OPTIMIZATION OF COP DIAMETER AT BOTTON RING RAIL STAGE IN RING SPINNING PROCESS USING TAGUCHI METHOD

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ABSTRACT: *The ring-spinning process is an important manufacturing process for the mass customization of clothing goods, especially for large-run yarns. Cop quality is one of the most important characteristics concerning ring-spun yarns. It is mainly evaluated and compared via the diameter of a cop. This study aimed to optimize the ring spinning parameters influencing the cop diameter. The optimization of the spinning process was investigated using the Taguchi method. Using the S/N ratio, the best combination of factor levels that yield the highest value of cop diameter was detected efficiently.*

Keywords: *Taguchi method, optimization, ring spinning, yarn, cop diameter.*

OPTIMIZACIJE PREČNIKA NAMOTAJA U DONJEM POLOŽAJU PRSTENA U PROCESU PRESTENESTOJ PREDENJE PO TAGUCHI METODE

APSTRAKT: *Prtoces predenja prstena je važan proizvodni process za masovno prilagođavanje odevnih premeta, posebno za prediva velikih serija. Kvalitet namotka je jedna od najvažnijih karakteristika prstenestih prediva. Uglavnom se procenjuje i poredi preki prečnika namotka. Ova studija je imala za cilj optimizaciju parametara u process prstenestoj predenje koji utiču na prečnik namotka. Optimizacija procesa predenja je ispitavana primenom Taguči metode. Koristeći odnos S/N, efikasno je otkrivena najbolja kombinacija nivoa faktora koja daje najveću vrednost prečnika namotka.*

Ključne reči: *Taguči metoda, optimizacija, predivo, dijametar namotka.*

1. INTRODUCTION

The commonly used, ring spinning process is one of the oldest process-oriented spinning used for staple spinning. The ring spinning process is quite simple. The roving is the input for the process and passes through a basic, and usually 3 roll, drafting system. After drafting, the fiber is twisted into a yarn structure by a whirling spindle, which has a removable bobbin on it. The staple fiber such as cotton and wool or mixed with synthetic staple fiber has to go through a series of processes until reaching the finished product or the yarn package [1]. Ring spun yarn is made by twisting and thinning the cotton strands to make a very fine, strong, soft rope of fiber. The twist that provides the final entanglement is built up from the outside to the inside. The structure of ring-spun yarn gives final products visual, tactile, aesthetic, and elastic fabric properties suitable for a wide range of end uses [2-4]. Ring-spun yarn are also suitable for functionalization with biopolymer [5,6].

The winding of yarn in ring spinning is complex. The yarn is wound in layers along the length of the trapped plastic bobbin, mounted on the spindle, the action of which is termed „cop building“ [7]. This layering of yarn enables it to be easily unwound without slough-off and with undue tension variations during high-speed yarn rewinding. The point of the lay of yarn on the bobbin is periodically moved up and down by the motion of the ring rail, and after each cycle (one chase), the bottom-most point of yarn lay is shifted upwards a little by means of a step in height of the start position of the ring rail's periodic motion. The wound bobbin or „cop“ has three distinct parts: a lower curved base, a cylinder in the middle, and a conical tip [1]. While forming the base of the cop, the upward shift of the ring rail at the bottom of the chase is kept low, giving a shorter traverse. Since the length of yarn delivered during each traverse stroke is the same, the volume per layer is increased, thereby generating curvature. The average speed of the traverse of the ring rail is slower during its upward stroke than during its downward stroke. The slow traverse of the rail during its upward stroke helps in laying more coils of yarn, i.e. with a short pitch. These coils are called „winding coils“. Since the bobbin is trapped with its diameter reducing from the bottom to the top, the winding rpm must increase from the bottom to the top. This leads to a progressive decrease in the pitch of the coils or an increasing package density from the bottom to the top. To maintain a constant package density, the ring rail is accelerated during its upward motion. For the same reason, the ring rail decelerates during its downward stroke. The yarn coils laid during the downward stroke are „binding coils“ with a long pitch.

