Optimization of Process Parameters in CNC Drilling of EN 36

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Abstract: *The selection of optimum machining parameters plays a significant role for maximize the productivity and quality characteristics of products. The objective of the study is to optimize drilling Process parameter such as spindle speed, feed rate, depth of cut and drill diameter using Taguchi method to obtain optimal levels for Material Removal Rate (MRR) and Surface Roughness Characteristics (R_a, R_q and R_z). The experiments were conducted as per the standard L16 orthogonal array on CNC Drilling Machine on EN 36 material using carbide coated HSS twist drills. Signal to Noise (S/N) ratio was employed to optimize process parameters which affects the MRR, R_a, R_q and R_z. ANOVA is carried out on response variables and factors influencing on each response variables are determined. To convert the multi-objective problem to single objective problem, Grey Relational Analysis is carried out and grey grades were determined to identify the optimum combination of factors.*

Keywords: *EN 36, Taguchi, ANOVA, Grey Relational Analysis, MRR, Surface Roughness Characteristics*

1. Introduction

Drilling is a process of metal removal operation at minimum cost consistent with the required quality levels. The attainment of his straight forward objective can present challenges to those responsible for establishing and maintaining efficient production operation.

Productivity and Quality are two important factors which are interrelated with each other in any machining operation. Drilling operation is evaluated based on the performance characteristics such as surface roughness, material removal rate (MRR), tool wear, tool life, cutting force, hole diameter error, power consumption and are strongly correlated with the drilling parameters such as speed, feed, depth of cut, and tool geometry.

In this context, four parameters spindle speed, feed, depth of cut and drill tool diameter are selected as controllable parameters and parameters like MRR and Surface Roughness are considered as the required productivity & quality characteristic responses. In this research work, Material Removal Rate (MRR) and Surface Roughness of the work piece (EN 36) resulted by CNC Drilling Machine are studied procedure to find out the solution (optimum parameters).

Taguchi method was used which allows the process optimization with minimum number of experiments without need for process model development. Thus, by this method, it is possible to reduce the time and cost for experimental investigations and thus enhance the performance characteristics. Followed by ANOVA and Grey Relational Analysis.

2. Literature Review

Deng and Chin (2006) investigated the roundness of holes in BTA deep-hole drilling on AISI 1045 steel by Taguchi methods. The machining parameters include tool diameter, shaft length, feed rate and rotational speed, day of the week (as noise factor). Result shows that strongly influence factors were feed rate, rotational speed and tool diameter, moderate influence of shaft length and no or little influence of noise factor on the roundness of the hole.

A. Noorul Haq et al., (2007) investigated the optimization of drilling parameters on drilling Al/SiC metal matrix composite with multiple responses based on orthogonal array with grey relational analysis. Drilling tests are carried out using TiN coated HSS twist drills of 10 mm diameter under dry condition. In this study, drilling parameters namely cutting speed, feed and point angle are optimized with the considerations of multi responses such as surface roughness, cutting force and torque. A grey relational grade is obtained from the grey analysis. Based on the grey relational grade, optimum levels of parameters have been identified and significant contribution of parameters is determined by ANOVA.

Zhang and Chen, (2009) study effect of feed rate, spindle speed, peck rate, & tool type also noise factors were shop vibration and the presence or absence of magnetism in the work piece material on surface roughness in a (CNC) drilling of 1018 low carbon steel plates forming L9 orthogonal array & Taguchi method. The effect of tool type and spindle speed on surface quality were greater than the effect of feed rate, also different peck rates had an impact on the surface finish of the drilled holes, work piece magnetism & vibration did not generate significant impacts on drilling hole surface roughness.

M. Kaladhar et al., (2011) investigated the Application of Taguchi Method and utility concept in solving the Multi-objective problem when turning AISI 202 Austenitic Stainless Steel. From the results it is concluded that feed has more influence on the parameters followed by speed and depth of cut.

C. Dhavamani et al., (2012) conducted the Optimization of Machining Parameters for Aluminum & Silicon carbide composite using Taguchi method, ANOVA, F-test Genetic Algorithm in CNC Drilling Machine, the input parameters taken are Drilling Speed (m/min), Feed rate (mm/rev), Diameter of cut (mm) whereas the output parameters were MRR, Surface finish, Minimization of specific energy and Flank wear.

K. Lipin et al., (2013) conducted an experiment to review on Multi Objective Optimization of Drilling Parameters in CNC drilling machine using Taguchi Methods on Mild Steel using Taguchi Orthogonal Array, Grey Relational Analysis taking the input parameters as Cutting Speed (m/min), Feed Rate (mm/rev) & point angle (degrees). Response variables were MRR & Surface Roughness.

