(REFEREED RESEARCH)

THE USE OF THE TAGUCHI DESIGN OF EXPERIMENT METHOD IN OPTIMIZING SPIRALITY ANGLE OF SINGLE JERSEY FABRICS

TAGUCHİ DENEYSEL TASARIMININ SÜPREM KUMAŞLARIN MAY DÖNMESİ AÇISININ OPTİMİZASYONUNDA KULLANIMI

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ABSTRACT

In this paper, spirality angle of single jersey fabrics was optimized using the Taguchi experiment design technique, which is a recently famous approach. In the evaluations, analysis of variance (ANOVA) and signal to noise ratio (S/N) were used. Nine fabric configurations with respect to L9 orthogonal design for Taguchi approach were knitted and tested. Relaxation treatment, yarn type and loop length, effecting on spirality angle were selected as control factors. Based on the S/N ratio and ANOVA analyses, the optimum levels of these parameters obtained in this paper, relaxation type of dry relaxation, yarn type of open end yarn, loop length of 0,25 cm. By using the Taguchi experimental design approach, low number of experiments can be performed to achieve the combination providing the best performance. Thus, before starting manufacturing in factory, it can be easily predict the spirality angle of single jersey fabrics using the defined factors.

Key Words: Experimental design, Taguchi design, Knitted fabrics, Spirality, Optimization.

ÖZET

Bu çalışmada, son yıllarda kullanımı yaygınlaşmaya başlayan Taguchi deneysel tasarımına göre süprem kumaşların may dönmesi açısının optimizasyonu gerçekleştirilmiştir. Değerlendirmelerde varyans analizi (ANOVA) ve sinyal gürültü oranı (S/N) kullanılmış olup, L9 ortogonal dizaynına göre üretilen 9 farklı örme kumaş ile denemeler yapılmıştır. Relaksasyon türü, iplik üretim tipi ve ilmek iplik uzunluğu may dönmesini etkileyen kontrol faktörleri olarak seçilmiştir. S/N oranı ve varyans analizine göre; relaksasyon türü olarak kuru relaksasyon, iplik üretim tipi olarak open end iplik ve ilmek iplik uzunluğu olarak 0.25 cm bu parametrelerin optimum düzeyleri olarak elde edilmiştir. Taguchi tasarımının kullanılması az sayıda deneme ile en iyi performansın elde edilmesini ve üretimden önce, belirli faktörler yardımıyla may dönmesi açısının tahminlenmesini sağlamıştır.

Anahtar Kelimeler: Deneysel tasarım, Taguchi tasarım, Örme kumaşlar, May dönmesi, Optimizasyon.

1. INTRODUCTION

Fabric spirality is a major problem, especially in plain knitted fabrics, and comes mainly from two sources: from the yarn and from the machine. The spirality problem is that when we knit a rectangular piece of fabric, it leans towards one side and becomes a parallelogram. The wales are no longer at right angles with the courses. The spirality is measured with an angle θ*sp* which is the angle between the direction at right angles with the courses and the distorted wale direction as seen in Figure 1. If the spirality angle θ*sp* exceeds 5° it is considered an important problem (1).

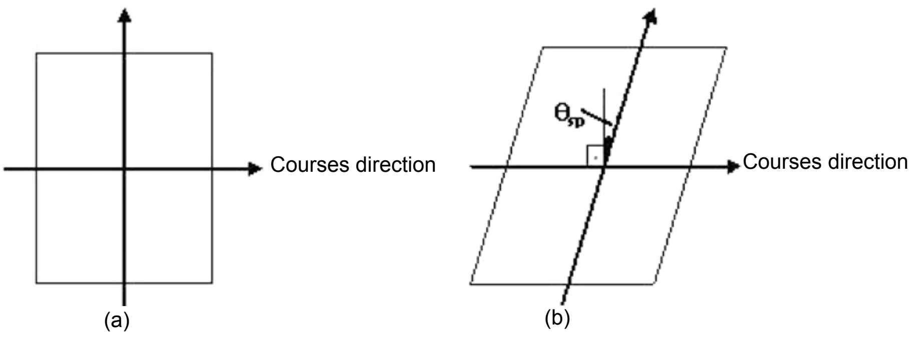

Figure 1. Schematic representation of spirality problem: (a) normal fabric; (b) spiral fabric

