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# Optimization of Process Parameters of CNC End Milling using Grey based Taguchi Method

**Prajwal Patil[1], Md Ashfaq Hussain[2], Md Qalequr Rahaman[3]**

PG Student, Mechanical Engineering (CIM), GND Engineering College, Bidar, India[1]

Assistant Professor, Mechanical Engineering, GND Engineering College, Bidar, India[2,3]

**Abstract:** The surface roughness is one of the most specified customer requirements in metal cutting industries and it plays a vital role in determining, how a real object interacts with its environment. Rough surface usually wear more quickly and have higher friction coefficients than smooth surfaces, since roughness is a good predictor of the performance of a mechanical components, its measurement carries vital importance. Since productivity is linked to Material Removal Rate (MRR), its investigation is also equally important. End milling is the most important milling operation and it is widely used in most of the manufacturing industries due to its capability of producing complex geometric surfaces with reasonable accuracy and surface finish. However, with the inventions of CNC milling machine, the flexibility has been adopted along with versatility in end milling process. Proper setting of cutting parameter is important to obtain better surface quality. Unfortunately, conventional trial and error method is time consuming as well as it incurs high cost. The purpose for this study is to determine the most significant parameter and its optimum range in CNC end milling process using various statistical tools such as Taguchi's grey relational method, Analysis of variance (ANOVA), and Regression analysis. It is also proposed to develop a mathematical model, which can be used for prediction. The spindle speed, feed rate, and depth of cut have been chosen as predictors in order to predict the multiple responses surface roughness and Material Removal Rate (MRR) simultaneously. For initial investigation of ANOVA, grey relational analysis and regression analysis may be employed to determine, which is most significant parameter among Spindle speed, feed rate, and depth of cut that influence surface roughness and MRR. With the optimum combination of levels from ANOVA, Grey relational analysis, and Regression analysis, confirmation test is proposed to be conducted. The experiment are planned to be conducted on YCM EV 1020A vertical CNC milling machine and the response will be measured by Mitutoyo SURFTEST SJ-210. In this work, Minitab 16 expert will be used for developing a regression mathematical model, which in turn can be used for prediction.

**Keywords:** Milling operation, Analysis of Variance (ANOVA), Signal to Noise Ratio (SN), Grey Relational Analysis, Regression Analysis.

## I. INTRODUCTION

In modern industry, one of the trends is to manufacture low cost, high quality products in short time. Automated and flexible manufacturing systems are employed for that purpose. CNC machines are considered most suitable in flexible manufacturing system. Above all, CNC milling machine is very useful for both its flexibility and versatility. CNC end milling is a process in which material is machined under a CNC machine to give best surface finish to the material & to get best accuracy in short time. Surface quality and productivity are two important concepts in any machining operations. Therefore, it is essential to optimize quality and productivity simultaneously CNC end milling process is carried out. Dimensional accuracy, surface smoothness & fulfilment of functional requirements in described area of application are the important quality attributes of the product. End milling is the most important milling process in which rotating end mill tool is used that contain number of flutes to remove materia1 from metal and it is widely used in most of the manufacturing industries due to its capability of producing complex geometric surfaces with reasonable accuracy and surface finish.

The figure below shows the end milling process.

In end milling, surface finish and material removal rate are two important aspects, which plays vital role in industry, personnel & as well as in research & development to achieve higher surface smoothness, because these two factors greatly influence machining performances. In modern industries, one of the trends is to manufacture low cost, high quality products in short time. Automated and flexible manufacturing systems are mainly employed for that purpose. CNC machines are considered most suitable in flexible manufacturing system. These machines are capable of achieving best accuracy and surface finish. Processing time is a1so very 1ow as compared to some of the conventional machining process.

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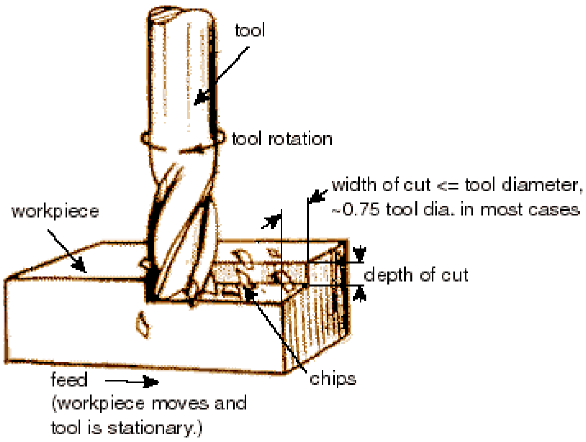


Figure No. 1.1 End milling process

In this study based on literature we selected aluminum Al 6061 T6 material for experimentation. From the literature the processing parameters were selected are spindle speed, feed rate and depth of cut using 4 levels for each parameter. The experiment was conducted on YCM EV1020 A CNC milling machine using the tungsten carbide end mill tool 16mm diameter with 4 flutes. There are 16 pockets are made on work piece which are 30×30mm in dimension. There are 16 experiments were conducted based on an L16 orthogonal array of Taguchi method. After the machining, the surface roughness is measured by Mitutoyo SURFTEST SJ-210 instrument, & material removal rate is calculated by measuring machining time. A grey relational grade obtained from the grey relational analysis is used to solve the end milling operation with the multiple performance characteristics. Additionally, the analysis of variance (ANOVA) is also utilized to identify the most significant parameter. Surface roughness is the outer most component of surface of the product & it is a measurement of the fine1y spaced surface irregularities. It is quantified by the deviations of a real surface from its ideal form. If these deviations are large, the surface is rough. If they are small, the surface is smooth. The surface texture is one of the important parameter to control friction and transfer layer formation during sliding & avoid rusting. Roughness plays a vital role in determining how a real object will interact with its surrounding environment. Usually rough surfaces wear more quickly and have higher friction coefficients than smooth surfaces. Material removal rate (MRR), which indicates processing time of the work piece, it is another important aspect that influences production rate and cost. The MRR is calculated by measuring machining time. When machining operation get started the contact between tool & work piece leads to removal of material.