G. Gangadhar et al., (2014) conducted the Experimental Approach of CNC Drilling Operation for Mild Steel Using Taguchi Design & ANOVA with input parameters Spindle Speed (rpm) Feed rate (mm/min), Drill tool point and output parameters were MRR, Circularity. It is concluded that Material removal rate (MRR) decreases when spindle speed, feed and tool diameter decrease. Circularity Error is mostly affected by spindle speed and feed rates.

YD Chethan et al., (2014) conducted the Parametric optimization in drilling EN-8 tool steel and drill wear monitoring using machine vision applied with taguchi method, ANOVA in Radial Drilling Machine with input parameters Spindle Speed (RPM), Feed rate (mm/rev) & Drill Diameter (mm) whereas output parameters were Tool wear.

Ms. Ashvini et al., (2016) investigated the Parametric Optimization of Drilling Machining Process of M.S Material in CNC Drilling Machine by using Factorial Regression Method and the input parameters were Spindle Speed (RPM), Feed Rate (mm/min) & Depth of Cut (mm) whereas the output parameters were Material removal rate and SR. It is concluded that the effect of Depth of Cut on the MRR value is significant and observed that the effect of Depth of Cut as well as spindle speed on the SR value is significant.

3. Experimental Details

A number of experiments are conducted to study the effects of various drilling parameters on CNC drilling machine. These studies have been under taken to investigate the effects of Spindle Speed, Feed Rate, Depth of Cut and Drill diameter on Metal Removal Rate (MRR) and Surface Roughness characteristics of EN 36. Which is machined on CNC drilling machine (AGNI BMV 45 T20) using carbide coated HSS twisted drills.

3.1 Selection of process parameters are their levels.

Selection of right combination of process parameters and setting the range of the process parameters is very important step in machining process. Process parameters are taken as fixed and Controllable. In the study, Tool geometry, work piece properties and mechanical properties are considered as fixed parameters which will not change throughout the investigation. Whereas Spindle speed, feed, depth of cut & drill diameter are considered as the process parameters which will be affected with the process of investigation. The process parameters with their levels and L16 orthogonal array are shown in table 1 & table 2.

Table 1: Process Parameters and their levels

Parameter	Units	Level-1	Level-2	Level-3	Level-4
Spindle Speed (N)	rpm	1000	1500	2000	2500
Feed Rate (fr)	mm/min	50	150	200	250
Depth of cut (d)	mm	6	8	12	15
Drill diameter (D)	mm	10	12	15	18

Table 2: L16 Orthogonal Array

Experiment No.	A	B	C	D
	1	2	3	4
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	1	4	4	4
5	2	1	2	3
6	2	2	1	4
7	2	3	4	1
8	2	4	3	2
9	3	1	3	4
10	3	2	4	3
11	3	3	1	2
12	3	4	2	1
13	4	1	4	2
14	4	2	3	1
15	4	3	2	4
16	4	4	1	3

3.2 Selection of response variables

a) Material Removal Rate (MRR)

In any machining operation, material removal rate is an important factor to enhance the productivity. Hence the characteristics for Material Removal Rate is "larger the better".

MRR= (π/4*D^2*f*N) mm^3/min------ (1)

Where, MRR=Material removal rate
D=diameter of the drill bit in mm
F=feed in mm/rev,
N=spindle speed in rev/min

b) Surface Roughness Characteristics

In all machining processes, Surface Roughness characteristics are mostly aimed to achieve better surface finish. The surface roughness characteristics are measured SJ 301.

3.3 Taguchi Method

"Orthogonal Arrays" provide a set of well balanced (minimum) experiments and Dr. Taguchi's Signal-to-Noise ratios (S/N), which are log functions of desired output, serve as objective functions for optimization, help in data analysis and prediction of optimum results

Higher-the-Better

To obtain optimal drilling performance, the higher-the-better quality characteristics for material removal rate (MRR) must be taken. The S/N ratio for the higher-the-better quality characteristics can be expressed as:

$$\text{S/N ratio} = -10\log\left(1/n \sum_{k=1}^{n}\left({}^{1}/_{y^2}\right)\right)$$

Lower-the-Better

To obtain the optimal drilling performance, the lower-the-better quality characteristics for surface roughness must be taken. The S/N ratio for the lower-the-better quality characteristics can be expressed as:

$$\text{S/N ratio} = -10\log \sum_{k=1}^{n} {}^{y^2}/_{n}$$

3.4 Grey Relational Analysis

The major advantage of Grey theory is that it can handle both incomplete information and unclear problems very precisely. Grey relational analysis is applied to optimize control parameters having multi-responses through grey relational grade.

