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Experimental and Numerical Studies to Optimise Turning Process

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***Abstract*— It is well known that the relation between different input process parameters and surface roughness in all machining operations . The same things happen in turning operation also. In turning operation, the input parameters like (spindle) speed, feed, depth of cut affect the surface finish of the product output. Many engineer and researchers have tried to do optimize of this. But still, there is a gap in determining of the exact contribution of speed, feed and depth of cut to get optimum surface finish of work piece in turning operation.**

Taguchi method is efficient method for designing process that operates consistently and optimally over a variety of conditions. Taguchi approach to design of experiments easy to adopt and apply for users with limited knowledge of statics, hence gained wide popularity in the engineering and scientific community. The desired cutting parameters determined by handbook. Cutting parameter are reflected on surface roughness,

Grey relational analysis has been reported efficient in transforming multiple quality responses into a single grade. Several researches have used the grey grade for deciding the optimal factor levels. In this context, this work proposes an approach for optimizing multiple quality responses in the Taguchi method using regression models and grey relational analysis; where the former will be used to complete the response values for all factor level combinations, whereas the latter will be used to determine optimal factor levels.

***Objective:* It is also well known that surface finish is the one of the output parameters in turning operations. So the present work attempts to study the effects of input parameters like speed, feed and depth of cut on the surface finish in turning operation.**

***Methodology/approach:* This experimental work presents the optimization of turning parameters for mild steel bar using the Grey Taguchi Method, A plan of experiments based on Taguchi's L9 orthogonal array was established and turning experiments were conducted with prefixed cutting parameters for mild steel bar using tungsten carbide tool. The turning parameters are cutting speed, feed rate and depth of cut and the responses are surface finish , Taguchi's signal-to-noise (S/N) ratio are determined based on their performance characteristics. A grey relational grade, S/N ratio is obtained Based on response value, optimum levels of parameters have been identified by using response Table and response graph and the significant contributions of controlling parameters are estimated using analysis of variances (ANOVA).**

***Results:* In the single response method, percentage contribution of feed rate is most effective input parameters for getting good surface finish. It has been found by using both Taguchi and GRA techniques. The best combination (S1-F1-D1) is to get best surface finish output results.**

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Research limitations/implications: **Kirby et al. (2004) developed the prediction model for surface roughness in turning operation. The regression model was developed by a single cutting parameter and vibrations along three axes were chosen for in-process surface roughness prediction system. By using multiple regression and Analysis of Variance (ANOVA).**

Index Terms— **ANOVA, Taguchi, surface finish, S/N ratio, orthogonal array, Grey.**

I. INTRODUCTION

A common method to manufacture parts to a specific dimension involves the removal of excess material by machining operation with the help of cutting tool. Turning process is the one of the methods to remove material from cylindrical and non-cylindrical parts.

Taguchi method is a powerful tool for the design of high quality systems. It provides simple, efficient and systematic approach to optimize design for performance, quality and cost. Taguchi method is efficient method for designing process that operates consistently and optimally over a variety of conditions. Taguchi approach to design the of experiments easy to adopt and apply for users with limited knowledge of statics, hence gained wide popularity in the engineering and scientific community. The desired cutting parameters determined by handbook. Cutting parameter are reflected on surface roughness.

II. PHYSICAL DESCRIPTION OF THE PROBLEM

In the present experimental study, spindle speed, feed rate and depth of cut have been considered as process parameter. For the present work, the experiments have been done for different levels. The process parameters with their units are listed in table.

TABLE I. PROCESS PARAMETERS AND THEIR LIMITS

Process variables			
Levels	Speed (RPM)	Feed (mm/rev)	Depth of Cut (mm)
1	280	0.045	0.3
2	450	0.090	0.6
3	560	0.125	0.9

III. MATHEMATICAL FORMULATION

Design of experiment techniques, i.e. Taguchi's technique have been used to accomplish the objective. L9 orthogonal array used for conducting the experiments. ANOVA and factorial design technique is employed to analyze the percentage contribution and influence of Process Parameters.

$$\eta_j = \left\{-10\log_{10}\left(\frac{1}{K}\sum_{r=1}^{K} {y_{ij}}^2\right)\right\} \quad \text{for STB}$$

$$\eta_j = \left\{-10\log_{10}\left(\frac{1}{K}\sum_{r=1}^{K} \frac{1}{{y_{ij}}^2}\right)\right\} \quad \text{for LTB}$$

$$\eta_j = \left\{10\log_{10}\left(\frac{s_i^2}{\bar{y}_i^2}\right)\right\} \quad \text{for NTB}$$

Where, $\bar{y}_i$ and s_i are the estimated average and standard deviation of y_{ij} is response and k is the number of trail.