## II. LITERATURE SURVEY

**Thakur Paramjit Mahesh** et al. (2014) have worked on optimizing process parameters in CNC end milling of AL7075-T6 aluminium alloy using Taguchi-fuzzy approach by considering speed, feed, depth cut, and nose radius as parameters at 3 levels for each. The material used is AL7075-T6 material for CNC end milling process. Here the author uses Taguchi L27 orthogonal array. The machine used is vertical milling machine centre (makino S33) and ISCAR (16mm) tool is used. The responses are surface roughness, material removal rate. The experiment result shows the significant improvement in surface roughness, material removal rate. The main parameters that effect the experiment are depth of cut 20.45%, nose radius 11.47%. [1]

**Lohithaksha M Maiyar** et al. (2013) have optimized process parameters for end milling of INCONEL 718 super alloy using Taguchi based grey relational analysis by considering cutting velocity, depth of cut, feed rate as parameters using 3 levels for each. In this paper Inconel718 super alloy material is used for optimization of end milling operation. Here the author uses taguchi(L9 orthogonal array) experimentation. Hass –US 5 axis, high speed CNC machine is used for machining. The tool used is tungsten carbide 10mm diameter with 4 flutes. Surface roughness is measured on Make-mahr surf test. The responses are surface roughness, material removal rate. It has been established that grey relational analysis is an effective optimization tool for machining of Inconel 718 alloy in end milling & optimum cutting lies at 75m/min for cutting velocity 0.06mm/tooth for feed rate & depth of cut & 64.8% increase in material removal rate & at the same time 9.52% decrease in surface roughness. Analysis of variance indicates that cutting velocity is the most significant machining parameter that effect 56.88%. [2]

**W. Li** et al. (2014) have focus their study on tool wear effect during end milling on Inconel 718 alloy by considering cutting speed, feed, radial depth of cut, axial depth of cut as parameters. In this paper the material used is Inconel alloy 718 & the experiment is done on 3 axis (CNCINAATI arrow, 500, CNC vertical machining centre) cutting tool is XOEX 120408R, F40m. 20mm diameter. Surface roughness is measured by knoop indicator. The responses are roughness, material removal rate. [3]

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**Surasit Rawangong** et al. (2013) have investigated the optimum cutting condition of face milling aluminium semi solid 2024 using carbide tool of diameter 30mm on CNC face milling machine by considering cutting speed, feed rate, and depth of cut as parameters. Here the author uses gas induced semi solid technique is used & surface roughness is measured by mitutoyo 301 surftest machine. Response is surface roughness. It was found that mean absolute percentage error(MAPE) of surface roughness obtained from predictive comparing to the value of 3.48%. It is acceptable, good result. [4]

**Reddy Sreenivasulu.** (2013) have optimized surface roughness & delamination damage of GFRP composite material in end milling using taguchi design method(L9 orthogonal array) & ANN, ANOVA technique using CNC vertical machining centre(KENT & ND co. ltd. Taiwan make) by considering cutting speed, feed rate, depth of cut as parameters. It performs slot operation using k10 carbide tool 10mm diameter. Surface roughness measuring device is TALY SURF 50. From the result of ANOVA it was concluded that cutting speed, depth of cut contribution in order found to be 26.84%, 40.44% respectively. Confirmatory experiments show that 5.052 micrometer surface roughness & 1.682 as de-lamination damage. Hence deviation found is 3.7% from analysis shows feed rate factor has less significance 7% on de-lamination factor. [5]

**Wei Zhao** et al. (2015) have conducted an experiment to evaluate cutting Performance of end mills for titanium aircraft components by considering speed, feed, radial depth of cut, axial depth of cut as parameters. The experiment was carried out on Mikron UPC 710 five-axis machine using solid AlTiN coated cemented carbide tools for pocket mill operation. Here author uses Fuzzy comprehensive evaluation technique. Tool wear is measured by optical microscope. Surface roughness is tested on Mahr S3P, surface roughness Tester and 3D coordinate measuring machines. It was found that the insert WSM35S is better than WSP45S for the rough milling pocket 1, 2 and 3. The solid carbide tool MC326 is better than 17762900A for the finish milling pocket 1, but worse than 17762900A for pocket 2 with tilted thin-rib. [6]

**Seyed Ali Niknam** et al. (2014) have analyzed on friction and burr formation in slot milling using aluminium ally AAS-6061-T5 by considering cutting speed, feed/tooth, depth of cut as parameters on 3 axis CNC machine tool using Iscar end milling tool. Experimental results show that lower friction angle is resulted when using larger chip load. Response is material removal rate consequently, larger friction angle is obtained when exit up milling side burr thickness decreases and exit bottom burr thickness increases. [7]