Step 1: Data Pre-Processing

In grey relational analysis, the data pre-processing is the first step performed to normalize the random grey data with different measurement units to transform them to dimensionless parameters. If the original sequence data has quality characteristic as 'larger-the-better' then the original data is pre-processed as 'larger-the-best':

$$x_i(k) = \frac{y_i(k) - \min y_i(k)}{\max y_i(k) - \min y_i(k)}$$

If the original data has the quality characteristic as 'smaller-the better', then original data is pre-processed as 'smaller-the-best':

$$x_i(k) = \frac{\max y_i(k) - y_i(k)}{\max y_i(k) - \min y_i(k)}$$

Here $x_i(k)$ is the value after grey relational generation, min $y_i(k)$ is the smallest value of $y_i(k)$ for the k^{th} response, and max $y_i(k)$is the largest value of $y_i(k)$ for the k^{th} response.

Step 2: Deviation Sequencing

Deviation sequencing is calculated for the obtained pre-processing data by considering ideal value 1. Deviation sequencing can be calculated by using the following formula, Δ_{0i} = 1- $x_i(k)$,

Where Δ_{0i} = Deviation sequencing for the k^{th} pre-process data and $x_i(k) = k^{th}$ pre-process value.

Step 3: Grey Relational Coefficient [ξ_i(k)]

Grey Relational coefficient ξ_i is calculated for all the obtained deviational sequencing data individually, Grey relational coefficient ξi(k) is calculated using the formula:

$$\xi_i(k) = \frac{\Delta_{\min} + \psi\Delta_{\max}}{\Delta_{0i}(k) + \psi\Delta_{\max}}$$

Where ψ is the distinguishing coefficient 0 $\leqslant \psi \leqslant$1, therefore ψ is take as 0.5

Δ_{0i} (k) = Deviation sequencing of k^{th} value

Δ_{max} = Maximum deviation value form the k^{th} deviation values

Δ_{min} = Minimum deviation value form the k^{th} deviation values

Step 4: Grey Relational Grade

After obtaining the grey relational coefficient in final step relational grade is calculated by the following formula. Here n is the number of process responses.

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n}\xi_i(k)$$

After finding Grey relational grade, Taguchi analysis is done to obtain the overall grey relational grade from which optimal process parameters for both MRR and Surface roughness are selected. ANOVA is performed on the grey relational grade to find out the contribution of each process parameters on both the MRR and Surface roughness.

4. Results and Discussions

A series of experiments are conducted on the material EN 36 with different drill diameters of HSS carbide coated tool. The components after machining are tested for surface roughness and material removal rate through their respective procedures. The S/N ratios are obtained for MRR at larger-the-better and Surface Roughness at smaller-the-better. All the results are shown in Table 3 & 4. The Minitab software tool is used to calculate Taguchi analysis and ANOVA.

Table 3: Experimental results of output responses.

Runs	MRR (mm^3/min)	R_a (μm)	R_q(μm)	R_z(μm)
1	471	7.33	9.11	24.36
2	1017	4.97	6.03	18.32
3	2120	4.96	6.53	20.14
4	2200	3.93	4.83	14.15
5	1300	3.80	4.79	13.73
6	1526	5.13	5.99	17.23
7	1178	4.25	5.47	14.67
8	1200	4.89	5.94	18.04
9	3052	6.06	7.25	19.85
10	1900	3.76	4.93	14.97
11	678	7.25	8.61	24.00
12	707	6.39	7.64	20.50
13	1696	3.92	5.05	14.72
14	800	4.73	5.95	15.48
15	2000	3.90	4.89	12.90
16	1060	5.68	6.96	19.97

Table 4 : S/N ratios of process responses

Runs	S/N (MRR)	S/N (R_a)	S/N (R_q)	S/N (R_z)
1	53.4604	-17.3021	-19.1904	-27.7335
2	60.1495	-13.9271	-15.6063	-25.2585
3	66.5247	-13.9096	-16.2983	-26.0812
4	66.8485	-11.8879	-13.6789	-23.0151
5	62.2789	-11.5957	-13.6067	-22.7534
6	63.6713	-14.2023	-15.5485	-24.7257
7	61.4192	-12.5678	-14.7597	-23.3286
8	61.5836	-13.7862	-15.4757	-25.1247
9	69.6917	-15.6495	-17.2068	-25.9552
10	65.5751	-11.5038	-13.8569	-23.5044
11	56.6277	-17.2068	-18.7001	-27.6042
12	56.9822	-16.1100	-17.6619	-26.2351
13	64.5865	-11.8657	-14.0658	-23.3582
14	58.0618	-13.4972	-15.4903	-23.7954
15	66.0206	-11.8213	-13.7862	-22.2118
16	60.5041	-15.0870	-16.8522	-26.0076

