ICIC Express Letters
Part B: Applications
Volume **11**, Number **10**, October **2020**

ICIC International ©2020 ISSN 2185-2766
pp. **939–944**

A STUDY ON THE APPLICATION OF TAGUCHI SN RATIO TO RSM IN A HIGH NOISE PRODUCTION ENVIRONMENT

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Received February 2020; accepted May 2020

Abstract. *In an environment where the uncontrollable noise effects are large and affect production, there are cases where the effects are not obtained using existing experimental planning techniques. This is because there is noise in the field that cannot be controlled. In this paper, we propose a method for applying SN [Signal-Noise] Ratio of Taguchi method, which minimizes noise effects, to RSM [Response Surface Method] method, which proposes optimal solutions. This method combines the advantages of the Taguchi method which is resistant to noise and the advantages of the RSM method which presents optimal values within the experimental range. In this paper, a paper helicopter was built and tested to prove the proposed method. Equipment which allowed for the elimination of measurement error was also manufactured and tested. This paper contributes to the feasibility of this method with accurate experimental data. In the future, this method is expected to be applied in the field to improve productivity.*
Keywords: RSM, Taguchi method, SN ratio, Paper helicopter

1. **Introduction.** Quality engineers try to apply Six Sigma and other quality improvement techniques such as DOE (Design of Experiments) to the field of industrial production. However, some companies are disappointed that DOE effects are not substantial enough. DOE has been tested and improved in controlled environments (such as a controlled laboratory), but there are variables that cannot be controlled in experiments conducted at the production site. For example, workplace conditions (such as temperature and humidity), fatigue of workers, inconsistent quality of raw materials, and deterioration of machines are inevitable and uncontrollable variables. This is exacerbated in the case of SMEs (Small and Medium-sized Enterprises), where it is impossible to strictly control all such variables for economic reasons.

The DOE techniques suitable for these sites are Taguchi methods. Taguchi methods have been proven to be successful in the field [3]. Taguchi methods are a technique of obtaining a good solution that minimizes noise conditions. Taguchi methods reduce variation of characteristic values by finding noise-resistant control factor conditions that affect characteristic values. Taguchi methods should be tested in various conditions according to the noise level. The number of experiments required depends on the noise level. Taguchi methods find the optimum condition by selecting the control factors level with SN [Signal-Noise] ratio [2,6,8-10]. The SN ratio with which to measure the variation of the characteristic value, which is the experimental result, is calculated as the representative value of the experiment to find the optimum condition. The SN ratio formula is shown in Table 1 [3].

The RSM [Response Surface Method] gives an optimal value by using regression equations according to the experimental results with 2 or 3 influential key control factors.

DOI: 10.24507/icicelb.11.10.939

TABLE 1. Static quantity characteristic value SN ratio formula

Static quantity characteristic value	SN ratio formula
Smaller better characteristic	$SN = -10\log_{10}\sum_{i=1}^{n}\frac{y_i^2}{n}$
Larger better characteristic	$SN = -10\log_{10}\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}$
Target characteristic	$SN = 10\log_{10}\left(\frac{\bar{y}}{V}\right)^2$

The disadvantage of the RSM is that it is difficult to apply it realistically due to the increase in the number of experiments required if there are many control factors. If there are no noise conditions, then RSM finds the best excellent optimum condition [5]. RSM, however, cannot provide effective improvements with noise in the field.

We propose a new method which is combining RSM and Taguchi SN ratio in noisy production environments. This method is a new approach and can be employed effectively and practically in the field. To prove this idea, we devised a paper helicopter experiment, in which we made a special device to measure the fall time of the paper helicopter. The device helped to eliminate measurement error. The program for the experiment analysis used was Minitab 14 version.

This paper is introduced in Chapter 1, and Chapter 2 examines previous studies on Taguchi and RSM integration. In Chapter 3, the procedure of applying the new technique is presented in this paper, and paper helicopter experiments to prove it and analyzed. The final conclusion suggests the usefulness of this technique.

2. **Survey Integration of Taguchi and RSM.** The research contents related to the integration of Taguchi and RSM methods are as follows. Leon et al. [4] proposed a parameter design method using PerMIA (Performance Measure Independent of Adjustment) as an alternative to Taguchi SN ratio. However, this method has the disadvantage of being difficult to use when there is not enough prior knowledge in that the model for the characteristic value should be known in advance. Vining and Myers [11] have also suggested ideas for the fundamental integration of Taguchi and RSM methods. The idea was mainly mathematically proved by RSM and presented as a dual-response surface technique. However, it is difficult to practically use in the field. Jang [1] insisted that the Taguchi method has problems regarding the SN ratio and that it is difficult to distinguish between inner and outer arrangements, suggesting instead that a central composite design method could be more useful. Ree [7,10] proposed that Taguchi methods be used to select the important factors of the many control factors used in RSM.