A. Grey Relational Analysis

In grey relational analysis, experimental data i.e. measured features of quality characteristics of the product are first normalized ranging from zero to one. This process is known as grey relational generation. Next, based on normalized experimental data, grey relational coefficient is calculated to represent the correlation between the desired and actual experimental data. Then overall grey relational grade is determined by averaging the grey relational coefficient corresponding to selected responses. The overall performance characteristic of the multiple response process depends on the calculated grey relational grade. This approach converts a multiple- response- process optimization problem into a single response optimization situation, with the objective function is overall grey relational grade. The optimal parametric combination is then evaluated by maximizing the overall grey relational grade.

Step1: for each experiment calculate the value S/N ratio, η_{ij}, at experiment *i* for each response *j* using an appropriate equation from the following formulas:

$$\eta_j = \left\{-10\log_{10}\left(\frac{1}{K}\sum_{r=1}^{K} y_{ij}{}^2\right)\right\} \quad \text{for STB}$$

$$\eta_j = \left\{-10\log_{10}\left(\frac{1}{K}\sum_{r=1}^{K}\frac{1}{y_{ij}{}^2}\right)\right\} \quad \text{for LTB}$$

$$\eta_j = \left\{10\log_{10}\left(\frac{S_i^2}{\bar{y}_i^2}\right)\right\} \quad \text{for NTB}$$

Where $\bar{y}_i$ and s_i are the estimated average and standard deviation of y_{ij} replicates at the *i*th experiment. The *K* denotes the number of replicates.

Step 2: Formulate the multi linear regression for response *j* using the calculated η_{ij} in step 1. Then, obtain the η_{ij} values for all factor level combinations. That is,

$\eta_j = f\,(x1, x2, \ldots\ldots x_f)$

Step 3: Let z_{ij} $(0 \le z_{ij} \le 1)$ represents the normalized η_{ij} for *j*th QCH at experiment *i*. Calculate the z_{ij} values for each response using following eqn.

$$Z_{ij} = \frac{\max(\eta_{ij}) - \eta_{ij}}{\max(\eta_{ij}) - \min(\eta_{ij})}$$

The max $(\eta_{ij})$is the maximum value of η_{ij}.The Min (η_{ij}) is the minimum value of η_{ij} .Then calculate ξ_{ij} .as follows:

$$\xi_{ij} = \frac{\Delta_{min} + \xi\Delta_{max}}{\Delta_{ij} + \xi\Delta_{max}}, \quad \Delta_{ij} = |1 - Z_{ij}|$$

Where ξ is the distinguishing coefficient ranges between zero and one usually ξ equals 0.5. Also, Δ'_{ij} is the difference of the absolute value between the ideal setting, η_{0j} and η_{ij} Δ_{min} and Δ_{max} are the smallest and largest values of all the η_{ij} from all responses.

Step 4: Let γ_i denoted the grey relational grade for the *i*th experiment from all *q* responses. Calculate γ_i using Eq.

$$\gamma_i = \frac{1}{q}\sum_{i=1}^{q}\xi_i$$

Step 5: Let, $\bar{\gamma}_{lf}$ denotes the average of γ_i values at level *l* of factor *f*. Calculate the $\bar{\gamma}_{lf}$ values for all factor levels. For each factor *f* decide the optimal level as the level that maximizes the $\bar{\gamma}_{lf}$ for this factor.

B. Analysis of Variance (ANOVA)

ANOVA is used to determine the influence of any given process parameters from a series of experimental results by design of experiments and it can be used to interpret experimental data. Since there will be large number of process variables which control the process, some mathematical model are require to represent the process. However these models are to be develop using only the significant parameters which influences the process, rather than including all the parameter steps for percentage contribution.

Step 1: find level average and average of response.

$$\text{Level average,} \quad \eta_x = \frac{\Sigma\eta_j}{3}, \quad \eta_m = \frac{\sum_{i=1}^{n}\eta_j}{n}$$

Where, η_j,responce,$\eta_x$is level average and n is the number of experiments.