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The Taguchi method, pioneered by Dr. Genichi Taguchi and also called the “robust design method”, greatly improves engineering productivity (2). Taguchi focused on minimizing the effect of causes of variation. The product or process performs consistently on target and is relatively insensitive to uncontrollable factors. In comparison with a traditional full factorial design of experiments, Taguchi’s methods in general provide a significant reduction in the size of experiments, thereby speeding up the experimental process (3). In Taguchi design approach, there are three design stages, which are system, parameter and tolerance designs (2, 4, 5). The parameter design approach has been adopted for studying the effect of parameters on the spirality of single jersey knitted fabrics.

Taguchi methodology for optimization can be divided into four phases. viz. planning, conducting, analysis and validation. Each phase has a separate objective and contributes towards the overall optimization process (6-8). The primary goal is to keep the variance in the output very low even in the presence of noise inputs. Thus, the processes/products are made robust against all variations (7).

Two major tools used in Taguchi method are the orthogonal array (OA) and the signal to noise ratio (SNR or S/N ratio). OA is a matrix of numbers arranged in rows and columns. A typical OA is shown in Figure 2.

Factors

Experiments	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

$L_9(3^4)$

Figure 2. $L_9(3^4)$ orthogonal array

In this array, the columns are mutually orthogonal. That is, for any pair of columns, all combinations of factor levels occur; and they repeat an equal number of times. Here there are four parameters A, B, C, and D, each at three levels. This is called an "L_9" design, with the 9 indicating the nine rows, configurations or prototypes which are to be tested (9).

Taguchi suggests that the response values at each inner array design point be summarized by a performance criterion called a signal to noise ratio. S/N ratio is expressed in decibels (dB). Conceptually, the S/N ratio (η) is the ratio of signal to noise in terms of power. Another way to look at it is that it represents the ratio of sensitivity to variability (4, 10). The higher the SNR, the better quality of product is. The idea is to maximize the SNR and thereby minimizing the effect of random noise factors has significant impact on the process performance (5, 11).

Therefore, the method of calculating the S/N ratio depends on whether the quality characteristic is smaller-the-better, larger-the-better, or nominal-the-best (4, 8, 11, 12).

In our study, we adopt the “smaller is better” approach. The S/N ratio for this type of response was used and given below:

$$S/N = -10\log\left[\frac{1}{n}\sum_{i=1}^{n} y_i^2\right] \qquad (1)$$

Where; n is the number of experiments in the orthogonal array and y_i is the ith measured value.

Taguchi design has been applied many different areas, even in service systems (5). However, studies about application of Taguchi design in textile industry are very new. Some researchers used this design for different textile process (2, 5, 13-22). The effects of different characteristics of the structure of knitted fabrics on their spirality angle and prediction of spirality angle have been investigated by some researchers (23-27). In these studies, correlations between spirality angle and the structural parameters of fabrics like stitch length, tightness factor, yarn twist value, yarn linear density, number of courses and wales were investigated. In some of these studies, the regression equations were formed. In general, it was determined that yarn twist value, loop length and yarn linear density were the most important factors on fabric spirality in these studies. Also, any research has been conducted on the spirality angle of knitted fabrics from yarn and fabric parameters using Taguchi design. In the present study, it was focused on optimizing the yarn and fabric parameters affecting the spirality angle of single jersey fabrics. For this purpose, Taguchi experimental design technique was employed. Firstly, factors were chosen from cause-effect diagram, which has an effect on the spirality angle of the knitted fabrics. Taguchi’s parameter design approach has been used to plan, analyze and confirm the experiments.