Although there have been many attempts to bundle Taguchi and RSM methods into one method, there are no methods that are currently being used in the field as of yet. We did not find any papers citing RSM using Taguchi SN such as the one that is being proposed in this paper.

3. **Method of Combining RSM and Taguchi SN Ratio in Noise Production Environment.** The new method used RSM analysis with characteristic values converted from experiments values to Taguchi SN in a noisy production environment. Since this method is not a method to modify the structure of the existing method, it is not proved by any mathematical formula. Rather, the practicality and feasibility of this method are proven by actual experiments.

The application of this method proceeds in the following order.

1) Select 2-3 core control factors that much affect the characteristic value.

2) Define the noise factors that greatly affect the characteristic values in a noisy production environment, and identify strong and weak levels of noise factors.
3) Present the RSM experiment plan conditions using Minitab software.
4) Add the noise levels in the presented experimental plan condition.
5) Perform an experiment to obtain the characteristic value according to noise level.
6) Convert characteristic values obtained by experiment into Taguchi SN ratios which are in turn used as a representative value of characteristic values.
7) RSM analysis is performed using the representative value calculated SN ratio to find the optimum condition.
8) Check if given solution is optimal.

Since there is difficulty establishing a factory to perform the above method in the field, in this paper, we opted to experiment with a paper helicopter in a laboratory.

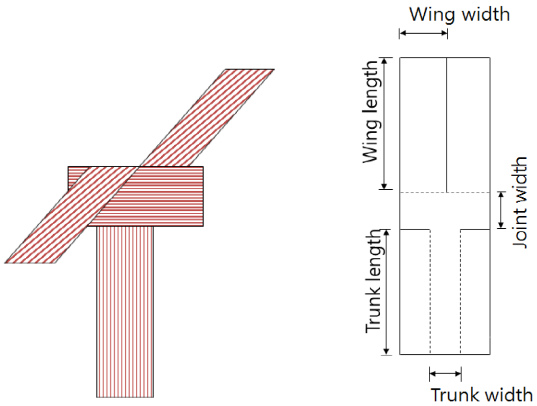
3.1. **Paper helicopter experiment device.** For this experiment, we made a special device to measure the fall time of a paper helicopter. We experimented with the paper helicopter according to order of the experiment. The paper helicopter was created as shown in Figure 2(a), which we had hoped would hover long time in the air. The biggest error in paper helicopter experiments concerns time measurement. The falling time at 2 meters is between 1 and 2 seconds, since the operator operates the stopwatch manually, it is difficult to consistently measure when repeatedly tested. The measured data had 0.4 seconds or more error rendering the data unreliable. Paper helicopter experiments are difficult to obtain reliable data without resolving the issue of time measurement.

(a) (b) (c)

Figure 1. Drop test instrument of paper helicopter. (a) The scene fixed at the top of the paper helicopter; (b) dropping the disc on the sensor look of paper helicopter; (c) fall time measurement machine of paper helicopter.

In order to solve the time measurement issue plaguing paper helicopter experiments, a special device was designed in cooperation with a machine manufacturer (Figure 1). The device is designed to automatically measure fall time measurements. The drop experiment first involves fixing the paper helicopter to the top of the device (Figure 1(a)), pressing the drop button and dropping it onto the disc (Figure 1(b)), which automatically measures the time (Figure 1(c)). The time measured through this system produces accurate and reliable data with no measurement error.

3.2. **Control factor and noise selection.** The factors related to the long flight of a paper helicopter (Figure 2(a)) are wing width, wing length, trunk length, trunk width, joint width (Figure 2(b)) which are the control factors because they are controllable.



(a) (b)

FIGURE 2. (a) Paper helicopter; (b) design of paper helicopter

In this experiment, only the wing and trunk lengths were used as the most influential control factors [10]. The remaining factors were fixed as constant. The two control factors were set at two levels each. There is a ceiling heater in the laboratory where the experiment was performed. The intensity of the warm wind was set to noise because it had a strong influence on the time of the paper helicopter but was uncontrolled. These are summarized in Table 2.

TABLE 2. Factor and level of paper helicopter

Division	Indication	Factor	1-Level	2-Level
Control factor	A	Wing length	50	70
	B	Trunk length	50	70
	C	Wing width	20	20
	D	Trunk width	20	20
	E	Joint width	10	10
	F	No of clip	1	1
Noise factor	N	Wind strength	2 different levels of noise factor	

In order to reduce the error as much as possible and to improve the accuracy of the experiment, all the clips used here were only 0.17 g in weight. The weight of the paper was also made uniform with A4 paper.

3.3. **RSM experimental plan design.** Experiments were performed with RSM of a two factor central composite method. Figure 3 shows the experiment plan design screen.