Step 2: Determination of sum of square:

$$SS_f = q\left(\sum_{x=1}^{3}(\eta_x - \eta_m)^2\right), \quad SS_t = \sum_{j=1}^{n}(\eta_j - \eta_m)^2, \quad SS_e = SS_t - \Sigma SS_f$$

Where, SS_fsum of square due to factor, q is the number of experiment in same level SS_t sum of square total and SS_e=sum of square due to error.

Step 3: Determination of degree of freedom:

DOF for any factor, X= number of level-1

Total DOF= Total no. of experiments-1

Step 4: Determination of mean square (MS):

$$MS_f = \frac{SS_f}{DOF}$$

Step 5: Calculation of percentage contribution:

$$\text{\% contribution of each factor} = \frac{SS_f}{SSt} \times 100$$

IV. RESULTS AND DISCUSSIONS

The results of experiments carried out in the present work is presented and discussed Percentages contribution of input variables on surface finish using Taguchi technique.

The results and discussion of the present work mainly consists of the following;

I) Percentages contribution of input variables on surface finish using Taguchi technique.

II)Percentages contribution of input variables on surface finish using Grey Relational Analysis technique.

i) Percentages contribution of input variables on surface finish using Taguchi technique.

The data obtained from the experiments (L_9) have been used to get the percentage contribution of the input variables.

TABLE II. EXPERIMENTAL RESULTS FOR TAGUCHI L_9

Exp.No.	S	F	D	Ra(μm)	S/N (db)
1	1	1	1	1.626	-4.22241
2	1	2	2	2.153	-6.66088
3	1	3	3	3.033	-9.63745
4	2	1	2	2.253	-7.05522
5	2	2	3	2.413	-7.65115
6	2	3	1	4.1	-12.2557
7	3	1	3	2.52	-8.02801
8	3	2	1	2.706	-8.64656
9	3	3	2	6.603	-16.3948

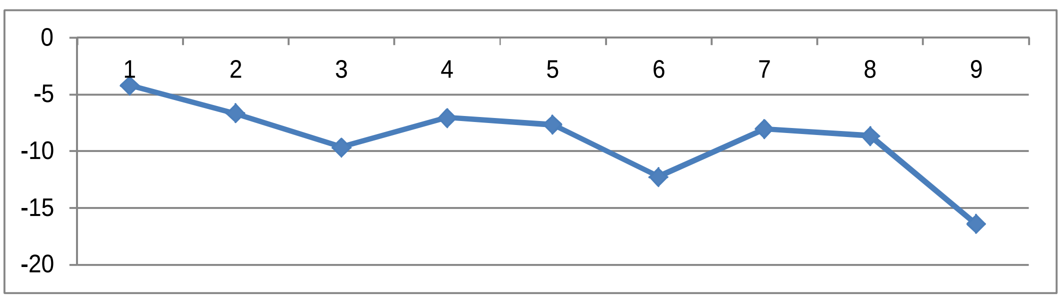

Figure 1. Variation of SN ratio with number of experiments

TABLE III. LEVEL AVERAGE TAGUCHI L_9

Level	SPEED	FEED	DEPTH OF CUT
1	-6.84025	-6.43522	-8.37488
2	-8.98738	-7.65286	-10.0370
3	-11.0231	-12.7627	-8.43887
Delta(Max-Min)	4.18285	6.32758	1.59813
Rank	2	1	3