**Mehmet Emre Kara** et al. (2015) have performed optimization of Turn-milling processes by considering speed, depth of cut, feed, work rotational speed as parameters. The orthogonal turn-milling were carried out on Mori Seiki NTX 2000 Multi-Tasking Machine using cylindrical work piece of SAE 1050 steel of 100 mm diameter and 150 mm length & seco quattre mill with CVD coated cutting tool. Surface finish was determined using MITUTOYO SJ 301 surf test instrument. Here the author uses genetic algorithm, pareto optimal solution technique. Tool flank wear was measured by Nano Focus μ surf surface metrology system. For a good surface roughness and circularity, speed ratio should be kept as high as possible. Tool life & MRR are increased by 30% & 4% respectively. [8]

## III. EXPERIMENTAL SETUP AND DESIGN

**3.1 SELECTION OF PARAMETERS FOR MILLING EXPERIMENT:** Based on literature survey many controllable and uncontrollable parameters were found, they are as follows spindle speed, cutting force, tool deflection, cutting time, torque, tool wear, feed rate, depth of cut, cutting temperature, pressure, applied load, vibration, tool angle, etc…

We have selected three controllable parameters such as spindle speed, feed rate and Depth of cut which caused more influence on surface quality and material removal rate in a milling process.

The selection of the levels of the input parameters is very important. This selection will define the output parameters which will affect the result of the experiment. The selection of parameters has to be carried out according to the standards. A standard range of parameters levels have been obtained from the "Manufacturing & engineering technology" book, where a range for the input parameters has been mentioned. For the output parameters to be optimum we have select the levels of the parameters form this range. The levels with which the experiment has been carried out is given below. The table below shows the parameters and the levels that we are taking into account to conduct the experiment.

Table No. 3.1- Parameters and levels of Experiment.

| PARAMETERS | LEVELS | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| Speed (rpm) | 5500 | 6000 | 6500 | 7000 |
| Feed (mm/rev) | 660 | 720 | 780 | 840 |
| DOC (mm) | 0.12 | 0.16 | 0.20 | 0.24 |

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**3.2 DESIGN OF THE EXPERIMENT:**
No. of parameters = 3
No. of levels for each parameters = 4
Total degree of freedom for 3 parameters = 3x (4-1) = 9
Therefore the minimum no. of experiments = Total DOF for parameters +1= 9 + 1 = 10
Therefore minimum no of experiments = 10.
As we have 3 factors and 4 levels in the experiment, so L16 orthogonal array of Taguchi is to be selected. The table below shows the L16 orthogonal array.

Table No 3.2- Taguchi's L16 Orthogonal Array.

| Expt. No | Column | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| 1 | 1 | 1 | 1 | 1 | 1 |
| 2 | 1 | 2 | 2 | 2 | 2 |
| 3 | 1 | 3 | 3 | 3 | 3 |
| 4 | 1 | 4 | 4 | 4 | 4 |
| 5 | 2 | 1 | 2 | 3 | 4 |
| 6 | 2 | 2 | 1 | 4 | 3 |
| 7 | 2 | 3 | 4 | 1 | 2 |
| 8 | 2 | 4 | 3 | 2 | 1 |
| 9 | 3 | 1 | 3 | 4 | 2 |
| 10 | 3 | 2 | 4 | 3 | 1 |
| 11 | 3 | 3 | 1 | 2 | 4 |
| 12 | 3 | 4 | 2 | 1 | 3 |
| 13 | 4 | 1 | 4 | 2 | 3 |
| 14 | 4 | 2 | 3 | 1 | 4 |
| 15 | 4 | 3 | 2 | 4 | 1 |
| 16 | 4 | 4 | 1 | 3 | 2 |

The table below shows the factors allotment to the column by using Linear Graph, based on this we have conducted the experiments.

Table No 3.3-Parameters of the Experiment according to L16 Orthogonal Array.

| Expt. No | Column | | | | |
|---|---|---|---|---|---|
| | 1 Spindle speed (rpm) | 2 Feed rate (mm/rev) | 3 Depth of cut (mm) | 4 (e) | 5 (e) |
| 1 | 5500 | 660 | 0.12 | 1 | 1 |
| 2 | 5500 | 720 | 0.16 | 2 | 2 |
| 3 | 5500 | 780 | 0.20 | 3 | 3 |
| 4 | 5500 | 840 | 0.24 | 4 | 4 |
| 5 | 6000 | 660 | 0.16 | 3 | 4 |
| 6 | 6000 | 720 | 0.12 | 4 | 3 |
| 7 | 6000 | 780 | 0.24 | 1 | 2 |
| 8 | 6000 | 840 | 0.20 | 2 | 1 |
| 9 | 6500 | 660 | 0.20 | 4 | 2 |
| 10 | 6500 | 720 | 0.24 | 3 | 1 |
| 11 | 6500 | 780 | 0.12 | 2 | 4 |
| 12 | 6500 | 840 | 0.16 | 1 | 3 |
| 13 | 7000 | 660 | 0.24 | 2 | 3 |
| 14 | 7000 | 720 | 0.20 | 1 | 4 |
| 15 | 7000 | 780 | 0.16 | 4 | 1 |
| 16 | 7000 | 840 | 0.12 | 3 | 2 |

**3.3 EXPERIMENTAL PROCEDURE:**
The experiment were conducted on Aluminium 6061-T6 Alloy of rectangular plate of size 10.62 mm×10.62 mm×7.28 mm, with 16mm diameter carbide four flute end mill cutting tool using YCM EV 1020A vertical 3 axis milling

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machine. On which pocketing operation of size 30mm×30mm is done with selected parametric values of parameters. After the machining the surface roughness (Ra) is measured using Mitutoyo SURFTEST SJ-210 instrument and material removal rate (MRR) is calculated based on machining times & weights.