In Minitab, the RSM of the 2 factor central composite method, is shown in Table 3, Experiment 13 at $N = 1$, where the noise factor is weak (wind does not affect),

Central composite design			
Factor:	2	Set replication No:	1
Basic run:	13	Total run No:	13
Based block:	1	Total block No:	1
2-Level factor design:	Complete factor design		
Cube point:	4		
Cube center point No:	5		
Axil point:	4		
Axil center point:	0		
alpha:	1.41421		

FIGURE 3. 2 factor RSM central composite plan design

also Experiment 13 at $N = 2$, where the noise factor is strong (wind can affect). The experimental results are shown in Table 3. Table 3 calculates the larger better SN ratio because they must fly for a long time. SN ratio is the calculated value of the larger better SN ratio formula (Table 1).

Table 3. Plan of RSM experiment and response value

StdOrder	RunOrder	PtType	Block	Wing length	Trunk length	$N = 1$	$N = 2$	SN
1	1	1	1	50	50	1.35	0.91	0.06
2	7	1	1	70	50	1.22	1.18	0.16
3	12	1	1	50	70	1.03	1.09	0.05
4	10	1	1	70	70	1.2	0.91	0.02
5	6	−1	1	45.8579	60	1.34	1.07	0.15
6	9	−1	1	74.1421	60	1.22	1.19	0.16
7	5	−1	1	60	45.8579	1.34	1.08	0.15
8	8	−1	1	60	74.1421	1.03	1.19	0.08
9	3	0	1	60	60	1.03	0.93	−0.02
10	2	0	1	60	60	1.03	0.92	−0.03
11	11	0	1	60	60	1.03	0.93	−0.02
12	4	0	1	60	60	1.03	0.92	−0.03
13	13	0	1	60	60	1.03	0.93	−0.02

3.4. **RSM analysis and results.** Each characteristic value was analyzed. Regression coefficients each characteristic value (Figure 4), contour diagram (Figure 5) were as follows.

Estimated regression coefficient for SN				
Term	Coefficient	SE coefficient	T	P
Constant	−0.02400	0.01572	−1.527	0.171
Wing length	0.01052	0.01243	0.846	0.425
Trunk length	−0.03112	0.01243	−2.505	0.041
Wing length ∗ Wing length	0.07387	0.01333	5.544	0.001
Trunk length ∗ Trunk length	0.05388	0.01333	4.043	0.005
Wing length ∗ Trunk length	−0.03250	0.01757	−1.849	0.107
$S = 0.03515$ R-Square = 88.2% R-Square(Adjust) = 79.8%				

Figure 4. The estimated regression coefficients

The contour plot is shown in Figure 5.

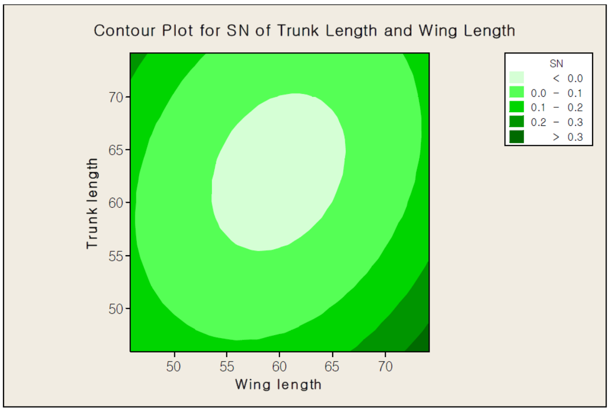


Figure 5. Contour plot

Table 4. Optimal condition of RSM & Taguchi SN

Control factor	$N = 1$	$N = 2$	SN
Wing length	50	70	70
Trunk length	50	70	50

The optimal values are shown in Table 4.

The answer provided by the SN is a more effective answer when produced over a long period of time considering noise conditions.

4. **Conclusions.** In this paper, we propose an adapted method of Taguchi SN ratio to the RSM method to be used in cases where the effect cannot be obtained by using the existing experimental planning technique in environments where the uncontrollable noise effect is large. This method combines the advantages of a Taguchi method which minimizes noise and the advantages of the RSM method which presents optimal values within the experimental range.

In this paper, a paper helicopter was built and tested to prove the proposed method. Equipment which can eliminate the measurement error was manufactured and tested. Experiments were conducted in order according to the method proposed in the paper. This paper contributes to the feasibility of using the technique by making the equipment.

Since the case presented in the paper was carried out in the laboratory, not in the field, it is not possible to exclude the possibility that a new problem may arise when applied to the field. In the future, this method is expected to be applied in the field to improve productivity.

Acknowledgment. This research was supported by Seokyeong University in 2020. The authors also gratefully acknowledge the helpful comments and suggestions of the reviewers, which have improved the presentation.

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