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Experimental Investigation of Various Process Parameters during CNC-Turning Using Taguchi Method

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Abstract— **The productivity and quality are two important characteristics those control most of the manufacturing processes. This paper refers to the parametric optimization of turning process applying Taguchi method in order to improve quality of manufacturing goods, and engineering development of designsfor studying variation. There are three parameters i.e. spindle speed, feed rate and depth of cut. Different experiments are done by varying one parameter and keeping other two constant.**

There were two main purposes of study. First was to explain and demonstrate a systematic procedure of Taguchi parameter design and applying it to the data on turning. And the second important aim was to find out the the optimal combination of various process parameters based on S/N ratio and to know the significance of each parameter.

Taguchi orthogonal aray was designed with three levels of turning parameters with the help of Minitab-15. Taguchi method stresses the importance of studying the response variation using the signal to noise(S/N) ratio, resulting the minimization of quality characteristic variation due to uncontrolled parameters. It is predicted thatTaguchi method is a good method for optimization of parameters as it reduces the number of experiments. The results indicate the optimum values of the input factors and the results are confirmed by a confirmatory test.

Index Terms—**CNC, Taguchi Method, optimization.**

I. INTRODUCTION

Among various cutting processes, turning process is one of the most fundamental and most applied metal removal operations in a real manufacturing environment. Turning is method of machining a part in which a pointed cutting tool is fed parallel onto the surface of the material being rotated. In cases where it is possible, it takes much higher time due to the need for frequent dimensional measurement to prevent overcutting.

It is thus obvious that automated motion control would replace manual "handwheel" control in modern manufacturing. Development of computer numerically controlled (CNC) machines has also made possible the automation of the machining processes with flexibility to handle production of small to medium batch of parts. Initially, the CNC technology was applied on lathes, milling machines, etc. which could perform a single type of metal cutting operation. Later, attempt was made to handle a variety of workpieces that may require several different types machining operations and to finish them in a single set-up. Thus CNC machining Centres capable of performing multiple operations were developed.

Palanikumar, L. Karunamoorthy(2013) found that since the Surface finish and material removal rate in turning has been found to be influenced in varying amounts by a number of factors such as feed rate, work material characteristics, work hardness, unstable built-up edge, cutting speed, depth of cut, cutting time, tool nose radius and tool cutting edge angles, stability of machine tool and work piece setup, chatter, and use of cutting fluids,the need for selecting and implementing optimal machining conditions and the most suitable cutting tool has been felt. *Vipindas et al (2013)* concluded that the advantages of Taguchi method in simplifying the experimentation was effectively utilized in this investigation for design and analysis for surface quality. *Umesh Khande et al(2012)* proposed that Utility based Taguchi method has been found fruitful for evaluating the optimum parameter setting and solving such a multi-objective optimization problem. *LB Abhang et al* (2012) presented an application of parameter design of the taguchi method in optimization of turning process and concluded that the parameter design of the Taguchi method provides a simple, systematic and efficient methodology for the optimization of machining parameters. *Sarbeshwar Rout (2013)* conducted experiments on lathe machine using solid carbide inserts and stainless steel to determine the optimum settings of feed rate, cutting speed and depth of cut so that the forces, tool wear, chip thickness, and surface roughness can be minimized. *Lin et al. (2001)* adopted an abdicative network to construct a prediction model for surface roughness and cutting force. Once the process parameters: cutting speed, feed rate and depth of cut were given; the surface roughness and cutting force could be predicted by this network. Regression analysis was also adopted as second prediction model for surface roughness and cutting force.Hemant Jain et al (2015) concluded that The experimental results demonstrate that the insert spindle speed and feed rate are the main parameters among the three controllable factors (spindle speed, feed rate and depth of cut) that influence the material removal rate inturning smart alloy Inconel-25.

II. EXPERIMENTAL PROCEDURE

All the experiments were were carried out *in **Jharkhand Govt. Msme Tool Room, Tatisilwai, ranchi.*** Equipments involved during the whole experiment are as shown:

1) **Machine used:**FANUC 21 series based EMCO CNC-Turning machine.
2) **Workpiece used:** EN-31 steel.
3) **CNC-commands used:**

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G-codes: These are commands usedfor movement instructions. The G- codes mostly used were *G00, G01, G72, G73 and G74.*

M-codes: These commands are used for machine instructions. The main M-codes used were *M00, M01, M03, M04, M05, M08, M09 and M30*.

4) Insert used: Carbide insert.

