn faults are measured over a 100km yarn length. Frequently occurring yarn faults are measured over a 1km yarn length. Frequently occurring yarn faults are thick places, thin places and neps. Imperfection index (IPI) is the sum of yarn thin places (-50), thick places (+50) and neps (+200) per kilometer. Yarn imperfection indices are given in the *Table III*. The impact of break daft, spacer size and rubber cots hardness on imperfection index is given in *Figure 5*.

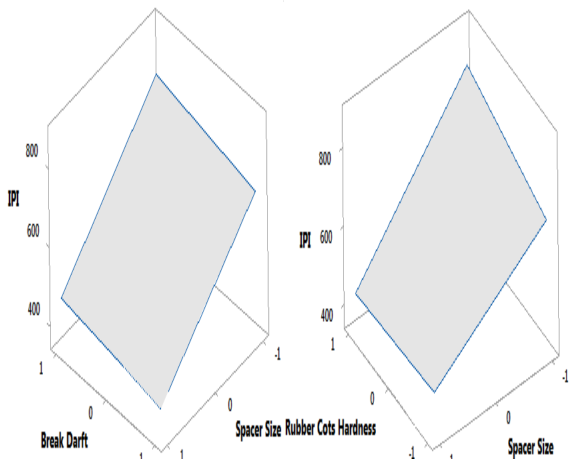

FIGURE 5. Yarn Imperfection Index at different levels of break draft, spacer size and rubber cots hardness.

It is clear from *Figure 5* that yarn faults were significantly affected by spacer size. Yarn faults were reduced by increasing the spacer size. This may be due to the change in cohesive forces between fibers, causing them to smoothly attenuate the fiber assembly. The smooth attenuation of the fiber assembly yields an improved yarn structure and uniformity. As a result thick, thin and neps are reduced. Additionally, a pin type spacer provides extra support to the drafted fiber assembly by introducing a rod (also known as a pin) between the cradle and top front roller. It converts the complete drafted fiber assembly to the front roller without any distortion (stretching and accumulation of fibers) and yarn faults are thus reduced. The correlation between yarn unevenness and imperfection index is shown in *Table VI*. The yarn unevenness is statistically significant and has a positive effect on yarn faults. This indicates that an increase in yarn evenness (decrease in unevenness) decreases yarn faults.

It is also clear from *Figure 5* that yarn faults were slightly affected by rubber cot hardness. The amount of IPI increases by increasing the hardness of the rubber cots. Handling the fibers with a stiffer rubber material disturbs the fibers stream. The IPI is also affected by the break draft. The imperfections are increased by increasing the break draft. This may be due to the distribution of the draft at the main and back drafting zones. An increase in break drafts results in a decrease in draft at the main drafting zone. This change in distribution of the draft leads to improper drafting of the fiber assembly and causes yarn faults. The regression equation for imperfection index is given in *Table V*. The R^2 value of the regression equation for imperfection index is 99.81 percent.

<u>Yarn Hairiness</u>

A Uster Tester can be used to determine hairiness from the ratio of the total length of protruding fibers (in centimeters) per centimeter of yarn. Yarn hairiness values are given in the *Table III*. The impacts of break daft, spacer size and rubber cot hardness on yarn hairiness are given in *Figure 6*.

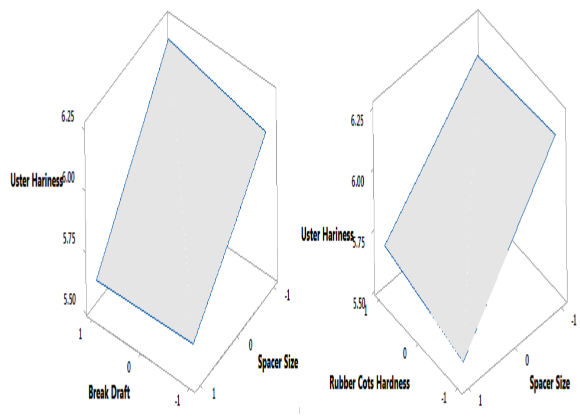

FIGURE 6. Yarn hairiness at different levels of break draft, spacer size and rubber cots hardness.

It is observed from statistical analysis and *Figure 6* that spun yarn hairiness was affected by spacer size. An increase in spacer size reduces the value of yarn hairiness. The resulting reduction in cohesiveness provides smoother attenuation of the fiber assembly. This yields a more highly integrated yarn structure and better yarn uniformity and reduces the yarn hairiness. The correlation between yarn hairiness and unevenness is shown in *Table VI*. The unevenness is statistically significant and has a positive effect on yarn hairiness. An increase in yarn evenness (decrease in unevenness) decreases yarn hairiness. The rubber cot hardness also affects the spun yarn hairiness. The handling of the fiber assembly with stiffer rubber cots disturbs the fiber stream and leads to a more hairy yarn structure. The regression equation for spun yarn hairiness is given in *Table V*. The R^2 value of the regression equation for hairiness is 99.86%.

<u>Tensile Properties</u>

The tensile properties of textile yarn are measured in terms of breaking force (maximum load developed in a tensile test), tenacity (force per unit linear density), rupture per kilometer (theoretical length of a yarn whose own weight would exert a force to break) and count lea strength product (CLSP). CLSP is defined as the product of the nominal lea count and lea strength of a yarn. Yarn strength measurements are given in the *Table IV*. The impacts of break draft, spacer size and rubber cot hardness on yarn strength are given in the *Figure 7*.

It can be seen from *Figure 7* that spun yarn strength is significantly affected by spacer size. An increase in spacer size increases yarn strength. The reduction in cohesiveness provides smoother attenuation of the fiber assembly, leading to an integrated yarn structure. The correlation between yarn hairiness and yarn strength is shown in *Table VI*. Yarn hairiness and yarn strength are statistically significant terms with a negative relationship. This means that spun yarn with lower hairiness has increased strength due to a more integral structure.

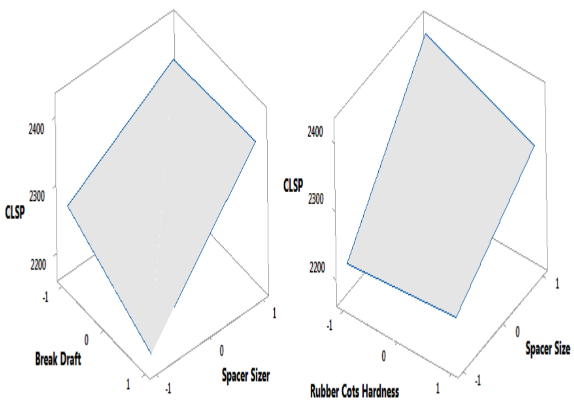

FIGURE 7. Yarn strength at different levels of break draft, spacer size and rubber cots hardness.

The rubber cot hardness also affects the spun yarn hairiness. Decreasing hardness increases fiber integrity within the yarn structure and consequently yarn is strength improved. The regression equation for spun yarn CLSP is given in *Table V*. The R^2 value of the regression equation for hairiness is 99.98%.

CONCLUSION

The effects of three drafting parameters (breaking draft, pin spacer size and rubber cot hardness) on yarn quality using full factorial experimental design were investigated. It is concluded that ring yarn spun with low break draft value, higher pin spacer size and low rubber cot hardness provides improved yarn properties. Statistical analysis shows that pin spacer size has a significant effect on yarn unevenness, imperfection index, hairiness and strength. Yarn unevenness, imperfection index and hairiness were reduced and yarn strength was increased by increasing the spacer size.

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