(REFEREED RESEARCH)

MOORA-BASED TAGUCHI OPTIMIZATION FOR SELECTION OF MURATA VORTEX SPINNER MACHINE PARAMETERS

MURATA VORTEKS EĞİRME MAKİNESİ PARAMETRELERİNİN SEÇİMİ İÇİN MOORA TABANLI TAGUCHI OPTIMIZASYONU

Esra AKGÜL[1], Emel KIZILKAYA AYDOĞAN[2*], Diyar AKAY[3], Hüseyin Gazi TÜRKSOY[4]

[1] *Department of Industrial Design Engineering, Erciyes University, Kayseri, Turkey*
[2] *Department of Industrial Engineering, Erciyes University, Kayseri, Turkey*
[3] *Department of Industrial Engineering, Gazi University, Ankara, Turkey*
[4] *Department of Textile Engineering, Erciyes University, Kayseri, Turkey*

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ABSTRACT

Murata Vortex Spinner (MVS) is accepted as one of the most promising new generation air jet spinning technology. Selection of optimum MVS machine parameter which affects properties of the final yarn is difficult and complex task in textile industry. This study proposes the Multi-Objective Optimization on the Basis of Ratio Analysis (MOORA) - based Taguchi approach to select optimum nozzle pressure and delivery speed among available alternatives for cotton MVS yarn. The performances of these parameters are evaluated based on seven quality characteristics of MVS spun yarn using this method.

Keywords: Yarn Quality, MOORA, Taguchi Method, MVS, Optimization

ÖZET

Murata Vortex Eğirme (MVS) en umut verici yeni nesil hava jetli eğirme teknolojilerinden biri olarak kabul edilmektedir. Nihai iplik özelliklerini etkileyen optimum MVS makine parametresi seçimi tekstil sektöründe zor ve karmaşık bir görevdir. Bu çalışmada, MVS pamuk ipliği için, mümkün olan alternatifler arasından optimum düze basıncı ve üretim hızını seçmek için Multi-Objective Optimization on the Basis of Ratio Analysis (MOORA) tabanlı Taguchi yaklaşımı önerilmiştir. Bu parametrelerin performansları, bu method kullanılarak eğrilmiş MVS ipliklerinin yedi kalite karakteristiğine dayandırılarak değerlendirilmiştir.

Anahtar Kelimeler: İplik Kalitesi, MOORA, Taguchi Metodu, MVS, Optimizasyon

Corresponding Author: Emel Kızılkaya Aydoğan e-mail: ekaydogan@erciyes.edu.tr

1. INTRODUCTION

Murata Vortex Spinner (MVS) technology is a new generation of air jet spinning systems, firstly introduced to market by Murata Machinery in Japan in 1997, and is accepted as a successful commercial implementation of staple yarn spinning technology [1]. MVS technology differs from other classical spinning systems with high production speed up to 500 m/min which is approximately 20 times faster than ring spinning and 3 times faster than open end rotor spinning systems. Also, this system has low maintenance cost and elimination of processing stage comparatively ring spinning [1, 2].

Besides the distinctive features of the systems, vortex yarn with ring-like structure and fabrics are claimed to have several superior advantages such as low hairiness, reduced fabric pilling, better abrasion resistance, high moisture absorbsion and diffusion properties, quick dry characteristics and better durability enabling high functionality over a long period [1,3,4]

In MVS technology, the sliver is fed to four roller/apron drafting unit. As the fibers come out of the front rollers, they are sucked into the spiral shaped opening of air jet nozzle, which provides a swirling air current to twist the fibers. The movement of the fibers towards a hollow spindle is controlled by a guide needle within the nozzle. The leading ends of the fiber bundle are drawn into the hollow spindle by the fibers of the preceding portion of the fiber bundle being twisted into a spun yarn. The finished yarn is then wound onto a package [2, 5, 6].