5) Roughness measuring instrument: portable surface roughness tester, *Mitutoyo SJ401*.

III. PROCESS VARIABLES AND THEIR LIMITS:

The working ranges of the parameters for subsequent design of experiment, based on Taguchi's L9 Orthogonal Array (OA) design have been selected. In the present experimental study, spindle speed, feed rate and depth of cut have been considered as process variables. The process variables with their units (and notations) are listed in Table 3.

Table-1. Process variables and their values

Values in coded form	Spindle Speed (*N*) (RPM)	Feed (*f*) (mm/rev)	Depth of cut (*d*) (mm)
1	1000	0.08	0.10
2	1200	0.10	0.15
3	1500	0.15	0.20

Table-2. Taguchi's L_9 orthogonal array

Cutting speed(rpm)	Feed rate(mm/rev)	Depth of cut(mm)
1	1	1
1	2	2
1	3	3
2	1	2
2	2	3
2	3	1
3	1	3
3	2	1
3	3	2

IV. DATA COLLECTION:

Performing the above programme nine times by varying the values of S, U and F, we collected following data:

Experimental data of the experiment

Trial no	Spindle speed (rpm)	Feed rate (mm/rev)	Depth of cut (mm)	Surface roughness (microns)	MRR (mm^3/s)
1	1000	0.088	0.1	2.9	148.41
2	1000	0.1	0.15	2.07	171.83
3	1000	0.15	0.2	0.87	248.21
4	1200	0.08	0.15	0.57	161.85
5	1200	0.1	0.2	0.67	205.37
6	1200	0.15	0.1	1.22	199.54
7	1500	0.088	0.2	1.72	165.76
8	1500	0.1	0.1	2.83	126.75
9	1500	0.15	0.15	0.92	207.26

V. RESULT:

All the experimental results are analyzed by a power full statistical tool named Minitab software of latest version 15. First of all the input parameters are defined in the software as per their corresponding value and then give the responses data to optimize. Here, the main objective of the problem is to minimize the value of surface roughness and maximize the material removal rate. So, the criterion of Smaller-The-Better is adopted for the optimization of surface roughness whereas for the optimization of surface roughness, larger-the-better has been used.

Taguchi method uses the S/N ratio to measure the quality characteristic deviating from the desired value. The S/N ratio η is defined as $\eta = -10\log(M.S.D.)$; where M.S.D. is the mean square deviation

Analysis of surface roughness:

Observing all the nine experiments and the applying Taguchi method on the result using minitab-17, we can draw the following table describing the S/N ratio and mean for the surface roughness.

Experimental results for surface roughness and corr. S/N ratio and mean

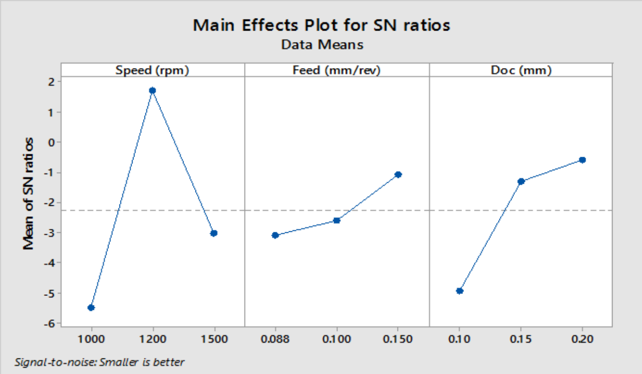
Trial no	Spindle speed (rpm)	Feed rate (mm /rev)	Depth of cut (mm)	Surface roughness (microns)	S/N ratio	Mean
1	1000	0.088	0.1	2.9	9.26292	2.9
2	1000	0.1	0.15	2.07	7.51327	2.07
3	1000	0.15	0.2	0.87	0.30945	0.87
4	1200	0.08	0.15	0.57	4.80664	0.57
5	1200	0.1	0.2	0.67	2.79324	0.67
6	1200	0.15	0.1	1.22	2.41148	1.22
7	1500	0.088	0.2	1.72	4.78599	1.72
8	1500	0.1	0.1	2.83	3.10672	2.83
9	1500	0.15	0.15	0.92	1.1381	0.92

Response table for S/N ratio for surface roughness (smaller-the-better)

Level	Speed(rpm)	Feed(mm/rev)	Depth of cut (mm)
1	-5.4889	-3.0808	-7.1011
2	1.7295	-4.7830	-1.2816
3	-5.1843	-1.0800	-0.5611
Delta	7.2184	3.7029	6.5400
Rank	**1**	**3**	**2**