4.1 S/N RATIO AND ANOVA ANALYSIS FOR MRR

4.1.1 Signal to noise ratios for MRR

Table 5: Response S/N ratios for MRR

Runs	Spindle Speed	Feed rate	Depth of cut	Drill Diameter
1	61.75	62.50	58.57	57.48
2	62.24	61.86	61.36	60.74
3	62.22	**62.65**	63.97	63.72
4	**62.29**	61.48	**64.61**	**66.56**
DELTA	0.55	1.17	6.04	9.08
RANK	4	3	2	1

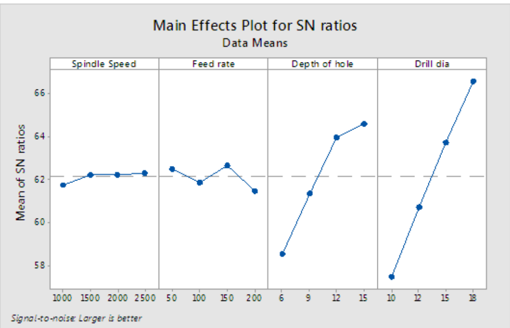


Figure 1: Main effects plot for SN ratios (MRR)

The optimal parameters from the table 5 by Taguchi design for MRR are spindle speed = 2500 rpm, feed rate = 150 mm/min, depth of cut = 15 mm and drill diameter = 18 mm. The Fig 1 shows the Taguchi optimal parameters for MRR. The Results of the confirmation experiment for MRR are shown in table 6.

4.1.2 Predicted MRR

Predicted S/N Ratio = Y+ (A_4-Y) + (B_3-Y) + (C_4-Y) + (D_4-Y)

Where, Y = Average of S/N Ratio values for MRR

i.e. Y = 62.12

Predicted S/N Ratio =62.12+ (62.29-62.12) + (62.65-62.12) + (64.61-62.12) + (66.56-62.12) = 69.75.

For higher –the – better, S/N Ratio= -10 log (1/(MSD)) = -10 log(1/(MRR)^2) =MRR = 3072.56 mm^3/min

Table 6: Results of the confirmation experiment for MRR

Confirmation experiment for MRR (mm^3/min)		
Level	**Predicted value**	**Experimental results**
A_4, B_3, C_4, D_4	3072.56	3052

4.1.3 Analysis of Variance for MRR:

Table 7: ANOVA Results for MRR

Source	DF	Adj. SS	Adj.MS	F	P
Spindle Speed	3	170448	56816	0.67	0.627
Feed	3	309140	103047	1.21	0.440
Depth of cut	3	2025423	675141	7.91	0.062
Drill Diameter	3	4409874	1469958	17.23	0.021
Error	3	255933	85311		
Total	15	7170816			

S= 292.080, R-sq = 96.43%, R-sq(adj) = 82.15%.

From the ANOVA table 7, the most significant factors that affect MRR are Drill diameter (mm), followed by Depth of cut (mm), feed (mm/min) and Spindle Speed (rpm). The percentage contribution of Drill diameter is 63.76%.

4.2 S/N RATIO AND ANOVA ANALYSIS FOR R_a

4.2.1 Signal to noise ratios for R_a

Table 8: Response S/N ratios for R_a

Runs	Spindle Speed	Feed rate	Depth of cut	Drill Dia
1	-14.26	-14.10	-15.95	-14.87
2	**-13.04**	**-13.28**	-13.36	-14.20
3	-15.12	-13.88	-14.21	**-13.02**
4	-13.07	-14.22	**-11.96**	-13.39
DELTA	2.08	0.94	3.99	1.85
RANK	2	4	1	3

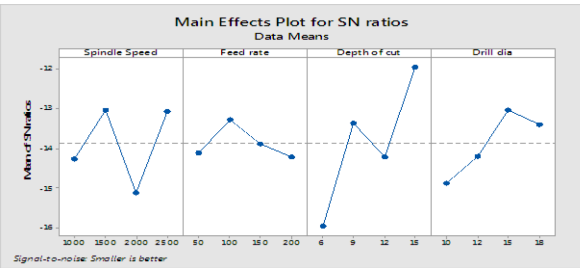


Figure 2: Main effects plot for SN ratios ($R_{a)}$

The optimal parameters from the table 8 by Taguchi design for R_a are Spindle speed=1500 rpm, Feed rate = 100 mm/min, Depth of cut = 15 mm and Drill diameter = 15 mm. The Fig 2 shows the Taguchi optimal parameters for R_a. The Results of the confirmation experiment for R_a are shown in table 9.