MVS yarn properties are influenced by different machine parameters such as nozzle pressure, delivery speed, draft ratio, nozzle angle, distance between front roller nip point and spindle, spindle diameter and others [6-10]. Also, the relatively new technologies should make to their own knowledge to optimise machine parameters for better outcomes with the desired final yarn properties. It is observed that the effects of the process parameters on the properties of MVS yarn have usually been examined with classical statistically approach [6-11]. In addition, the earlier works on identifying machine parameters for producing MVS yarn are determined by traditional experimental design, which requires a number of experiments that entails more cost and manpower waste.

On the other hand, Taguchi method can improve process quality, reduce the number of experiments, minimize the processing variation and maintenance and promote a steady quality. However Taguchi method is used to optimize a single quality characteristic [12-16]. Therefore, when MVS machine parameters for MVS yarn which has multiple quality characteristics are to be optimized with Taguchi method, Multi Criteria Decision Making (MCDM) methods can be implemented to turn multiple quality characteristics into single quality characteristic by decision maker. MCDM based Taguchi applications such as Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) based Taguchi, Vlse Kriterijumska Optimizacija I Kompromisno Resenje (VIKOR) - based Taguchi, Grey Relational Analysis (GRA) - based Taguchi, Multi-Objective Optimization on the Basis of Ratio Analysis (MOORA) - based Taguchi have applied to solve multi-responsible problems for different studies [17-23]. There exists yet no work in the literature focusing on the determination of MVS machine parameters among alternatives using MOORA-based Taguchi method.

Although, a lot of MCDM methods are available to select appropriate parameters for different spinning technologies such as TOPSIS, GRA, VIKOR, PROMETHEE [24-27], in this study we proposed to use the MOORA-based Taguchi method which is quite simple, less time-consuming, and there is no need for complex mathematical calculations compared to other MCDM based Taguchi such as TOPSIS, GRA, VIKOR.

In this paper, the effects of nozzle pressure and delivery speed of MVS machine on cotton yarn quality characteristics were investigated Taguchi method based on MOORA. Finally, the best combination of performance characteristics of the MVS machine parameters (nozzle pressure and delivery speed) was determined for cotton yarn quality characteristics by applying this method.

2. MATERIALS AND METHOD

2.1. Materials

In order to select appropriate nozzle pressure and delivery speed, cotton fiber with 4.45 micronaire, 29.89 mm 2.5% span length, uniformity ratio of 46.6, uniformity index of 82.6, breaking elongation of 5.2% and strength of 28.81 g/tex was used for producing Ne 40 MVS yarn. The cotton carded yarn samples were produced on the MVS 851 model spinning machine which origin from Japan. In order to improve fiber alignment and sliver evenness, three passages of drawing process were used for MVS spinning efficiency and after three passages of drawing; the slivers with a linear density of 2.48 ktex were transferred to MVS 851 machine.

There were two main parameters in MVS machines, including nozzle pressure of 4, 5, 6 kgf/cm^2 and delivery speed of 300, 350, 400 m/min. These values were chosen according to the limits which stated in the Instruction Manual of MVS 851 [5]. Nine different yarn samples with specifications have been shown in Table 1.

Table 1. Yarn samples and process parameters

Alternative	Nozzle pressure (kgf/cm^2)	Delivery speed (m/min)
K1	4	300
K2	4	350
K3	4	400
K4	5	300
K5	5	350
K6	5	400
K7	6	300
K8	6	350
K9	6	400

All yarn samples were produced 70^0 nozzle discharge angle, 2P130d L7-9, 3 type needle holder, 1.2 mm spindle inner diameter, 36-36-49 mm top roller gauges and 36-36-44.5 mm bottom roller gauges spinning conditions on the MVS 851 spinning machine.

Quality characteristics of yarn were tested on an Uster Tester 4 SX for yarn unevenness (CVm %), imperfections which are thin places (-50%)/km, thick places (+50%)/km and neps (+200)/km, and hairiness (Uster index). Rupture per kilometer (RKM) and elongation (%) were tested on an Uster Tensorapid 3. Test results are given in Table 2. All results were obtained from ten iterative tests.