Total mean S/N ratio= 4.60147

The main effect plot for the S/N ratio for surface roughness is plotted below:

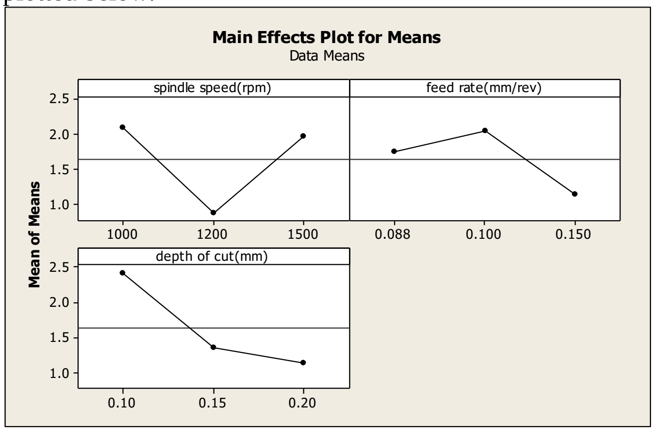


Taguchi Analysis: Main effect plot for S/N ratio for surface roughness

Response table for means

Level	Speed(rpm)	Feed(mm/rev)	Depth of cut (mm)
1	2.0817	1.7383	2.4183
2	0.8733	2.0433	1.3633
3	1.9683	1.1417	1.1417
Delta	1.2083	0.9017	1.2767
Rank	**2**	**3**	**1**

The main effect plot for the S/N ratio for surface roughness is plotted below:



Taguchi Analysis: Main effect plot for means for surface roughness

Hence, from the graph, it can be seen that the optimum cutting parameter can be obtained by points or values of parameters having the peak position in the graph. Therefore Factor levels for predictions:

Predicted values of parameters for surface roughness

Parameters	Speed(rpm)	Feed(mm/rev)	Depth of cut(mm)
Optimum value	1200	0.15	0.2

The above combination of the values of the cutting parameters is going to provide the minimum surface finish.

Anova and effects of parameters on surface roughess

Analysis of variance (Anova) was used to determine the design parameters significantly influencing the surface roughness (response). The table shows the results of Anova for surface roughness. This analysis was evaluated for a confidence level of 95%, that is for significance level of ∝= 0.05(6).

Table-5.5. ANOVA result for surface roughness

Source	DF	AdjSS	AdjMS	F-Value	P-Value
Spindle speed	2	2.6719	1.33597	19.79	0.048
Feed rate	2	1.262	0.63102	9.35	0.097
Depth of cut	2	2.792	1.39602	20.68	0.046
Error	2	0.135	0.06751		
Total	8	6.861			

Notes: DF, Degrees of freedom; Adj SS, Adjusted sum of squares; Adj MS, Adjusted mean Squares.
S= 0.259829, R-sq= 98.03%, R-sq= 92.13%, R-sq(pred)= 60.15%

It can be observed from the results obtained in the table 4.5 that depth of cut was the most significant parameter having the highest statistical influence (P=0.046) and the spindle speed(P=0.048) followed by feed rate(P=0.097). When the P-value for this model is less than 0.05, then the parameter can be considered as statistically significant. This is desirable as it demonstrates that the parameter in the model has a significant effect on the response. The coefficient of determination (R^2) is defined as the ratio of the explained variation to the total variation. It is a measure of the degree of the fit. When R^2 approaches unity a better response model results and it fits the actual data. The value of R^2 calculated for this model was 0.98 i.e., very close to unity, and thus acceptable. It demonstrates that 98.03 of the variability in the data can be explained by this model. Thus, it is conferred that this model provides reasonably good explanation of the relationship between the independent factors and the response.

Regression analysis for surface roughness:

A multiple linear regression analysis attempts to generate the relationship between two or more predictor variables and a response variable by fitting a linear equation to the observed data. Best on the virtual experimental results, multiple linear regression models are developed using MINITAB15. Regression equations generated establish correlation between the significant terms obtained from ANOVA, namely spindle speed, feed rate and depth of cut.