4.2.2 Predicted Surface Roughness (R_a) : Predicted S/N Ratio = Y+ (A2-Y) + (B2-Y) + (C4-Y) + (D3-Y)
Where, Y = Average of S/N

Ratio values for Surface

Roughness, Y = -13.87

Predicted S/N Ratio:= -13.87+ (**-13.04** - (-13.87)) + (**-13.28** - (-13.87)) + (**-11.96** - (-13.87)) + (**-13.02** - (-13.87)) = -9.69

For smaller the better (S/N Ratio= -10 log (MSD)), -9.69 = -10 log $((R_a)^2)$, Therefore, R_a = 3.051 μm.

Table 9: Results of the confirmation experiment for Surface Roughness

Confirmation experiment for R_a (μm)		
Level	**Predicted value**	**Experimental results**
A_2, B_2, C_4, D_3	3.051	3.35

4.2.3 Analysis of Variance for R_a:

Table 10: ANOVA Results for R_a

Source	DF	Adj. SS	Adj.MS	F	P
Spindle Speed	3	5.0050	1.66832	20.97	0.016
Feed	3	0.9791	0.32636	4.10	0.138
Depth of cut	3	11.8148	3.93827	49.51	0.005
Drill Diameter	3	3.0814	1.02714	12.91	0.032
Error	3	0.2386	0.07954		
Total	15	21.1189			

S= 0.282028, R-sq = 98.87%, R-sq(adj) = 94.35%, R-sq(pred)= 67.86%.

From the ANOVA table 10, the most significant factors that affect the Surface roughness (R_a) are Depth of cut (mm), followed by Spindle speed (rpm), Drill diameter (mm) and Feed (mm/min). The percentage contribution of Depth of cut is 56.59%

4.3 S/N RATIO AND ANOVA ANALYSIS FOR R_q

4.3.1 Signal to noise ratios for R_q

Table 11: Response S/N ratios for R_q

Runs	Spindle Speed	Feed rate	Depth of cut	Drill Dia
1	-16.19	-16.02	-17.57	-16.78
2	**-14.85**	**-15.13**	-15.17	-15.96
3	-16.86	-15.89	-16.12	-15.15
4	-15.05	-15.92	**-14.09**	**-15.06**
DELTA	2.01	0.89	3.48	1.72
RANK	2	4	1	3

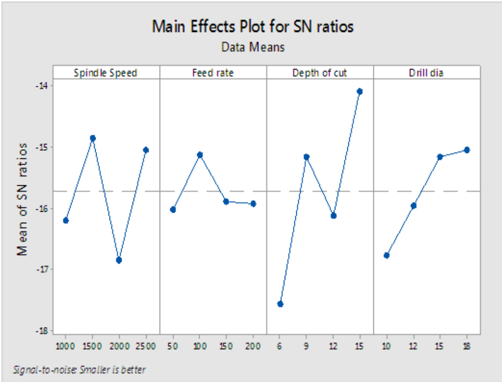


Figure 3: Main effects plot for SN ratios (R_q)

The optimal parameters from the table 5.9 by Taguchi design for R_q are Spindle Speed = 1500 rpm, Feed rate = 100 mm/min, Depth of cut = 15 mm and Drill diameter = 18 mm. The Fig 3 shows the Taguchi optimal parameters for R_q. The Results of the confirmation experiment for R_q are shown in table 12.

4.3.2 Predicted Surface Roughness (R_q): Predicted S/N Ratio = Y+ $(A_2$-Y) + $(B_2$-Y) + $(C_4$-Y) + $(D_4$-Y)
Where, Y = Average of S/N

Ratio values for Surface

Roughness i.e. Y = -15.74

Predicted S/N Ratio: = -15.74+ (**-14.85** – (-15.74)) + (**-15.13** – (-15.74)) + (**-14.09** – (-15.74)) + (**-15.06** – (-15.74)) = -11.91

For smaller –the – better, S/N Ratio= -10 log (MSD), -11.91= -10 log $((R_q)^2)$, Therefore, R_q = 3.94 μm.