The cop size in ring spinning is very much limited both by the size of the ring and by the permissible height. The ring diameter varies from 35 to 52 mm and the lift (length of the bobbin over which yarn is wound or ring rail traverse) from 175 to 205 mm [8]. The ratio of the lift to ring diameter is around 4 to 7.5. Since the yarn tension is inversely proportional to sinα, i.e. Rb/R, reducing the bobbin diameter below the ring radius leads to excessive tension on the yarn and end breaks. The maximum yarn content in the cop is around 60 to 110 g, which necessitates frequent stops on the machine for doffing the package. An increase in package height and diameter above the values indicated would result in uncontrollable yarn tension and excessive power consumption, as the power to rotate the package is proportional to the ring diameter to the power of 2.75.

Many research works have been conducted on the prediction and evaluation properties of yarns [9,10], while minor ones operated on the optimization of spinning parameters. The purpose of this study is to optimize cop diameter in the ring-spinning process using Taguchi method.

2. EXPERIMENTAL PART

2.1. Materials

Yarns were obtained from a mixture of cotton and polyester fiber. The fiber properties are given in Table 1.

Table 1: Properties of fibers used for yarn producing

Cotton Type	Cotton part in the blend (%)	Linear density (dtex)
Russian I Class	51	1.68
Maklen	49	1.67

2.2. Spinning process

The cotton carded yarn with 15 tex linear density was produced on a ring spinning frame.

2.1. Methods

A cop diameter, dc, was determined by the direct method by measuring the diameter of each individual coli with a precision ruler.

There are various factors affecting the cop diameter. However, factors that could be controlled easily were chosen in this study. Taguchi analysis was conducted using Minitab software.

Cop diameter was larger-the-best characteristic value and the S/N ratio of each experiment was calculated using Equation 1.

$$S/N = -10\log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{{y_{ij}}^{2}}\right) \quad (1)$$

where: y_{ij} is j-th characteristic value of i-th experiment and n is the repeat count of y in an experiment

In this study, the cop diameter was chosen for response value y and 9 S/N ratios were calculated using three values of cop diameter.

3. RESULT AND DISCUSSION

Nine groups of combination of coded parameters were performed and the result of the cop diameter is shown in Table 2. The experiments were conducted by following the settings spinning process parameters. Taguchi used the single-to-noise (S/N) ratio to measure the

value of the quality characteristics of choice [11]. S/N is characterized into three categories: normal is the better, smaller is the better, and larger is the better [12].
In this paper, the larger the better characteristic was applied due to the intention to achieve a higher cop diameter. The S/N ratio of the determined cop diameter is shown in Table 2.

Table 2: Parameter code, determined cop diameter, the mean value, and S/N ratio

Exp. No.	Parameter code			Experiment (cop diameter, mm)			y_{exp}	S/N ratio
	Traveler mass (mg) K	Spindle speed (min^{-1}) L	Doff stage (mm) M	y_1	y_2	y_3		
1	1	1	1	y_{11}	y_{12}	y_{13}	37.8	31.55
2	1	2	2	·	·	·	42.0	32.47
3	1	3	3	·	·	·	37.9	31.57
4	2	1	2	·	·	·	42.3	32.53
5	2	2	3	·	·	·	37.7	31.53
6	2	3	1	·	·	·	36.1	31.15
7	3	1	3	·	·	·	37.2	31.41
8	3	2	1	·	·	·	36.4	31.22
9	3	3	2	y_{91}	y_{92}	y_{93}	40.1	32.07

The optimum conditions for this approach were obtained by sorting the delta in an order of significantly affecting the process (Table 3). The higher the delta value signifies the more effects its parameter contributes.