2.2. MOORA-Based Taguchi Method

Taguchi method is a statistically technique developed by Genichi Taguchi to estimate optimum process condition for experiments using orthogonal arrays [28-30]. Improving the product quality, reducing the number of experiments, minimizing the process variation and maintaining and promoting a steady quality are the aims of Taguchi methodology [18]. Although, it has been extensively used in the optimization of single response problem [12- 13, 15-19], this study proposes a multi response optimization approach with the help of MCDM based Taguchi method to determine the optimal nozzle pressure and delivery speed for Ne 40 MVS yarn. The MOORA method is used to convert the multi response optimization problem into a single response problem for this study. The application steps of MOORA-based Taguchi model are provided in Figure (1).

Table 2. Results of yarn quality characteristics

Alternative	RKM (kgf*Nm)	Elongation (%)	CVm (%)	(-50%)/km	(+50%)/km	Neps (+200%)/km	Hairiness (Uster index)
K1	13,02	4,82	19,1	388,3	514,8	650,8	3,98
K2	11,57	4,24	18,66	374,5	496,5	433,5	4,2
K3	9,97	3,71	19,67	530	677,3	478	4,98
K4	13,8	5,1	19,12	375	508,3	798,3	3,89
K5	12,41	4,5	18,82	349	470,8	460,8	4,43
K6	11,26	4,05	19,32	451	609	484,3	4,49
K7	13,21	5,27	19,44	438,3	527,5	1010,5	3,8
K8	13,55	4,92	19,23	413,5	549,5	593,8	4,13
K9	12,25	4,33	19,33	472,5	660	508,8	4,3

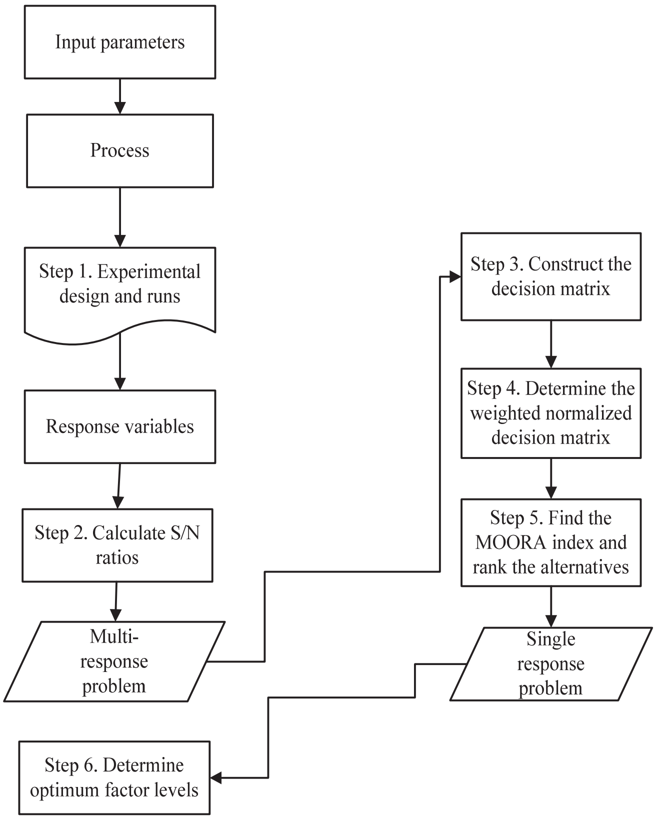

Figure 1. Flowchart of the MOORA-based Taguchi method

Step 1. The suitable orthogonal array is determined to study the quality characteristics of yarn with a small number of experiments. In this study, L_9 (3X3) orthogonal array containing 9 groups of experiment is employed.

Step 2. The signal-to-noise (S/N) ratio is the most useful way to obtain the quality characteristics deviating from the desired value [30, 31]. The method of calculating the S/N ratios depends on whether the quality characteristic is lower-the better, higher-the-better or nominal-the-best [29, 31]. The calculation of S/N ratios for the lower the better, higher the better and nominal the best is given by Eq. (1-3), respectively.