The formula for material removal rate is given below

$$\mathrm{MRR} = \frac{W_i - W_f}{\rho_s \times t}\ \mathrm{mm^3/min}\ \ldots\ldots\ldots(5.1)$$

Here, $W_i$ → Initial weight of work piece in gram
$W_f$ → Final weight of work piece in gram
t → Machining time in minute.
$\rho_s$ → Density of Aluminium Alloy ($2.7 \times 10^{-3}$ g/mm$^3$)

The below figure shows that Material selected for the experimentation is AL 6061 T-6

Figure 3.1-Work piece Material after Machining.

**3.4 EXPERIMENTED VALUES OF RESULTS FOR SELECTED RESPONSES:**

Table No 3.4- Parameters and their Responses.

| JOB NO. | PARAMETERS | | | RESPONSES | |
|---|---|---|---|---|---|
| | SPEED | FEED | DOC | Ra µm | MRR mm³/min |
| 1 | 5500 | 660 | 0.12 | 0.727 | 210.8003 |
| 2 | 5500 | 720 | 0.16 | 0.581 | 239.4015 |
| 3 | 5500 | 780 | 0.20 | 0.851 | 243.9024 |
| 4 | 5500 | 840 | 0.24 | 0.86 | 314.1057 |
| 5 | 6000 | 660 | 0.16 | 0.533 | 144.8207 |
| 6 | 6000 | 720 | 0.12 | 0.599 | 164.8855 |
| 7 | 6000 | 780 | 0.24 | 0.873 | 209.0323 |
| 8 | 6000 | 840 | 0.20 | 0.666 | 241.233 |
| 9 | 6500 | 660 | 0.20 | 0.441 | 182.4941 |
| 10 | 6500 | 720 | 0.24 | 0.632 | 204.0945 |
| 11 | 6500 | 780 | 0.12 | 0.606 | 177.0976 |
| 12 | 6500 | 840 | 0.16 | 0.468 | 186.6897 |
| 13 | 7000 | 660 | 0.24 | 0.588 | 182.4838 |
| 14 | 7000 | 720 | 0.20 | 0.762 | 209.5866 |
| 15 | 7000 | 780 | 0.16 | 0.575 | 180.2629 |
| 16 | 7000 | 840 | 0.12 | 0.621 | 194.4194 |

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## IV. DATA ANALYSIS OF THE EXPERIMENT

### 4.1 ANALYSIS OF VARIANCE (ANOVA):

In this study the Analysis of variance (ANOVA) is used as a statistical tool for determining most influencing parameter on the Reponses, with an optimum combination of the levels.
The below topics provides a complete analysis of the responses.

### 4.2 FOR SURFACE ROUGHNESS ($R_a$):

From ANOVA, it is found that, the spindle speed is most influencing parameter on response Ra, which is then followed by depth of cut and feed rate and also the optimum combination of factor, is found as follows.

1) Spindle speed should be at the level 1 i.e. 5500 Rpm
2) Depth of cut should be at the level 4 i.e. 0.24 mm
3) Feed rate should be at the leve1 3 i.e. 780 mm/min

The below table shows the ANOVA table for the experiment conducted for surface roughness.

Table No 4.1- ANOVA table for Surface Roughness.

| SURFACE ROUGHNESS | | | | | | | |
|---|---|---|---|---|---|---|---|
| ANALYSIS OF VARIANCE FOR SN RATIO | | | | | | | |
| **SOURCE** | **DF** | **Seq SS** | **Adj SS** | **MS** | **F** | **P** | **%I** |
| **SPEED** | 3 | 17.927 | 17.927 | 5.9755 | 6.05 | 0.030 | 38.37 |
| **FEED** | 3 | 8.470 | 8.470 | 2.8233 | 2.86 | 0.127 | 18.12 |
| **DOC** | 3 | 14.392 | 14.392 | 4.7974 | 4.85 | 0.048 | 30.80 |
| **ERROR** | 6 | 5.930 | 5.930 | 0.9884 | | | 12.69 |
| **TOTAL** | 15 | 46.719 | | | | | 100 |

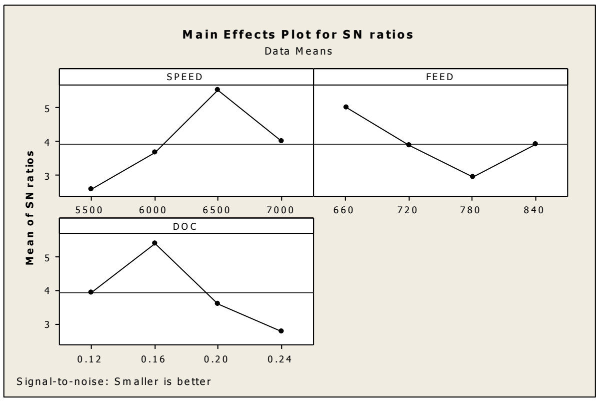


Figure No 4.1- Graph representing optimum parameters for Surface Roughness.