Table 3: Optimum conditions by utilizing the S/N ratios

	Factors and levels		
	K	L	M
Level 1	31.86	31.83	31.31
Level 2	31.73	31.74	32.35
Level 3	31.57	31.60	31.50
Delta	0.30	0.23	1.04
Rank	2	3	1
Optimum	K1	L1	M2

The highest plots of each parameter were chosen as could be seen in Figure 1, with the reason that the ratio set was the largest the better [13]. The same optimum conditions could be seen in Table 3 by the delta values therefore, the optimum conditions by this approach were as follows: K1L1M2.

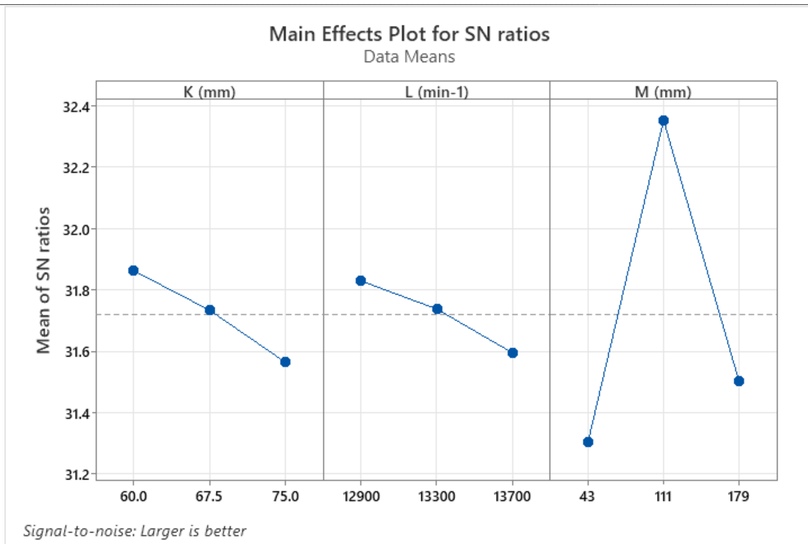

Figure 1: Main effect plot for S/N ratios

ANOVA is a statistical decision-making tool to detect differences in the average performance and helps test the significance of all main factors. The ANOVA method was utilized to understand the percentage of contribution of each parameter [14]. Table 4 showed that factor M had a significant influence on the cop diameter, while factors K and L had no influence on the cop diameter. Factor M had the highest value of 88.86% in contribution, which significantly affected the cop diameter in the ring spinning process.

Table 4: ANOVA results

Factor	Degree of freedom (Df)	Sum of squares (SS)	Mean square (MS)	F-value	p-value	Contribution (%)
K	2	0.13342	0.066709	9.00	0.100	6.42
L	2	0.08338	0.041692	5.62	0.151	4.01
M	2	1.84810	0.924952	124.64	0.008	88.86
Residual error	2	0.01483	0.007413			
Total	8	2.07973				

The purpose of the verification test was to confirm the validity of the predicted value. Minitab was utilized to predict the result of a cop diameter in the ring-spinning process with the optimum settings obtained by using the S/N ratio. The predicted result for crop diameter in Minitab was 42.5778 (Figure 2).

Prediction

Mean
42.5778

Settings

K	L	M
60	12900	111

Figure 2: *Prediction by Minitab*

To compare the experiment executed under the optimal conditions with the prediction that was generated by Minitab percentage of error was calculated. The percentage of error was 0.52% so the optimal conditions obtained by using different approaches were verified.

4. CONCLUSION

The diameter of the cop in the ring-spinning process was characterized and evaluated at the variation in spindle speed, traveler mass, and cop height. It was concluded that changing the doff stage over the cop had a severe effect on the diameter of the cop which gave a recommendation for engineering design too but the cop optimum diameter for the manufacturers and researchers. Traveler mass and spinning spindle had no effect. The optimization method of Taguchi gave a reasonable result to the maximum cop diameter corresponding to the specimen and test condition. According to the proposed levels of the control factors it was concluded that the maximum cop dimater at the bottom ring rail position could be achieved at the factor level K1L1M2.

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