Determination of design parameters

Due to the difficulty and cost of controlling certain parameters in practical scenarios, this study specifically emphasizes on factors associated with materials, which can be accepted as the major input.

During the relaxation treatment, knitted fabrics tend to go back to the original forms by getting away the stress. Since relaxation treatment has changed shape of the loop, it would be affect the spirality angle of fabrics. Also; the type of yarn production (ring, compact and open-end) impressed the physical features of yarns and fabrics produced from these yarns would be demonstrated different performance properties. If amount of yarn that is essential for one stitch are increased, the fabrics are looser and its weight decreases. Hence, some fabric performances are affected.

So, relaxation treatment, yarn type and loop length, effecting on spirality angle are selected as control factors. Here, yarn type is assumed as yarn parameter, relaxation treatment and loop length are assummed as fabric parameter effecting on spirality angle.

After determining the control factors, the levels of each factor have to be determined. The most commonly used yarn types were considered to determine the levels of the factors. Here, ring, compact and open-end yarns were selected as the yarn type. 0.25, 0.28, and 0.32 cm were selected as loop length (fabric tightness). Dry relaxation, wash relaxation and full relaxation were selected as relaxation type. Used yarns were produced at nearly closed machine settings each other. As a result, each of the control factors was evaluated with three levels.

2. MATERIAL AND METHOD

100% cotton Ne 30/1 yarns were knitted into single jersey structures on Orizio circular knitting machine (28-gauge 32-inch diameter, 2760 needle count, with a positive yarn feeding system). Yarn testing results are given in Table 1. Table 2 gives the levels of various parameters and their designation.

Table 1. Yarn properties

Parameter	Conventional ring yarn	Compact yarn	Open end yarn
	Ne 30	Ne 30	Ne 30
Actual count	29,36	29,36	28,80
Evenness U%	9,20	9,05	12,11
CVm %	11,60	11,40	15,23
Thin places (-50%)/km	0,3	0,0	59,2
Thick places (+50%)/km	7,1	6,6	75,3
Neps (+200%)/km	63,1	10,7	16,1
Hairiness	6,62	4,34	5,17
Breaking strength (gf)	354,1	381,9	226,2
Breaking elongation (%)	5,04	5,31	4,39
Rkm (kgf*Nm)	17,51	18,88	11,03
Breaking work (gf.cm)	482,7	535,6	283,2

Table 2. Parameters and their levels

		Levels		
Parameter	**Designation**	**1**	**2**	**3**
Relaxation treatment	A	Dry	Washing	Full
Yarn type	B	Ring	Compact	Open end
Loop length (cm)	C	0,25	0,28	0,32

The following relaxation treatments were applied to fabrics after knitting.

Dry relaxation: Fabrics were conditioned for at least 24 hours in the standard atmosphere (temperature: 20±2 ºC and relative humidity: 65±2%). *Washing relaxation:* After dry relaxation, fabrics were washed in a domestic washer at 30ºC min 45 using 0.05% wetting agent. After wetting, fabrics were briefly hydro extracted. Then they were conditioned in the same way as the dry relaxation method. *Full relaxation:* Washing relaxation procedure was repeated for five times. Before tests were taken, the fabrics were conditioned for 48 h in a standard atmosphere.

Measuring the angle of spirality, firstly by using colored yarn on the knit courses, the measuring areas are determined. It is taken into consider that for every fabric the measuring areas should be in the same limits. Spirality is measured from 5 points. The angle of spirality is measured by using a protractor between the specific course direction, signed by using a colored yarn and the wale direction, which is followed from this course direction. This test is applied according to the IWS 276 test method (28). The angle of spirality (θ*sp*) method is shown in Figure 3. All tests were performed under standard atmospheric conditions (temperature: 20±2 ºC and relative humidity: 65±2%).

