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AN EMPIRICAL STUDY ON MODIFIED SECOND ORDER RESPONSE SURFACE AND TAGUCHI DESIGNS FOR OPTIMIZING THE PROCESS PARAMETERS

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Abstract: In this paper, Following the works of Rajendar et al. (2004) and Prabhakar et al. (2014), we combine the methods of modified second order response surface design and Taguchi design of experiments to determine optimum level of process parameters. Here we mainly focused on the statistical analysis of these two methods and obtain the optimum response with a smaller number of design points by using modified second order response surface design. The results in our study showing that modified second order response surface designs required a smaller number of design points to obtain the optimum value. The optimal process parameters of surface roughness are determined using Modified response surface combinations and Taguchi approach along with response graphs.

Keywords: Taguchi approach; modified second order response surface designs; surface roughness.

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1. INTRODUCTION

Introduction. Taguchi has proposed a very powerful tool to carry out the experimental designs to improve the quality of products. Recently these methods are playing a vital role in the field of engineering and sciences. Generally, we are controlling the process either manual or automatic process. Box and Benhen (1960) developed three level designs for various factors to study the quantitative variables. Prabhakar et al. (2014) applied ANOVA and ANN Techniques to optimize the machincing parameters of CNC. Buddi et al. (2018) derived optimum process parameters using soya meal adhesive. Rajyalakshmi and Nageswara Rao (2019a) trace the optimum parameters of weld dilution for ST-37 plates using Modified Taguchi approach. Rajyalakshmi and Nageswara Rao (2019b) determined expected range using Modified Taguchi approach. Ganguly and Patel (2019) developed X bar control chart for multi-objective economic-statistical design. Dutta and Nageswara rao (2018) observed the performance of chevron criteria in the heat exchange applications. Chakravarthi et al. (2018) identified the workability and control conditions of microsturucture using processing maps. Tanuja et al. (2018) focused on the analysis of testing of high strength steel rocket motor casings using experimental stress. Satyanarayana et al. (2018) identified optimum process parameters of Laser beam welding using Taguchi CFD simulations. Dharmendra et al. (2019) suggested a simple and reliable taguchi approach to identify the process parameters.

An experimental work done by Prabhakar et al. (2014) help us in identifying the optimum process parameters of the surface roughness. They have presented surface roughness and material removal rates are as output responses. Considered ‘3’ input parameters, viz., Cutting speed, Feed rate, depth of cut and specified ‘3’ levels to each parameter. For all possible combinations of ‘3’ input parameters with ‘3’ levels, the number of required test runs are 27. For all these runs experimental data have presented in Table 3. To carry out the analysis of this paper, we considered only one output response of their test data namely surface roughness. Several authors have suggested various methods to find the optimum parameters and applied the concept of taguchi and response surface designs to different applications (Ref. 2-18).

The objective of this study is to compare the predicted responses of Taguchi approach, modified second order response surface designs and response surface designs. From the tables (1) and (2) we observed that the few runs of parameters at different levels obtained by modified second order response surface designs with 16 runs exhibits low surface roughness when compared with the values of Taguchi L27 orthogonal array and Response surface designs.

2. MATERIALS AND METHODS

The complete analysis and methodology of ANOVA and Artificial neural networks were employed by Prabhakar et al (2014) to optimize CNC machining parameters. To carry out this study, we consider the experimental data of Prabhakar et al. (2014) three input parameters, cutting speed (x_1), Feed rate (x_2), depth of cut (x_3) was taken as the input parameters and the output variable is surface roughness (Ra). They suggested Taguchi L_{27} Orthogonal array (OA) approach to predict the output response of '3' input parameters each at three levels. The % contribution of each parameter has presented in Table (2). By considering L_{27} OA we find the means of each factor. Based on the means we determine the predictions of Taguchi design for the given test data.

As per Taguchi design, the number of experiments (N) for the number of process parameters (v) and the number of levels (r) assigned to each process parameter can be found from

$$N = 1 + v(r - 1) \tag{1}$$

Response surface methodology is a collection of statistical techniques and analysis of problems in which response are influence by several variables. A design for fitting response surface consists of different suitable combinations at different levels of factors. The second order response surface designs is given by

$$Y_u = b_0 + \sum_{i=1}^{v} b_i x_{ui} + \sum_{i=1}^{v} b_{ii} x_{ui}^2 + \sum_{i \leq j}^{v} b_{ij} x_{uj} + e_u \tag{2}$$

If the second order response surface design satisfy the properties of simple symmetry, non-singularity and equation (3) then we called the design is said to be modified second order response surface design.

$$\left(\sum_{u=1}^{N} x_{iu}^{2}\right)^{2} = N\sum_{u=1}^{N} x_{iu}^{2}x_{ju}^{2} \tag{3}$$

Here we consider the modified response surface design (Box and Behnken) for three factors each at three levels in 16 points were recommended for the experiment related to finding the optimum parameters. The details of the factors and their levels are given in Table (3) and Table (4). The design points are represented with coded levels as -1,0 and 1. First, we identify the experimental data of modified design points from the data of Prabhakar (2014).