### 4.2.1 REGRESSION ANALYSIS

In this study the regression analysis is used to determine most influencing parameter on Surface roughness and M.R.R and also development of a mathematical model is done by using Minitab 16 expert for each response, which can be used for prediction.
The below data shows the development of mathematical model using regression analysis

### 4.2.2 REGRESSION ANALYSIS FOR SURFACE ROUGHNESS (RA)

The regression equation is

$$Ra = 0.649 - 0.000097 \times Speed + 0.000545 \times Feed + 1.10 \times DOC \qquad \text{……………..(4.1)}$$

Analysis of Variance

Table No. 4.2 ANOVA for response table of regression analysis for Ra

| **Source** | **DF** | **SS** | **MS** | **F** | **P** |
|---|---|---|---|---|---|
| **Regression** | 3 | 0.10746 | 0.03582 | 2.76 | 0.048 |
| **Residual Error** | 12 | 0.15591 | 0.01299 | | |
| **Total** | 15 | 0.26337 | | | |

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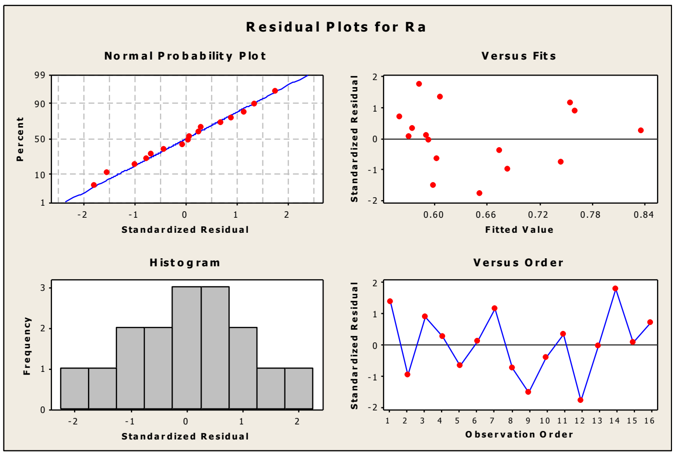

Figure No. 4.2 Residual plots for Ra

**4.3 FOR MATERIAL REMOVAL RATE (MRR):**

From ANOVA, it is found that the spindle speed is most influencing parameter on the response M.R.R, which is followed by feed rate and depth of cut and also the optimum combination o*f factor levels, is as follows

1) Spindle speed at level 1 i.e. 5500 Rpm
2) Feed rate should at level 4 i.e. 840 mm/min
3) Depth of cut at level 4 i.e. 0.24 mm

The below tables provide a complete analysis of variance for Material Removal Rate (MRR).

Table No 4.3- ANOVA table for Material Removal Rate.

| MATERIAL REMOVAL RATE | | | | | | | |
|---|---|---|---|---|---|---|---|
| ANALYSIS OF VARIANCE FOR SN RATIO | | | | | | | |
| SOURCE | DF | Seq SS | Adj SS | MS | F | P | %I |
| SPEED | 3 | 17.971 | 17.971 | 5.9902 | 18.98 | 0.002 | 47.09 |
| FEED | 3 | 9.354 | 9.354 | 3.1180 | 9.88 | 0.010 | 24.51 |
| DOC | 3 | 8.940 | 8.940 | 2.9801 | 9.44 | 0.011 | 23.42 |
| ERROR | 6 | 1.893 | 1.893 | 0.3155 | | | 4.96 |
| TOTAL | 15 | 38.158 | | | | | 100 |

**The graph shown below gives the SN ratio** plot for the Material Removal Rate.

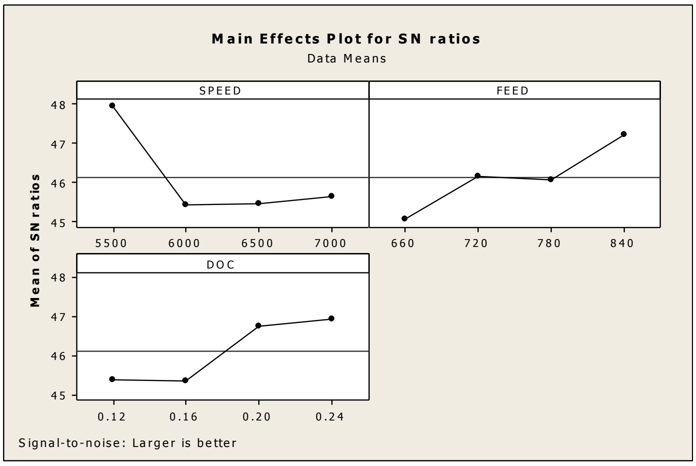

Figure No 4.3- Graph representing optimum parameters for Material Removal Rate.

**4.3.1 REGRESSION ANALYSIS FOR MRR**

The regression equation is

$$MRR = 166 - 0.0367 \times Speed + 0.267 \times Feed + 383 \times DOC \quad \ldots\ldots\ldots\ldots..(4.2)$$

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Analysis of Variance

Table No. 4.4 ANOVA for response table of regression analysis for MRR

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| **Regression** | 3 | 16557.9 | 5519.3 | 8.82 | 0.002 |
| **Residual Error** | 12 | 7507.8 | 625.6 | | |
| **Total** | 15 | 24065.6 | | | |

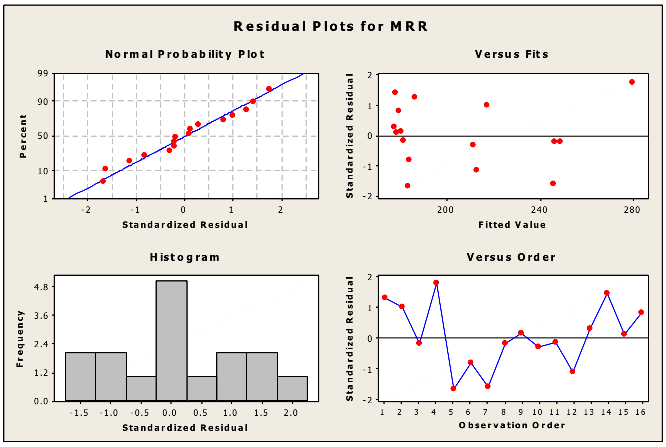


Figure No. 4.4 Residual plots for MRR

### 4.4 FOR TAGUCHI'S GREY RELATIONAL ANALYSIS:

In the grey relational analysis data processing is first performed in order to normalize raw data for analysis. In general, the lower the better is expected for surface roughness and higher the better for Material Removal Rate in milling process.