$$\eta_{ij} = -\frac{10\log 1}{n}\sum_{k=1}^{n} y_{ijk}^{2} \qquad (1)$$

$$\eta_{ij} = -10log\left(\frac{1}{n}\sum_{k=1}^{n}\frac{1}{y_{ijk}^{2}}\right) \qquad (2)$$

$$\eta_{ij} = \frac{10\log\left(\bar{y}_{ij}^{2}\right)}{S_{ij}^{2}} \qquad (3)$$

$$\bar{y}_{ij} = \frac{1}{n}\sum_{k-1}^{n} y_{ijk} \;;\; S_{ij}^{2} = \frac{1}{n-1}\sum_{k-1}^{n}\left(y_{ijk} - \bar{y}_{ij}\right)^{2} \qquad (4)$$

η_{ij} is the S/N ratio for the response j of scenario i, and y_{ijk} is the experiment's result for response j of scenario i in the kth replication, n total replications, $\bar{y}_{ij}$ is the average of the observed data; and S_{ij}^{2} is the varience of y_{ij} [18, 19, 22].

Once S/N ratios for each response of all experiments are available, the multiple response problem can then be converted to a single response problem with the following steps with MOORA method.

Step 3. The MOORA, a kind of MCDM method, is firstly introduced by Brauers in 2004 [32]. This method starts with a decision matrix presented in Eq. (5) showing the performance of different alternatives with respect to various attributes [22, 33, 34]

$$X = \begin{bmatrix} \eta_{11} & \eta_{12} \cdots & \eta_{1n} \\ \eta_{21} & \eta_{22} \cdots & \eta_{2n} \\ \eta_{31} & \eta_{32} \cdots & \eta_{3n} \\ \cdots & \cdots & \cdots \\ \eta_{m1} & \eta_{m2} \cdots & \eta_{mn} \end{bmatrix} \qquad (5)$$

where η_{ij} performance measure of i^{th} alternative on j^{th} attribute, m is the number of alternatives and n is the number of attributes.

Step 4. The performance measure is normalized with Eq. (6). In some instances, some attributes can be less important than the others. In order to give less importance to attribute, it should be multiplied with its corresponding weight [34]. The weighted normalized matrix in Eq. (8) is obtained using Eq. (7). Here, the weight of the response j, determined with the contribution of 19 experts' opinions who are academicians or professional in textile industry, is represented by w_j where.

$$\eta_{ij}^{*} = \frac{\eta_{ij}}{\sqrt{\sum_{i=1}^{m} \eta_{ij}^{2}}} \quad i=1,2,......m;\ j=1,2,......r \qquad (6)$$

$$Y_{ij} = \eta_{ij}^{*} w_j \qquad (7)$$

$$W = [Y_{ij}]_{mxn} \qquad (8)$$

where η_{ij}^{*} is a number without an unit representing the normalized S/N ratio of scenario i on response j.

Step 5. The MOORA index, determining the ranking scores, is calculated using Eq. (9). Here, the weighted normalized values are added in the case of maximisation (for beneficial attributes) and subtracted in the case of minimisation (for non-beneficial attributes) [33,35] Then, the problem becomes;

$$Y_{ij}^{*} = \sum_{j=1}^{t} Y_{ij} - \sum_{j=t+1}^{r} Y_{ij} \qquad (9)$$

where t is the number of maximized responses, (r-t+1) is the number of responses to be minimized, and $[\![(Y]\!]_{\downarrow i}^{\uparrow *}$) is the ranking score of i[th] scenario with respect to all responses. Then, the highest $[\![(Y]\!]_{\downarrow i}^{\uparrow *}$) value is the best alternative, while the worst alternative has the lowest $[\![(Y]\!]_{\downarrow i}^{\uparrow *}$) value.

Step 6. The multi response performance results for each alternative are converted into a single response score with the MOORA index $[\![(Y]\!]_{\downarrow i}^{\uparrow *}$). Finally, the Taguchi method is applied to select optimum machine parameters, in view of the fact that a larger MOORA value $[\![(Y]\!]_{\downarrow i}^{\uparrow *}$) indicates the better result.