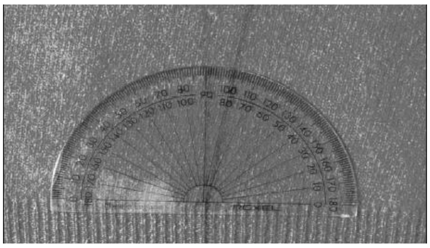


Figure 3. Measurement of the angle of spirality

An L_9 (3^3) orthogonal array table was used. With three factors, each having three levels, a total of 27 (3^3) full factorial experiments to explore all possible factor level combinations would be required, and the cost and effort of such experiments would be quite large. However, the experimental design of an orthogonal array required only nine experiments. The $L_9(3^3)$ orthogonal array table was shown in Table 3.

Table 3. Orthogonal matrix for sample production

	Parameters		
Order	**A**	**B**	**C**
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

3. RESULTS AND DISCUSSION

Briefly, the Taguchi optimization method consists of the following steps: Each S/N ratio can be obtained from observations according to the formula of lower the better. For each significant factor, the level corresponding to the highest S/N ratio is chosen as its optimum level. A search for the factors that have a significant effect on the S/N ratio is then performed through an analysis of variance (ANOVA) of the S/N ratios (2, 4). Table 4 shows the average value of the spirality angle of fabrics for each experimental point and the S/N ratios calculated by formula 1. It was seen that especially washing treatments and increasing the loop length rise the spirality angle in the previous studies to be used the similar materials. Closer results were also found in this study.

For all levels, it was obtained average SNR as shown in Table 5. Main effects plotted for SNR is shown in Figure 4. The largest S/N ratio (these were indicated by rounding in the graph) for each factor would be preferred. It implied that the largest impact in process consist of $A_1B_3C_1$ respectively. Minimum spirality degree levels configuration for SNR are $A_1B_3C_1$ which means that A (dry relaxation), B (open end yarn), C (0.25 cm loop length).

Table 4. Experimental layout using an L_9 orthogonal array table and S/N ratio of experimental results

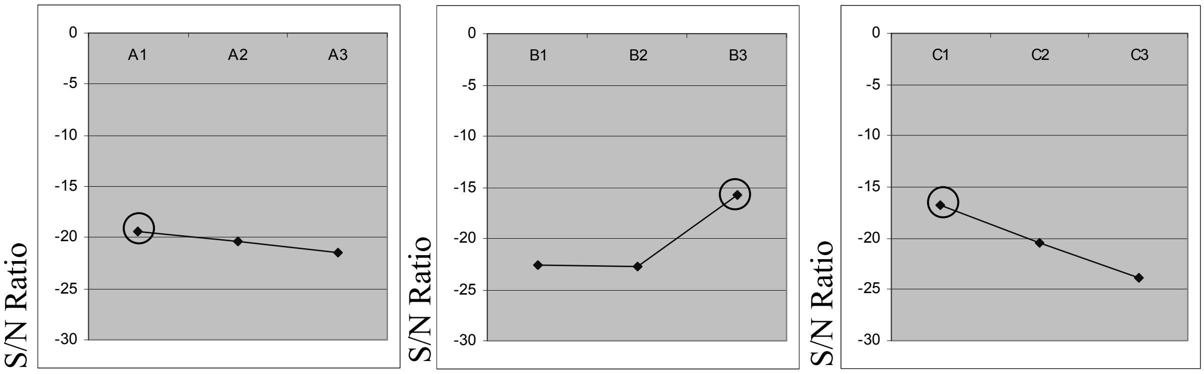
	Factors and levels				
Exp. no	**A**	**B**	**C**	**Average spirality angle (º)**	**S/N ratio (dB)**
1	DR	RY	0,25	8,2	-18,28
2	DR	CY	0,28	12,0	-21,64
3	DR	OEY	0,32	8,0	-18,09
4	WR	RY	0,28	13,2	-22,42
5	WR	CY	0,32	21,4	-26,61
6	WR	OEY	0,25	4,0	-12,15
7	FR	RY	0,32	22,4	-27,01
8	FR	CY	0,25	10,0	-20,02
9	FR	OEY	0,28	7,2	-17,19