### 4.4.1 NORMALIZED EXPERIMENTAL VALUE OF X1(k) FOR SURFACE ROUGHNESS & X2(k) FOR MRR IS AS FALLOWS:

In Grey relational generation, the normalized Ra values corresponding to the smaller-the-better (SB) criterion which can be expressed as:

$$x_i(k) = \frac{\max y_i(k) - y_i(k)}{\max y_i(k) - \min y_i(k)} \text{......(4.3)}$$

M.R.R should follow the larger-the-better (LB) criterion, which can be expressed as:

$$x_i(k) = \frac{y_i(k) - \min y_i(k)}{\max y_i(k) - \min y_i(k)} \text{ ..... (4.4)}$$

Where, $X_i$ (k) is the value after the grey relational generation, min $y_i$ (k) is the smallest value of $y_i$ (k) for the $k^{th}$ response, and the max $y_i$ (k) is the largest value of the $y_i$ (k) for the $k^{th}$ response. An ideal sequence is $x_0$(k) (k=1, 2….16).

### 4.5 GREY RELATION CO-EFFICIENT $\xi_i$ (k) FOR $R_A$ & MRR

$$\xi_i(k) = \frac{\Delta_{min} + \xi\Delta_{max}}{\Delta_{oi}(k) + \xi\Delta_{max}} \text{ ....... (4.5)}$$

Where,

$\Delta_{oi}$ (k) = ‖ $X_o$ (k)–$X_i$ (k)‖ = difference of the absolute value between $X_o$ (k) and $X_i$ (k)

$\Delta_{oi}$ (k)= 0.662037

ξ = Distinguishing coefficient, In this study ξ value is taken as 0.75 for Ra & 0.25 for MRR respectively by analytical hierarchical method

$\Delta_{min}$ = smallest value of $\Delta_{oi}$ (k)

$\Delta_{max}$ = largest value of $\Delta_{oi}$ (k)

### 4.6 EVALUATION OF GREY RELATIONAL COEFFICIENT AND GRADE VALUES:

**GREY GRADE= average of grey relation co-efficient $\xi_i$ (k) of Ra & MRR**

$$\gamma_i = \frac{(\xi(\Delta x1) + \xi(\Delta x2))}{2} \text{ ..........(4.6)}$$


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Below Table shows the normalized value for grey relational analysis & experimental results for grey relational coefficient with grey grade rank.

Table No. 4.5 Normalized value for grey relational analysis & experimental results for grey relational coefficient.

| Sl. No | Grey relation co-efficient after weighted | | | | | |
|---|---|---|---|---|---|---|
| | X1(k) | X2(k) | ξ (Δx1) | ξ (Δx2) | Grey grade $\gamma_i$ | Rank |
| 1 | 0.337963 | 0.389754 | 0.531148 | 0.290615 | 0.410882 | 15 |
| 2 | 0.675926 | 0.558707 | 0.534000 | 0.436000 | 0.485000 | 11 |
| 3 | 0.050926 | 0.585295 | 0.601000 | 0.645000 | 0.623000 | 5 |
| 4 | 0.030093 | 1 | 0.428571 | 1 | 0.714286 | 3 |
| 5 | 0.787037 | 0 | 0.736527 | 0.217972 | 0.477249 | 13 |
| 6 | 0.634259 | 0.118527 | 0.935757 | 0.2 | 0.567878 | 8 |
| 7 | 0 | 0.37931 | 0.81457 | 0.625183 | 0.719876 | 2 |
| 8 | 0.479167 | 0.569526 | 1 | 0.522947 | 0.761473 | 1 |
| 9 | 1 | 0.222544 | 0.672131 | 0.333547 | 0.502839 | 10 |
| 10 | 0.55787 | 0.350142 | 0.826736 | 0.503221 | 0.664979 | 4 |
| 11 | 0.618056 | 0.190666 | 0.899269 | 0.247049 | 0.573159 | 7 |
| 12 | 0.9375 | 0.247329 | 0.575663 | 0.388255 | 0.481959 | 12 |
| 13 | 0.659722 | 0.222483 | 0.670503 | 0.365982 | 0.518242 | 9 |
| 14 | 0.256944 | 0.382585 | 0.81457 | 0.390117 | 0.602343 | 6 |
| 15 | 0.689815 | 0.209364 | 0.56624 | 0.276754 | 0.421497 | 14 |
| 16 | 0.583333 | 0.29299 | 0.527394 | 0.291618 | 0.409506 | 16 |

From ANOVA, it is found that, the depth of cut is most influencing parameter on response Ra, which is then followed by spindle speed and feed rate and also the optimum combination of factor, is found as follows.