3. RESULTS AND DISCUSSIONS

The assessment of the optimum nozzle pressure and delivery speed of MVS 851 machine parameters is an important issue to obtain desired yarn properties. In this study, nozzle pressure and delivery speed are taken as control factors having three control levels that affect the MVS spun yarn quality. Additionally, L_9 orthogonal array (9 tests, 3 variables, 3 levels) is preferred to configure the machine parameters for experiments on desired Ne 40 cotton yarn. The control factors, their levels and L_9 orthogonal array are shown in Table 3.

Considering the target value of yarn quality, unevenness (CVm %), thin places (-50%), thick places (+50%), neps and hairiness are identified as the smaller the better type while RKM and elongation are defined as the larger the better type. The weights for each quality characteristics obtained from experts are presented in Table 4.

The mean values for each alternative, which were run for ten replications, are shown in Table 2. Then, the experimental data were used to calculate the S/N ratio of each alternative's response by using Eq. (1-2). The S/N ratio of each alternative is shown in Table 5, and this table forms the decision matrix.

Following the S/N ratios, the MOORA was implemented to find the MOORA indexes $[\![(Y]\!]_{\downarrow i}^{\uparrow *}$) using Eq. (6-9), providing the multi-response problem to be converted into a single response problem. The MOORA indexes are shown in Table 6.

Table 3. Control factors & levels and Taguchi orthogonal array

Alternative	**Control factors and levels**		**L_9 orthogonal array**	
	Nozzle pressure (kgf/cm^2) (A)	Delivery speed (m/min) (B)	Nozzle pressure (kgf/cm^2) (A)	Delivery speed (m/min) (B)
K1	4	300	1	1
K2	4	350	1	2
K3	4	400	1	3
K4	5	300	2	1
K5	5	350	2	2
K6	5	400	2	3
K7	6	300	3	1
K8	6	350	3	2
K9	6	400	3	3

Table 4. Quality characteristics and weights

Yarn quality characteristics	**Target values**	**Weights**
RKM (kgf*Nm)	Larger is better	0,144
Elongation (%)	Larger is better	0,134
Unevenness (CVm %)	Smaller is better	0,152
Thin places (-50%) per km	Smaller is better	0,134
Thick places (+50%) per km	Smaller is better	0,134
Neps (+200%) per km	Smaller is better	0,144
Hairiness (Uster index)	Smaller is better	0,152

Table 5. S/N ratios for Ne 40 MVS spun yarn

Alternative	RKM (dB)	Elongation (dB)	CVm (dB)	(-50%) (dB)	(+50%) (dB)	Neps (dB)	Hairiness (dB)
K1	22,292	13,660	-25,620	-51,783	-54,232	-56,269	-11,997
K2	21,266	12,547	-25,418	-51,469	-53,918	-52,739	-12,465
K3	19,973	11,387	-25,876	-54,485	-56,615	-53,588	-13,944
K4	22,797	14,151	-25,629	-51,480	-54,122	-58,043	-11,799
K5	21,874	13,064	-25,492	-50,856	-53,456	-53,270	-12,928
K6	21,037	12,149	-25,720	-53,083	-55,692	-53,702	-13,044
K7	22,416	14,436	-25,773	-52,835	-54,444	-60,090	-11,595
K8	22,639	13,839	-25,679	-52,329	-54,799	-55,472	-12,319
K9	21,762	12,729	-25,724	-53,488	-56,390	-54,130	-12,669

Table 6. The weighted normalized decision matrix and MOORA indexes

Alternative	Rkm (kgf*Nm)	Elongation (%)	CVm (%)	(-50%)/km	(+50%)/km	Neps (+200%)/km	Hairiness (Uster index)	MOORA index	Rank
K1	0,049	0,046	-0,050	-0,044	-0,044	-0,049	-0,048	0,332	5-6
K2	0,047	0,042	-0,050	-0,044	-0,044	-0,045	-0,050	0,324	9
K3	0,044	0,038	-0,051	-0,046	-0,046	-0,046	-0,056	0,330	5-6
K4	0,050	0,048	-0,050	-0,044	-0,044	-0,050	-0,047	0,336	2
K5	0,048	0,044	-0,050	-0,043	-0,043	-0,046	-0,052	0,329	7
K6	0,046	0,041	-0,050	-0,045	-0,045	-0,046	-0,052	0,329	8
K7	0,049	0,049	-0,051	-0,045	-0,044	-0,052	-0,046	0,338	1
K8	0,050	0,047	-0,050	-0,044	-0,044	-0,048	-0,049	0,335	3
K9	0,048	0,043	-0,050	-0,045	-0,046	-0,047	-0,051	0,332	4