Predictors for generating regression model

Predictors	Coef	SE Coef	T	P
Constant	4.280	2.291	2.10	0.089
Spindle speed(rpm)	0.000079	0.001351	0.06	0.155
Feed rate(mm/rev)	-12.09	10.34	-1.17	0.295
Depth of cut(mm)	-12.767	6.798	-1.88	0.119

S = 0.832592 R-Sq = 49.5% R-Sq(adj) = 19.2%

The regression equation generated from the table 4.6 is as:

surf. rough.(microns) = 4.82 + 0.00008 spindle speed(rpm) - 12.1 feed rate(mm/rev)- 12.8 depth of cut(mm)

Hence regression equation for surface roughness is a function of the parameters like spindle speed, feed rate and depth of cut. But from the table 4.6, it is found that feed rate has P-value 0.295, which is non-significance. So this parameter has lesser effect on the surface roughness (response).

The above equation can be used to predict the surface roughness in EN-31 steel during CNC-Turning. The constant in the equation is the residue. The regression coefficient obtained for the model was 0.495. The coefficient associated with spindle speed in the regression equation is positive and it indicates that as the spindle speed increases, the surface roughness during turning is also increases. The coefficient associated with the feed rate is negative and this suggests that the surface roughness decreases with increase in feed rate. Similarly the negative coefficient associated with depth of cut indicates that as the depth of cut increases, the surface roughness is decreased.

The confirmation Test for surface roughness:

In order to provide the regression model, confirmation surface roughness tests were conducted with parameter levels that were different from those used for analysis. The results of the confirmation test were obtained and a comparison was made between the virtual experimental surface roughness and the computed values obtained from the regression model.

Confirmation tests result

Test no.	Experiment	Model of equation	Error(%)
1	2.9	2.555	12.8
2	2.07	1.77	14.5
3	0.87	0.625	25.2
4	0.64	0.831	29.8
5	0.78	0.946	21.3
6	1.22	1.42	16.4
7	1.72	1.315	23.5
8	2.83	2.45	13.4
9	0.92	1.205	28.9

Analysis for material removal rate:

Table-20 shows the experimental results for the material removal rate of the workpiecebased on Taguchi's L-9 orthogonal array.

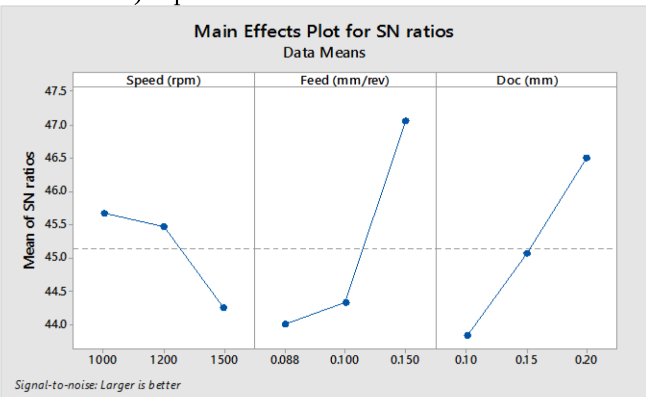
Experimental results for MRR and corr. S/N ratio and mean

Trial no	Spindle speed (rpm)	Feed rate (mm/rev)	Depth of cut (mm)	MRR (mm^3/s)	S/N ratio (dB)	Mean
1	1000	0.088	0.1	148.41	43.429	148.4
2	1000	0.1	0.15	171.83	44.702	171.8
3	1000	0.15	0.2	248.21	48.888	248.2
4	1200	0.08	0.15	161.85	44.182	161.9
5	1200	0.1	0.2	205.37	46.251	205.4
6	1200	0.15	0.1	199.54	46.001	199.5
7	1500	0.088	0.2	165.76	44.39	165.8
8	1500	0.1	0.1	126.75	42.059	126.8
9	1500	0.15	0.15	207.26	46.33	207.3

S/N response table for S/N ratio for MRR (larger-the-better)

Level	Speed(rpm)	Feed(mm/rev)	Depth of cut (mm)
1	45.67	44.00	43.83
2	45.48	44.34	45.07
3	44.26	47.07	46.51
Delta	1.41	3.07	2.68
Rank	3	1	2

The main effect plot for the S/N ratio for MRR(material removal rate) is plotted below:

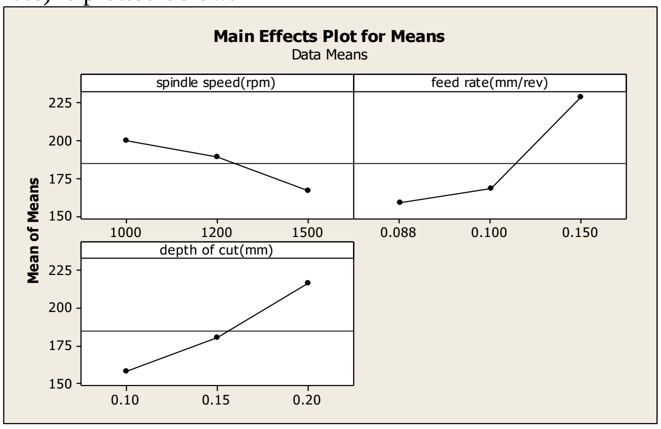


Taguchi Analysis: Main effect plot for S/N ratio for MRR

Response table for means

Level	Speed (rpm)	Feed (mm/rev)	Depth of cut (mm)
1	199.50	158.70	158.20
2	188.90	168.00	180.30
3	166.60	228.30	216.40
Delta	32.90	69.70	58.20
Rank	3	1	2

The main effect plot for the mean for MRR(material removal rate) is plotted below:



Taguchi Analysis: Main effect plot for means for MRR

Hence, from the graph, it can be seen that the optimum cutting parameter can be obtained by points or values of parameters having the peak position in the graph. Therefore Factor levels for predictions are given below:

Predicted values for parameters(for MRR)

Parameters	Speed(rpm)	Feed(mm/rev)	Depth of cut(mm)
Optimum value	1000	0.15	0.2

Anova and effects of parameters on MRR

ANOVA result for material removal rate

Source	DF	AdjSS	AdjMS	F-Value	P-Value
Spindle speed	2	1692.2	846.09	10.25	0.089
Feed rate	2	8582.2	4291.09	51.98	0.019
Depth of cut	2	5181.9	2590.97	31.39	0.031
Error	2	165.1	82.55		
Total	8	15621.4			

S= 9.08565 R-sq= 98.94% R-sq(Adj)= 95.77%
R-sq(Pred)= 7860

It can be observed from the results obtained in the table 1.5 that feed rate was the most significant parameter having the highest statistical influence (P=0.019) and the depth of cut(P=0.031) followed by spindle speed(P=0.089). The value of R^2 calculated for this model was 0.989, i.e., very close to unity, and thus acceptable. Thus, it is conferred that this model provides reasonably good explanation of the relationship between the independent factors and the response.

Regression analysis for material removal rate (MRR):

Predictors for generating regression model

Predictors	Coef	SE Coef	T	P
Constant	50.31	21.6	2.33	0.067
Spindle speed(rpm)	-0.06647	0.01273	-5.22	0.003
Feed rate(mm/rev)	1148.04	97.45	11.78	0
Depth of cut(mm)	582.13	64.09	9.08	0

S = 7.84962 R-Sq = 98.0% R-Sq(adj) = 96.8%

The regression equation generated from the table 4.6 is as:

MRR(mm^3/s)= 50.3 - 0.0665 spindle speed(rpm) + 1148 feed rate(mm/rev) + 582 depth of cut(mm)

The confirmation test for Material Removal Rate

Confirmation tests result

Test no.	Experiment	Model of equation	Error(%)
1	148.41	143.024	3.6
2	171.83	185.9	8.18
3	278.21	272.4	2.08
4	161.85	158.824	1.86
5	205.37	201.7	1.78
6	199.54	200.9	0.68
7	165.76	167.974	1.33
8	126.75	123.55	2.52
9	207.26	210.05	1.34

VI. Conclusion:

This paper has presented an application of parameter design of the taguchi method in the optimization of turning operations. The following conclusions can be drawn based on the experimental results of this study:

- Taguchi's robust orthogonal array design method is suitable to analyze the surface roughness (metal cutting) as well as material removal rate problem.
- It is also found that the different parametric design based on the Taguchi method provides a simple, systematic and efficient methodology for the optimization of the machining parameters.
- It can be concluded that spindle speed and depth of cut are the main parameters among the three controllable factors (spindle speed, feed rate, depth of cut) that influence surface roughness during CNC-Turning.
- This experiment also suggests that the material removal rate is highly influenced firstly by the feed rate and then depth of cut followed by spindle speed.
- In turning for minimum surface finish, use of medium cutting speed (1200rpm), higher depth of cut(0.2mm) and higher feed rate(0.15mm/rev) are recommended to obtain better surface roughness for the specific range.
- When we looking for higher material removal rate, smaller cutting speed(1000rpm), higher depth of cut(0.2mm) and higher feed rate(0.15mm) can be employed to get optimized result.

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