Table 12: Results of the confirmation experiment for Surface Roughness

Confirmation experiment for R_q (μm)		
Level	**Predicted value**	**Experimental results**
A_2, B_2, C_4, D_4	3.94	4.25

4.3.3 Analysis of Variance for R_q:

Table 13: ANOVA Results for R_q

Source	DF	Adj. SS	Adj.MS	F-value	P-value	% Contribution
Spindle Speed	3	6.6333	2.2111	21.44	0.016	24.53%
Feed	3	1.5592	0.5197	5.04	0.108	7.76%
Depth of cut	3	14.3996	4.7999	46.55	0.005	53.24%
Drill Diameter	3	4.4528	1.4843	14.40	0.028	16.47%
Error	3	0.3093	0.1031			
Total	15	27.3542				

S= 0.321102, R-sq = 98.87%, R-sq(adj) = 94.35%,

From the ANOVA table 13, the most significant factors that affect R_q are Depth of cut (mm) followed by Spindle Speed (rpm), Drill Diameter (mm) and feed (mm/min). The percentage contribution of Depth of cut is 53.24%

4.4 S/N RATIO AND ANOVA ANALYSIS FOR R_z

4.4.1 Signal to noise ratios for R_z

Table 14: Response S/N ratios for R_z

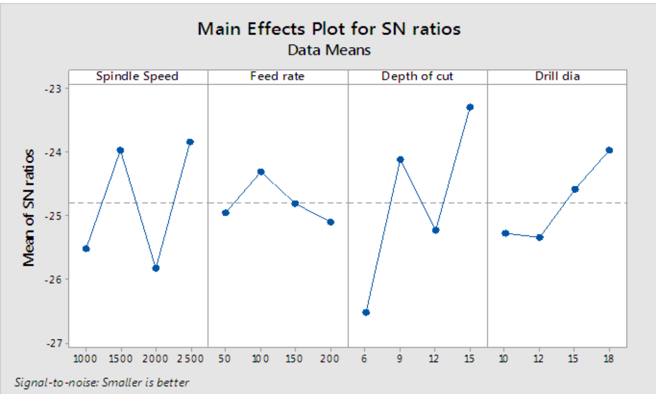
Runs	Spindle Speed	Feed rate	Depth of cut	Drill Dia
1	-25.52	-24.95	-26.52	-25.27
2	-23.98	**-24.32**	-24.11	-25.34
3	-25.82	-24.81	-25.24	-24.59
4	**-23.84**	-25.10	**-23.30**	**-23.98**
DELTA	1.98	0.77	3.22	1.36
RANK	2	4	1	3

The optimal parameters from the table 14 by Taguchi design for R_z are Spindle speed = 2500 rpm, Feed rate = 100 mm/min, Depth of Cut = 15 mm and Drill Diameter = 18 mm.

Figure 4: Main effects plot for SN ratios (R_z)

4.4.2 Predicted Surface Roughness (R_z):

Predicted S/N Ratio = Y+ (A_4-Y) + (B_2-Y) + (C_4-Y) + (D_4-Y)



Where, Y = Average of S/N Ratio values for Surface Roughness i.e. Y = -24.79

Predicted S/N Ratio: =- 24.79+ (**-23.84** – (-24.79) + (**-24.32** – (-24.79) + (**-23.30** – (-24.79) + (**-23.98** – (-24.79)= -21.07

For smaller –the – better S/N Ratio= -10 log (MSD),

-21.07= -10 log ((R_z) ^{2}), therefore R_z = 11.31 µm.

The Fig 4 shows the Taguchi optimal parameters for R_q. From the parameters it is clear that the responses obtained for optimum conditions are not in the orthogonal array values, so to find the response parameter values for this case a confirmatory test has to be conducted and the values obtained from the test are to be compared with the predicted values. It is shown in the table 15.

Table 15: Results of the confirmation experiment for Surface Roughness

Confirmation experiment for R_z (µm)		
Level	**Predicted value**	**Experimental results**
A_4, B_2, C_4, D_4	11.31	12.90

4.4.3 Analysis of Variance for R_z:

Table 16: ANOVA Results for R_z

Source	DF	Adj. SS	Adj.MS	F	P
Spindle Speed	3	55.310	18.437	11.43	0.038
Feed	3	7.695	2.565	1.59	0.356
Depth of cut	3	101.215	33.738	20.92	0.016
Drill Diameter	3	21.121	7.040	4.37	0.129
Error	3	4.838	1.613		
Total	15	190.180			

S= 1.26989, R-sq = 97.46%, R-sq(adj) = 87.28%,

From the ANOVA table 16, the most significant factors that affect R_z are Depth of cut (mm) followed by Spindle speed (rpm), drill diameter (mm) and feed (mm/min). The percentage contribution of Depth of cut is 54.61%

4.5 GREY RELATIONAL ANALYSIS

Taguchi analysis method can optimize a single objective function, it cannot solve multi-objective optimization problem. The optimal setting for a response variable cannot ensure other response variables within acceptable limits. So, one should go for such an optimal parameter setting so that all the objectives should fulfill simultaneously. These will be achieved using grey based Taguchi method.