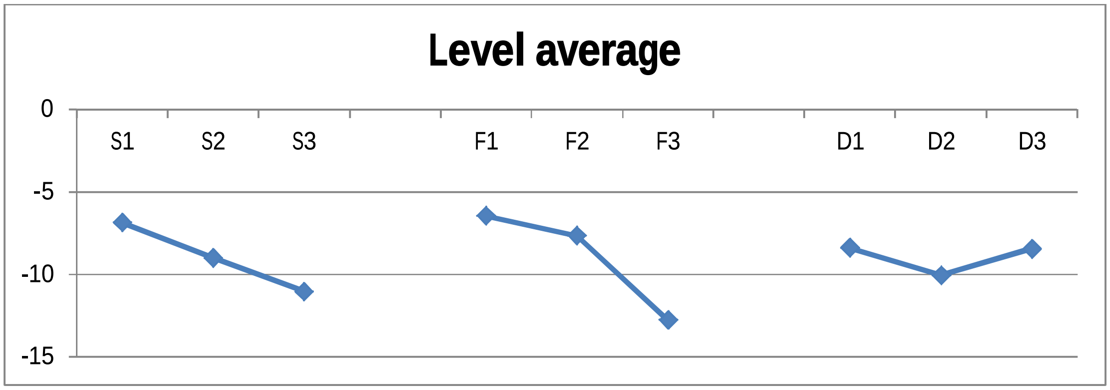

Figure 2. Variation of level average

TABLE IV. ANOVA FOR TAGUCHI L9

Factors	Sum of square(SS)	Degree of freedom(DOF)	Mean square (MS)	F ratio	% of contribution
S	26.2493	2	13.12466	18.2941	26.2493
F	67..63011	2	33.8156	47.1346	67.203
D	5.32075	2	2.66037	3.70822	5.2871
Error	1.43485	2	0.717425	---------	1.4257
Total	100.635	8	12.5793	---------	100

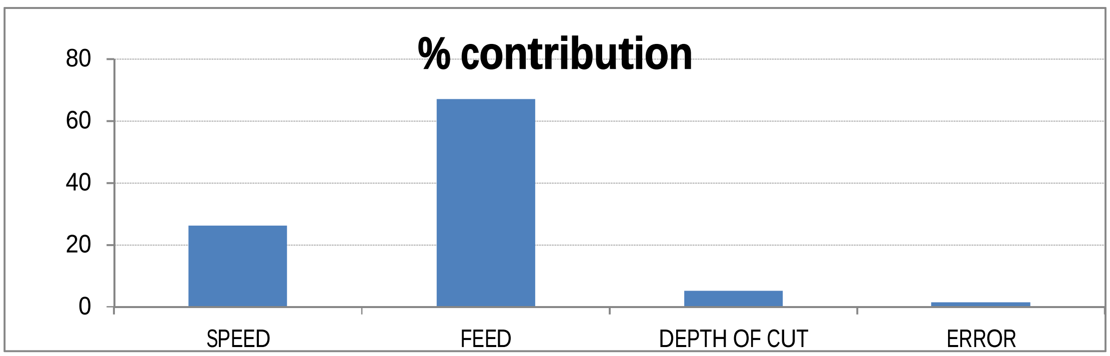

Figure 3. Percentage contribution with input parameters

It is observed from above (L_9-Taguchi) analysis that S1-F1-D1 is the optimal combination for getting best surface finish and corresponding S/N ratio is -4.22241. The percentage contribution of speed is 26.25%, of feed is 67.20 %, and of depth of cut 5.29 %. It indicates that for the above ranges of input parameters, the feed is most effective.

ii) Percentages contribution of input variables on surface finish using Grey Relational Analysis technique.

Using the data obtained from the table (Table II), the Gray relational grade of input variables have been calculated.

TABLE V. GRAY RELATIONAL ANALYSIS

Exp.No.	S/N ratio	Z_{ij}	Δ_{ij}	$\xi_{ij}=\gamma_{ij}$
1	-4.22241	1	0	1
2	-6.66088	0.799672	0.200328	0.71395
3	-9.63745	0.555138	0.444862	0.52917
4	-7.05522	0.767275	0.232725	0.68238

5	-7.65115	0.718319	0.281681	0.63964
6	-12.2557	0.340042	0.659958	0.43105
7	-8.02801	0.687358	0.312642	0.61527
8	-8.64656	0.636543	0.363457	0.57906
9	-16.3948	0	1	0.33333

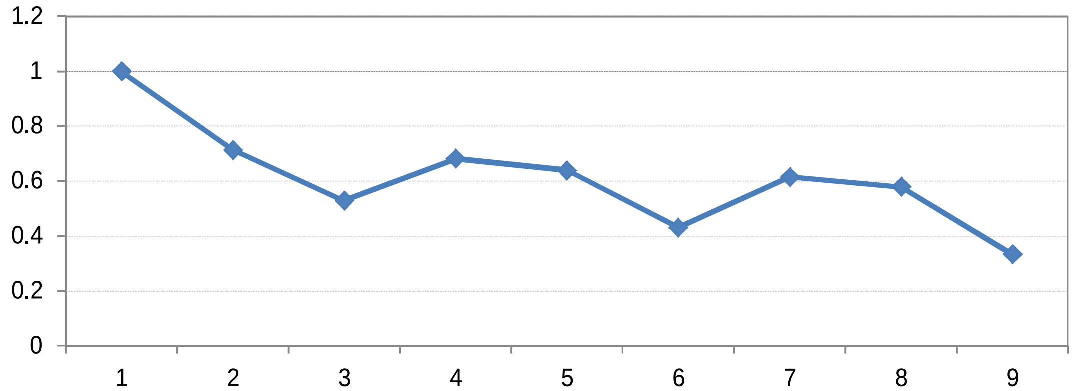

Figure 4. Variation of Gray relational grade (GRG) with number of experiments

TABLE VI. LEVEL AVERAGE OF PARAMETERS

Level	SPEED	FEED	DEPTH OF CUT
1	0.74771	0.76589	0.67003
2	0.58436	0.64423	0.57655
3	0.50923	0.43119	0.59470
Delta(Max-Min)	0.23848	0.33470	0.09348
Rank	2	1	3