DR: Dry relaxation, WR: Washing relaxation, FR: Full relaxation, RY: Ring yarn, CY: Compact yarn, OEY: Open end yarn

Table 5. Response table for S/N ratio

Factors	**Average S/N (dB)**			
	Level 1	Level 2	Level 3	Delta
A- Relaxation type	-19.34*	-20.39	-21.41	2.07
B- Yarn type	-22.57	-22.75	-15.81*	6.94
C- Loop length	-16.82*	-20.42	-23.90	7.08

*: Optimum parameter level



(a) **(b)** **(c)**

Figure 4. The effect of process parameters on S/N data-Factor A (relaxation type), factor B (yarn type), factor C (loop length)

Table 6. ANOVA table for the S/N

Factors	**Sum of squares**	**Degree of freedom**	**Mean square**	**F value**	**Prop**	**Percentage contribution (%)**
Model	175,75	6	29,29	128,17	0,0078	-
A	6,43	2	3,21	14,06	0,0664	3,65
B	93,99	2	46,99	205,62	0,0048	53,34
C	75,34	2	37,67	164,82	0,0060	42,75
Residual	0,46	2	0,23			0,26
Total	176,21	8				
R-squared: 0,997						

3.1. ANOVA analysis

Statistical methods are powerful tools for extracting useful information contained in data and ANOVA is one of the most frequently used tools (6). ANOVA is the quantitative measure of the influence of individual factors/ parameters. It is important for determining the relative importance of the various factors/parameters (29).

The end of results of S/N analysis was used for realization of ANOVA. That allows defining which factor and in which level influences the final results of experiments. ANOVA was performed for S/N ratios with Design

Expert 6.0.1 statistical program ($\alpha=0.05$). An ANOVA table for S/N ratio was given in Table 6.

The sum of squares, mean square, F value, residual and also percentage contribution of each factor were shown in above ANOVA table. The degrees of freedom (df) for each factor is calculated as:

df = number of level – 1

With respect to Table 6, prob values lower than 0.05 shows that the established model is meaningful. Since the value of R^2 is 0.997, expressiveness of the model is high. This indicated that yarn type (B) and loop length (C) the most significant effect on fabric spirality values. The contribution of different factors in decreasing order as: Yarn type (53.34 %), loop length (42.75 %), relaxation type (3.65 %) and undefined parameters (0.26 %).

3.2. Confirmation experiment

Based on the S/N ratios and ANOVA analyses, the optimal levels of all the control factors' combination were identified. As mentioned before the optimum setting of parameters is $A_1B_3C_1$. A confirmation experiment is the final step of a design of experiment. Its purpose is to verify that the optimum conditions suggested by the matrix experiment do indeed give the projected improvement. The confirmation experiment is performed by conducting a test with optimal settings of the factors and levels previously evaluated. The predicted value of multiple S/N ratio at optimum level (η_0) is calculated by formula 2.

$$\eta_0 = \eta_m + \sum_{i=1}^{j} \left(\eta_i - \eta_m\right) \qquad (2)$$

Where, j is the number of factors and η_m is the mean value of multiple S/N ratios in all experimental runs, η_i are the multiple S/N ratios corresponding to optimum factor levels (12, 30).

S/N ratio calculated for optimum level as follow:

$$\eta_o=\eta_m+(\eta A_1-\eta_m) + (\eta B_3-\eta_m)+(\eta C_1-\eta_m) \qquad (3)$$

η_o is optimum S/N ratio, η_m is the overall mean of S/N values, ηA_1 is the average value of S/N at first level of relaxation type, ηB_3 is the average value of S/N at the third level of yarn type and ηC_1 is the average value of S/N at first level of loop length. According to the formula 3, η_o was found as -11.21 dB.

If the S/N is known and we want to learn about the expected result that will make the S/N. The procedure is to back-transform S/N to find expected performance value (8, 31).

When -11.21 dB value could be set formula 1, obtained value is 3.63°. Values of spirality angle of other combinations will be expected with same formula.