4.5.1 Grey Relational Analysis

Step 1: Pre-processing data: The obtained process responses are pre-processes in the first step as explained. Table 17 shows the Pre-processing data for each individual response.

Table 17 Pre-processing data

Exp. No	MRR mm^3/min	Average Surface roughness R_a (µm)	Root mean square roughness R_q (µm)	Ten point mean roughness R_z (µm)
1	0.0000	0.0000	0.0000	0.0000
2	0.2117	0.6611	0.7130	0.5271
3	0.6387	0.6639	0.5972	0.3682
4	0.6699	0.9524	0.9907	0.8909
5	0.3212	0.9888	1.0000	0.9276
6	0.4088	0.6162	0.7222	0.6222
7	0.2737	0.8627	0.8426	0.8455
8	0.2824	0.6835	0.7338	0.5515
9	1.0000	0.3557	0.4306	0.3935
10	0.5537	1.0000	0.9676	0.8194
11	0.0803	0.0224	0.1157	0.0314
12	0.0912	0.2633	0.3403	0.3368
13	0.4745	0.9552	0.9398	0.8412
14	0.1275	0.7283	0.7315	0.7749
15	0.5924	0.9608	0.9769	1.0000
16	0.2281	0.4622	0.4977	0.3831

Step 2: Sequencing deviation (Δ_{0i}): Deviation sequencing is calculated for the obtained pre-processing data by considering ideal value 1. Results of sequencing deviation are shown in the Table 18.

Table 18: Sequencing deviation (Δ_{0i}) Ideal Value=l

Exp. No	MRR mm^3/min	Average Surface roughness R_a (μm)	Root mean square roughness R_q (μm)	Ten point mean roughness R_z (μm)
1	1.0000	1.0000	1.0000	1.0000
2	0.7883	0.3389	0.2870	0.4729
3	0.3613	0.3361	0.4028	0.6318
4	0.3301	0.0476	0.0093	0.1091
5	0.6788	0.0112	0.0000	0.0724
6	0.5912	0.3838	0.2778	0.3778
7	0.7263	0.1373	0.1574	0.1545
8	0.7176	0.3165	0.2662	0.4485
9	0.0000	0.6443	0.5694	0.6065
10	0.4463	0.0000	0.0324	0.1806
11	0.9197	0.9776	0.8843	0.9686
12	0.9088	0.7367	0.6597	0.6632
13	0.5255	0.0448	0.0602	0.1588
14	0.8725	0.2717	0.2685	0.2251
15	0.4076	0.0392	0.0231	0.0000
16	0.7719	0.5378	0.5023	0.6169

Step 3: Grey relational coefficient (ξ_i(k)): In the next step coefficient $\xi_i$is calculated for all the obtained deviational sequencing data individually, Grey relational coefficient ξi(k) is calculated. Grey Relational Coefficients are shown in the Table 19.

Table 19: Grey relational coefficient (ξ_i(k))

Exp. No	MRR mm^3/min	Average Surface roughness R_a (μm)	Root mean square roughness R_q (μm)	Ten point mean roughness R_z (μm)
1	0.333333	0.333333	0.333333	0.333333
2	0.388104	0.595993	0.635294	0.513901
3	0.580522	0.597990	0.553846	0.441789
4	0.602334	0.913043	0.981818	0.820917
5	0.424158	0.978082	1.000000	0.873476
6	0.458199	0.565769	0.642857	0.569583
7	0.407741	0.784615	0.760563	0.764000
8	0.410660	0.612350	0.652568	0.527139
9	1.000000	0.436965	0.467532	0.451893
10	0.528352	1.000000	0.939130	0.734615
11	0.352186	0.338389	0.361204	0.340463
12	0.354923	0.404304	0.431138	0.429857
13	0.487551	0.917738	0.892562	0.758940
14	0.364291	0.647913	0.650602	0.689531
15	0.550907	0.927273	0.955752	1.000000
16	0.393116	0.481781	0.498845	0.447656

Step 4: Grey Relational Grade, from the obtained coefficients in table 19, grey relational grade is calculated. Table 20 shows the Grey relational Grade values.

Table 20: Grey Relational Grade Value

Exp. No.	Grey Relational Grade	Exp. No.	Grey Relational Grade
1	0.333333	9	0.589097
2	0.533323	10	0.800524
3	0.543537	11	0.348060
4	0.829528	12	0.405055
5	0.818929	13	0.764198
6	0.559102	14	0.588084
7	0.679230	15	0.858483
8	0.550679	16	0.455350

Step 5: Taguchi for Grey Relational Grade: In the final step the obtained Grey relational grade has been nalysed by using Taguchi, AVOVA to obtain the optimal process parameter level.