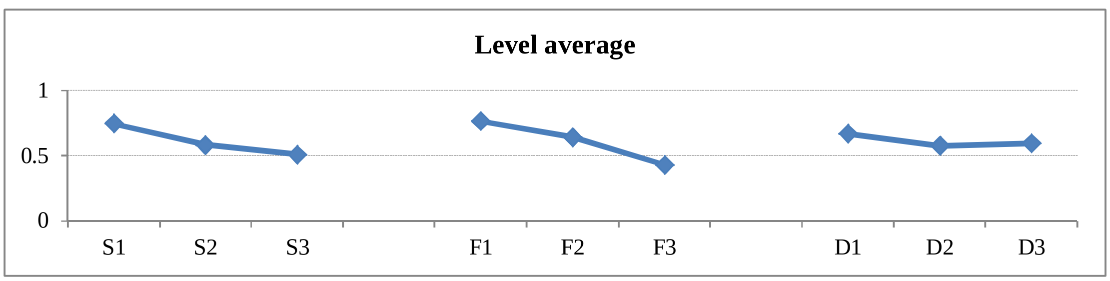

Figure 5. Variation of level average with factor

TABLE VII. ANALYSIS OF VARIABLES

Factor	Sum of square	Degree of freedom	Mean square	F ratio	% contribution
S	0.089204	2	0.044601	10.1053	31.30
F	0.17221	2	0.08610	19.5078	60.43
D	0.01474	2	0.007372	1.67029	5.17
Error	0.00883	2	0.004414	-------------	3.10
Total	0.284981	8	0.03562	--------------	100

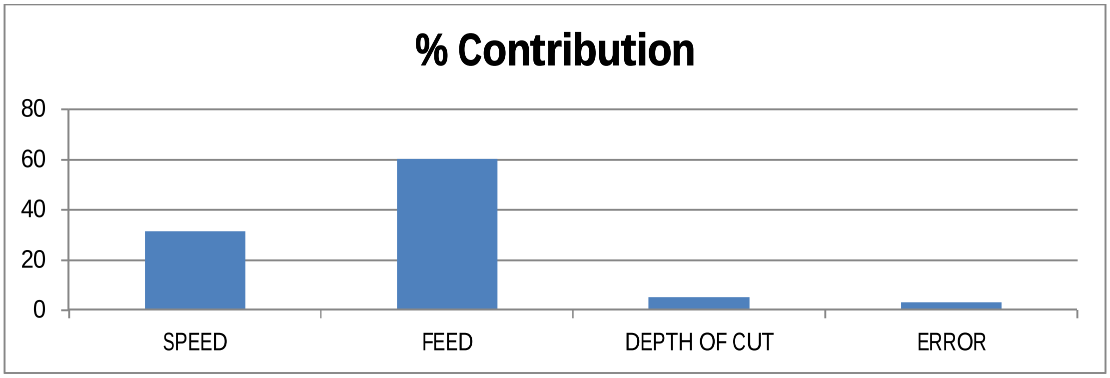

Figure 6. Percentage contribution of variables

It is observed from above (L_9-GRA) analysis that S1-F1-D1 is the optimal combination for getting best surface finish and corresponding gray relational grade is 0.713951. The percentage contribution of speed is 31.30 %, of feed is 60.42 %, and of depth of cut is 5.17 %. It indicates that for the above ranges of input parameters, the feed is most effective. The same trend is observed from previous (L_9-Taguchi) analysis also.

IV. CONCLUSIONS

In present work, turning operation has been optimised and percentage contribution of parameters calculated with different optimisation techniques. On the basis of results, percentage contribution of feed rate is most effective input parameters for getting good surface finish. It has been found by using both Taguchi and GRA techniques. The best combination (S1-F1-D1) is to get best surface finish output results.

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