3. RESULTS AND DISCUSSION

Prabhakar et al. (2014) presented an experimental study of L_{27} data for three factors each at levels. The experimental values are presented in the table (1). The % contribution of each factor has presented in table (2). The table shows that X_1 contribution is high with 66%, X_3 contribution is low with 9% and X_2 is 25% of the total. Table (3) representing the experimental data of '16' runs as per the modified second order response surface designs. We predict the equation using the experimental data is as follows:

$$\hat{y} = 0.9330 + 0.6001x_1 + 0.3203x_2 + 0.1749x_3 + 0.4355x_1^2 + 0.1337x_2^2 - 0.1095x_3^2$$
$$+0.0773\ x_1x_2 + 0.0195x_1x_3 + 0.0043x_2x_3 \tag{4}$$

Taguchi point have been obtained by using Table (2) and represented the predicted values in the last column of Table (3). Here we noted that the optimum parameters with coded levels are 0,-1 and -1. If we decoded into original values the optimum parameters with low surface roughness are X12, X_{21}, and X_{31} respectively. As per ANOVA the optimum parameters are obtained at the levels of cutting speed (1000), feed rate (10) and depth of cut (0.2).

Table-1: Input parameters and their levels (Prabhakar et al (2014))

Process parameters	Designation	Level-1	Level-2	Level-3
Cutting speed (rpm)	X1	500	1000	1500
Feed rate (mm/Min)	X_2	10	40	70
Depth of cut (mm) Z	X_3	0.2	0.5	0.8

Table 2: ANOVA Table

	Mean1	Mean2	Mean3	Grand mean	% contribution
X1	1.006111	**0.916556**	1.821	1.247888889	66
x2	**0.990778**	1.163667	1.589222	1.247888889	25
x3	**1.073667**	1.232556	1.437444	1.247888889	9

Table: 3: Optimum process parameters as per Modified second order response surface design

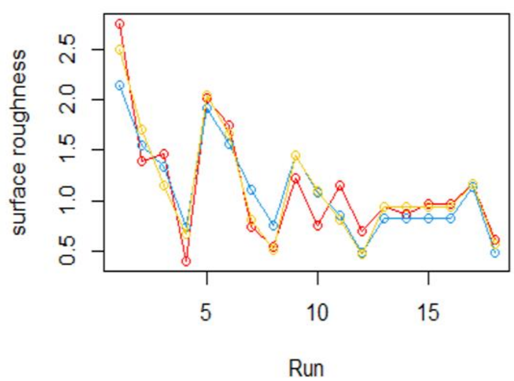
Sno	X1	X2	X3	Experimental data Surface Roughness	Predicted [1] Modified SORD	Taguchi Predicted [2]
1	1	1	0	2.764	2.4999	2.146778
2	1	-1	0	1.392	1.7047	1.548333
3	-1	1	0	1.458	1.1451	1.331889
4	-1	-1	0	0.395	0.6591	0.733444
5	1	0	1	2.021	2.0535	1.926111
6	1	0	-1	1.746	1.6647	1.562333
7	-1	0	1	0.733	0.8143	1.111222
8	-1	0	-1	0.536	0.5035	0.747444
9	0	1	1	1.225	1.4567	1.447222
10	0	1	-1	0.753	1.0983	1.083444
11	0	-1	1	1.153	0.8075	0.848778
12	0	-1	-1	0.698	**0.4663**	**0.485**
13	0	0	0	0.933	0.933	0.816778
14	0	0	0	0.867	0.933	0.816778
15	0	0	0	0.962	0.933	0.816778
16	0	0	0	0.97	0.933	0.816778

Table 4: Comparison of means and standard deviations with different approaches

	Experimental data	Response surface	Taguchi	Modified second order response surface
Mean	1.2479	1.2479	1.2477	1.2395
Standard deviation	0.7201	0.6144	0.5105	0.6286
Minimum	0.395	0.542	0.485	0.3985
Maximum	3.642	3.222	2.3517	2.5891

4. CONCLUSION

From the above analysis we can obtain the optimum parameters with less number of design points by using modified second order response surface designs. The results of test data, ANOVA table, predicted values using Taguchi approach and modified second order response surface design have been obtained and represented in Table 1, Table 2 and Table 3 respectively. The graphical representation clearly shows that the experimental and predicted data of all suggested designs for '16' runs (Figure 1) and '27 runs (Figure 2)



Red- Test data, Yellow-Modified, Blue-Taguchi

Figure 1: Experimental and predicted values of '16' runs under different approaches

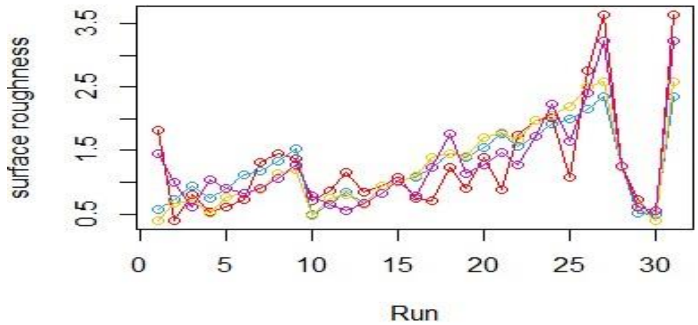


Figure 2: Experimental and predicted values of '27' runs under different approaches

CONFLICT OF INTERESTS

The authors declare that there is no conflict of interests.

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