1) Depth of cut should be at the level 4 i.e. 0.24 mm
2) Spindle speed should be at the level 2 i.e. 6000 Rpm
3) Feed rate should be at the leve1 2 i.e. 720 mm/min

The below tables provide a complete analysis of variance for the Grey Grade.

Table No 4.6- ANOVA table for Grey Grade.

| GREY GRADE | | | | | | | |
|---|---|---|---|---|---|---|---|
| ANALYSIS OF VARIANCE FOR SN RATIO | | | | | | | |
| SOURCE | DF | Seq SS | Adj SS | MS | F | P | %I |
| SPEED | 3 | 9.719 | 9.719 | 3.2398 | 5.79 | 0.033 | 20.88 |
| FEED | 3 | 8.060 | 8.060 | 2.6865 | 4.80 | 0.049 | 17.32 |
| DOC | 3 | 25.389 | 25.389 | 8.4629 | 15.12 | 0.003 | 54.56 |
| ERROR | 6 | 3.359 | 3.359 | 0.5598 | | | 7.21 |
| TOTAL | 15 | 46.527 | | | | | 100 |

The graph shown below is the SN ratio graph for the Grey Grade.

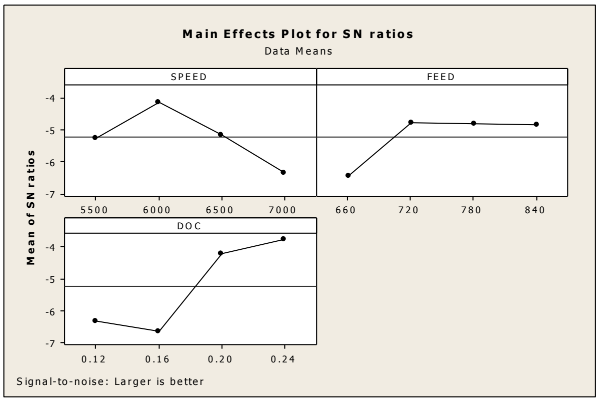


Figure No 4.5- Graph representing optimum parameters for Grey Grade.

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### 6.7.1 REGRESSION ANALYSIS FOR GREY GRADE

The regression equation is
GREY GRADE = 0.191 - 0.000057 SPEED + 0.000580 FEED + 1.62 DOC ………..(4.7)

Analysis of Variance

Table No. 4.7 ANOVA for response table of regression analysis for grey grade

| **Source** | **DF** | **SS** | **MS** | **F** | **P** |
|---|---|---|---|---|---|
| **Regression** | 3 | 0.124650 | 0.041550 | 7.13 | 0.005 |
| **Residual Error** | 12 | 0.069924 | 0.005827 | | |
| **Total** | 15 | 0.194574 | | | |

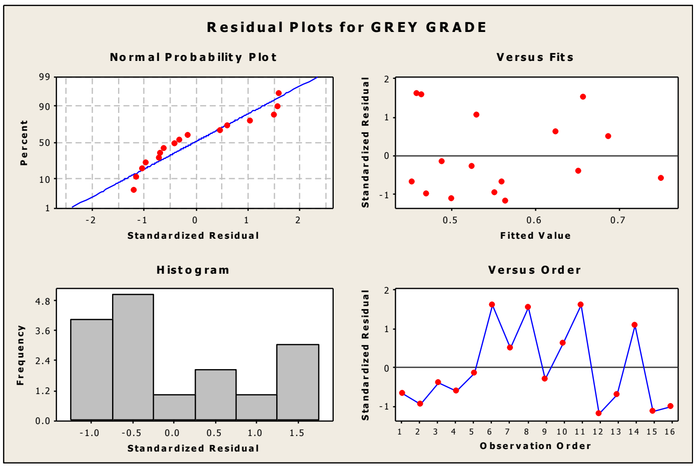


Figure No. 4.6 Residual plots for Grey Grade.

## V. CONFIRMATION TEST

Confirmation test is carried out to check the whether the parameters that are obtained are optimum are not. An operation is carried out on the work-piece using the optimal parameters.
Here we have performed 3 trials for experiment, an average of that we have taken the experimental values.

The table below shows the conformation test for the Predicted value.

Table No 5.1- Conformation Test for Ra, MRR, Grey Grade.

| RESPONCES | INITIAL FACTOR SETTING | | | OPTIMAL CONDITIONS | |
|---|---|---|---|---|---|
| | SPEED (rpm) | FEED (mm/rev) | DOC (mm) | PREDICTED VALUES (µm) | EXPERIMANTAL VLAUES (µm) |
| Surface Roughness | 5500 | 780 | 0.24 | 0.6012 | 0.652 |
| Material Removal Rate | 5500 | 840 | 0.24 | 320.35 | 340.26 |
| Grey Grade | 6000 | 720 | 0.24 | 0.7554 | 0.8025 |

## VI. RESULTS

### 6.1 COMPARISON OF RESULTS FROM EXPERIMENTEAL & PREDICTED VALUES FOR $R_a$

Table No 6.1 Comparison Table for Experimented and Predicted Values for Ra

| Sample No. | Experimented Values | Predicted values | Error % |
|---|---|---|---|
| | Surface Roughness Value (Ra) µm | Surface Roughness Value (Ra) µm | |
| 1 | 0.727 | 0.6072 | 19 |
| 2 | 0.581 | 0.6839 | 15 |
| 3 | 0.851 | 0.7606 | 11 |
| 4 | 0.86 | 0.8373 | 2 |