According to the MOORA indexes, the optimal factor levels of nozzle pressure and delivery speed as determined as A_3 (nozzle pressure: 6 kgf/cm^2) and B_1 (delivery speed: 300 m/min). Therefore, level 3 of nozzle pressure and level 1 of delivery speed are the best levels for Ne 40 cotton MVS yarn (see Figure 2). The value of A1, A2, A3, B1, B2, B3 is calculated as follows;

For A1; = (K1+K2+K3)/3

For A2; = (K4+K5+K6)/3

For A3; = (K7+K8+K9)/3

For B1; = (K1+K4+K7)/3

For B2; = (K2+K5+K8)/3

For B3; =(K3+K6+K9)/3

The weights of quality characteristics are also chosen as equally to test the stability of the purposed levels of nozzle pressure and delivery speed. The MOORA based Taguchi method was applied to recalculate the optimum levels of machine parameters with equal weights, which is 0,142857, i.e., 1/7. The Table 7 shows that the levels of nozzle pressure and delivery speed performance for all scenarios. The quality characteristics with equal weights do not change the optimal levels achieved with the initial set of weights.

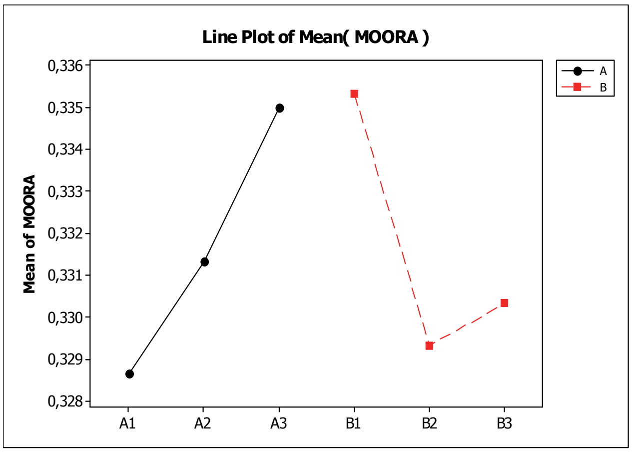

Figure 2. The main effects plot for nozzle pressure (A) and delivery speed (B) according to MOORA index

Table 7. Optimum setting control factors for different weighted

Scenerio	Weights							Optimum setting control factors
	RKM (kgf*Nm)	Elongation (%)	CVm (%)	(- 50%) /km	(+50%) /km	Neps (+200%) /km	Hairiness (Uster index)	
1	0.144	0,134	0,152	0,134	0,134	0.144	0,152	A_3B_1
2	0,142	0,142	0,142	0,142	0,142	0,142	0,142	A_3B_1

4. CONCLUSION

In this study, the MOORA-based Taguchi method is used to select optimum nozzle pressure and delivery speed of MVS machine parameters for Ne 40 cotton MVS spun yarn. The MOORA method is combined with the Taguchi method to transfer multi-response yarn quality characteristics problem into a single response problem. Nine yarn samples were manufactured according to Taguchi's experimental design. Seven quality characteristics of yarn samples were converted into a single response by the MOORA method. As a result of evaluations, nozzle pressure and delivery speed of MVS 851 machine parameter were determined as 6 kgf/cm^2 and 300 m/min respectively for desired yarn quality, and this finding is stable when the values of the indifference and preference threshold values are changed. The result of the MOORA-based Taguchi method shows that nozzle pressure and delivery speed are important factors for affecting the yarn quality characteristics. Consequently, the proposed method can be applied to select the optimum performance of machine parameters among possible alternatives and thereby helping MVS spun yarn producers to increase their quality and productivity. The MOORA based Taguchi method is also easy to apply without a high computational burden, promoting its widespread application in textile industry.

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