Optimal parameters from the table 21, by Taguchi design for Grey relational grade are Spindle speed = 2500 rpm, feed = 100 mm/min, Depth of cut = 15 mm and Drill diameter = 18 mm. The Fig 5 shows the Gray optimal parameters for R_q.

Table 21: Response Table for Signal to Noise Ratios

Level	Spindle Speed	Feed	Depth of Cut	Drill Diameter
1	-5.480	-4.552	-7.648	-6.341
2	-3.832	**-4.264**	-4.093	-5.536
3	-5.886	-4.787	-4.921	-3.949
4	**-3.776**	-5.372	**-2.313**	**-3.149**
Delta	2.110	1.109	5.335	3.192
Rank	3	4	1	2

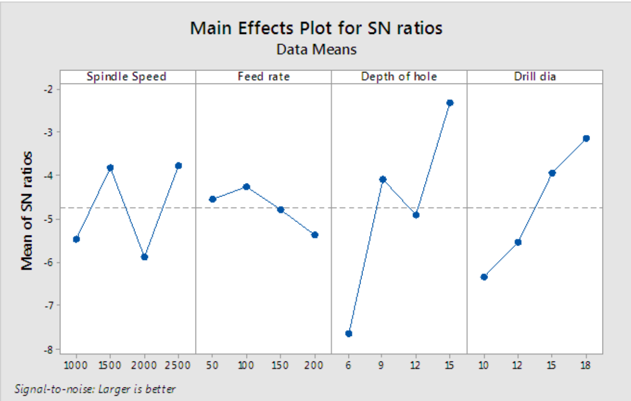


Figure 5: Main effect plot for Grey relational grade

4.5.2 Analysis of variance for Grey Relational Grade

From the ANOVA table 22, the most significant factors that affect the both MRR and Surface roughness are in Depth of cut, Drill Diameter, Spindle speed and feed respectively.

Table 22: Results of ANOVA for Grey Relational Grade

Source	DF	Adj SS	Adj MS	F	P
Spindle	3	0.05128	0.017094	2.26	0.260
Feed	3	0.01079	0.003598	0.48	0.721
Depth of	3	0.25293	0.084310	11.17	0.039
Drill	3	0.10853	0.036178	4.79	0.115
Error	3	0.02265	0.007550		
Total	15	0.44619			

S = 0.0868882, R-Sq = 94.92%, R-Sq (adj) = 74.62%,

Based on the percentage of contribution it can be said that Depth of cut has more affect on MRR and Surface roughness. The percentage contribution of Depth of Cut is 61.47%.

5. CONCLUSION

Based on the results obtained and discussion made in the earlier chapters the following conclusions are drawn:

- Drill diameter has higher influence on the MRR (Material removal rate) followed by Depth of cut, Feed rate and Spindle speed. When drill diameter is increased MRR increases.
- Depth of cut has higher influence on Average Surface Roughness (R_a) whereas Spindle speed has medium influence followed by Drill diameter and feed rate.
- Depth of cut has higher influence on Root Mean Square Roughness (R_q) whereas Spindle speed has medium influence followed by Drill diameter and feed rate.
- Depth of cut has higher influence on Ten Point Mean Roughness (R_z) whereas Spindle speed has medium influence followed by Drill diameter and feed rate.
- In the present work Taguchi L16 orthogonal array is selected.
- Analysis of Variance is carried out on response variables and the percentage contribution of each parameter is identified.
- In the present work Grey-Taguchi technique was successfully implemented for converting multi-objective criterion into a single objective function. The results obtained by grey-Taguchi analysis showed the best combination of the experiments conducted.

ANOVA for the Grey Relational Grade is carried out and the factor influencing the most is identified. Depth of cut has most influence in the machining process followed by Drill diameter, Spindle speed and feed.

FUTURE SCOPE

The present work was done to find out the parameters combination which will result in the optimum Surface Roughness and Material Removal Rate when a specific work piece is machined using a CNC Machine. The parameters considered were Speed, Feed and Depth of Cut Drill diameter. Further in each parameter four levels were taken, the Design of Experiments was Taguchi Method with L16 Orthogonal array is selected followed by ANOVA and Grey Relational Analysis for Multi-optimization. In future, we suggest the work can be improved by using different input parameters along with the Optimization techniques such as Genetic Algorithm or Response Surface Methodology.

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