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| | | | |
|---|---|---|---|
| 5 | 0.533 | 0.6027 | 11 |
| 6 | 0.599 | 0.5914 | 1 |
| 7 | 0.873 | 0.7561 | 15 |
| 8 | 0.666 | 0.7448 | 10 |
| 9 | 0.441 | 0.5982 | 26 |
| 10 | 0.632 | 0.6749 | 6 |
| 11 | 0.606 | 0.5756 | 5 |
| 12 | 0.468 | 0.6523 | 28 |
| 13 | 0.588 | 0.5937 | 0.9 |
| 14 | 0.762 | 0.5824 | 30 |
| 15 | 0.575 | 0.5711 | 0.6 |
| 16 | 0.621 | 0.5598 | 10 |
| Mean error % | 11.90 | | |

### 6.2 COMPARISON OF RESULTS FROM EXPERIMENTAL & PREDICTED VALUES FOR MRR

Table No 6.2 Comparison Table for Experimented and Predicted Values for MRR

| Sample No. | Experimented Values | Predicted values | Error % |
|---|---|---|---|
| | Material Removal Rate MRR $mm^3$/min | Material Removal Rate MRR $mm^3$/min | |
| 1 | 210.8003 | 186.33 | 13 |
| 2 | 239.4015 | 217.67 | 9 |
| 3 | 243.9024 | 249.01 | 2 |
| 4 | 314.1057 | 280.35 | 12 |
| 5 | 144.8207 | 183.3 | 20 |
| 6 | 164.8855 | 184 | 10 |
| 7 | 209.0323 | 245.98 | 15 |
| 8 | 241.233 | 246.68 | 2 |
| 9 | 182.4941 | 180.27 | 1 |
| 10 | 204.0945 | 211.61 | 3 |
| 11 | 177.0976 | 181.67 | 2 |
| 12 | 186.6897 | 213.01 | 12 |
| 13 | 182.4838 | 177.24 | 2 |
| 14 | 209.5866 | 177.94 | 17 |
| 15 | 180.2629 | 178.64 | 0.9 |
| 16 | 194.4194 | 179.34 | 8 |
| Mean error % | 8.05625 | | |

### 6.3 COMPARISON OF RESULTS FROM EXPERIMENTAL & PREDICTED VALUES FOR GREY GRADE

Table No 6.3 Comparison Table for Experimented and Predicted Values for Grey Grade

| Sample No. | Experimented Values | Predicted values | Error % |
|---|---|---|---|
| | Grey Relational Grade | Grey Relational Grade | |
| 1 | 0.410881 | 0.4547 | 9 |
| 2 | 0.485000 | 0.5543 | 12 |
| 3 | 0.623000 | 0.6539 | 4 |
| 4 | 0.7142857 | 0.7535 | 5 |
| 5 | 0.4772495 | 0.491 | 2 |
| 6 | 0.5678783 | 0.461 | 23 |
| 7 | 0.7198765 | 0.6902 | 4 |
| 8 | 0.7614733 | 0.6602 | 15 |
| 9 | 0.5028392 | 0.5273 | 4 |
| 10 | 0.6649787 | 0.6269 | 6 |
| 11 | 0.5731591 | 0.4673 | 22 |
| 12 | 0.4819589 | 0.5669 | 14 |

| | | | |
|---|---|---|---|
| 13 | 0.5182422 | 0.5636 | 8 |
| 14 | 0.6023432 | 0.5336 | 12 |
| 15 | 0.4214971 | 0.5036 | 16 |
| 16 | 0.4095059 | 0.4736 | 13 |
| Mean error % | 10.5625 | | |

## VI. CONCLUSION

The parametric study of end milling process on Aluminium Alloy 6061-T6 using CNC milling machine was successfully undertaken. Based on L16 orthogonal array experiment plan was designed by considering Spindle speed, Feed rate and Depth of cut as a main factors and surface roughness and material removal rate as response.

Based on Experimental results, following conclusions are reached

1) From investigation for L16 array experiment by ANOVA & Regression analysis, it is found that the speed is the most significant parameter on surface roughness with 38.37% significance, which then followed by depth of cut with 30.80% significance and feed rate is found to be a least significant parameter with 18.12% significance.
2) From investigation for L16 array experiment by ANOVA & Regression analysis, it is found that the speed is the most significant parameter on material removal rate with 47.09% significance and followed by feed rate with 24.51% significance and depth of cut is found to be a least significance with 23.42% contribution.
3) The grey relational analysis shows that by ANOVA & Regression analysis, it is found that depth of cut is most significant parameter on the multiple responses with 54.56 % significance, then it is followed by spindle speed with 20.88 % significance and feed rate with 17.32 % significance.
4) The mathematical model developed, successfully predicted the responses with 88% accuracy for Ra and 92% accuracy for M.R.R and 90 % of accuracy for Grey Grade within the acceptable range of error
5) Finally it is concluded that, higher spindle speed with minimum depth of cut and feed rate produce good surface quality and maximum depth of cut and higher feed rate leads to higher productivity.

## VII. FUTURE SCOPE

This study has concentrated on the application of Taguchi method coupled with Grey relation analysis for solving Multi criteria optimization problem in the field of end milling process. This method can be employed on shop floor for improving surface quality & production rate at an affordable cost.

Any how this study can be extended as fallows

1) Experimentation can be carried out by considering more Input parameters & Responses.
2) Different statistical tool can be used for analysis.
3) Expert system can be used for prediction such as Artificial neural network, Genetic algorithm, fuzzy logic, etc.

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