Also, knitted fabric was produced according to the optimum design and initial design. Spirality angle of these fabrics was measured from five different places of fabric. Average of the results was determined as 4,20° for optimum design (Table 7). This result is very close to the result estimated by Taguchi design (3,63°).

Initial design is accepted as $A_1B_1C_1$ then S/N ratio is obtained according to the initial and optimum design how much profit is provided to find with Taguchi design (Table 7).

Table 7 show that the improvement in S/N ratio at the optimum level was found to be 5,46 dB. The value of spirality angle (°) at this optimum level is 4,20 against the initial parameter setting of 8,0. As a result, the decrease in the value of spirality angle can be obviously seen.

3.3. Prediction of spirality angle of other conditions using Taguchi design

According to the Taguchi design, it was predicted the values of spirality angle of knitted fabrics for seven conditions (order) using formula 1 and 2. Predicted values were given with their experimental results in Table 8.

Also, the values of percentage relative error are evaluated, since software to be used, shortening the numbers by computer, personal mistakes are considered.

As seen from Table 8, experimental results and the predicted values are much closed.

Table 7. Results of optimum and initial design

	Initial	**Optimum levels**	
		Prediction	**Experimental**
Design	$A_1B_1C_1$	$A_1B_3C_1$	$A_1B_3C_1$
Performance values (°)	8,0	3,63	4,20
S/N (dB)	-18,07	-11,21	-12,61

Table 8. Comparison of experimental results with the predicted values from Taguchi design

Order	**A**	**B**	**C**	**Experimental (measured)**	**Predicted with Taguchi design (calculated)**	**% Relative error**
1	2	2	1	8,22	9,12	10,90
2	1	2	3	19,62	18,26	6,93
3	2	3	2	6,00	6,21	3,50
4	2	1	3	18,11	20,18	11,4
5	2	2	2	13,00	13,80	6,15
6	3	3	1	5,10	4,61	9,61
7	3	1	2	14,67	15,20	3,60

4. CONCLUSIONS

In this research, we intended to a process for optimizing single jersey fabric conditions using Taguchi design to minimize the spirality angle of single jersey fabrics. Firstly, important affecting parameters for the spirality angle of single jersey fabrics were determined as relaxation type, yarn type and loop length and an L_9 orthogonal array was used in planning the Taguchi experiments.

Based on the S/N ratio and ANOVA analyses, yarn type and loop length the most significant effect on fabric spirality angles. Also, the optimum levels of these parameters obtained in this paper, which was $A_1B_3C_1$; this corresponds to relaxation type of dry relaxation, yarn type of open end yarn, loop length of 0,25 cm. In addition to this, S/N ratio has been considerably improved as compared to initial parameter settings of the experiment. Closeness of the results of the predictions based on the calculated S/N ratios and experimental values show that Taguchi experimental design technique can be used successfully both optimization and prediction.

As the loop length increases, spirality angle increases. The reason for this behavior can be explained by concerning the chance of loops to turn freely in loose fabric structure. Spirality angle can also be increased by the activity of fabric tending to reach relaxation with washing process and exchanges created by the wet process. As already known, twist direction in open end spinning is from inward to outward, opposite of the ring and compact spinning. So the amount of twist is lower at the outer region with respect to the inner region in open end yarns. This means, the amount of torque created in open end spinning is lower with respect to ring and compact spinning during the knitting process. Because of these reasons, it is predicted that the spirality angle of a fabric knitted by open end yarns is lower. Also lower values of twist tendency created by yarn twist in open end yarns support these results.

The main advantage of the Taguchi parameter design, as opposed to the classic factorial design methods, lies in the introduction of noise factors in the experimentation which provoke an uncontrolled variation leading to a noise insensitive response, therefore to higher reproducibility. Taguchi approach provides systematic, simple and efficient methodology for the optimization of the near optimum design parameters with only a few well-defined experimental sets and determine the main factors to affect the process. Taguchi design is an important tool for robust design. It offers a simple and systematic approach to optimize design for performance, quality and cost.

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