Application of Taguchi Approach for Optimization Roughness for Boring operation of E 250 B0 for Standard IS: 2062 on CNC TC

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***Abstract*—In this research paper, E 250 B0 as per IS: 2062 steel material are turned on computer numeric controlled (CNC) turning center by using Chemical Vapor Deposition (CVD) coated cemented carbide inserts of 0.8 mm and 1.2 mm. This paper discusses an investigation of effect of process parameters (speed, feed, depth of cut & nose radius) on responding quality parameter (boring operation). This study utilizes a mixed L_{16} orthogonal array for determining the optimum quality parameters, with an applied noise factor. Excel and Minitab 16.0 software are used for analysis purpose. Analysis of variance (ANOVA) suggested that speed, nose radius and feed are the most significant parameters for boring operation and its percentage contribution 74.92, 11.09 & 11.12 respectively. Mathematical modeling and predication of surface roughness is accomplished by using the regression analysis. The predicted values are conformed by using validation experiments.**

***Index Terms*— ANOVA, IS: 2062, Mix Orthogonal Array, Optimization, S/N Ratio, Taguchi**

I. Introduction

In the challenge of modern machining industries around the world constantly strive for lower cost solutions with reduced lead time and better surface quality in order to maintain their effectiveness. Automated and flexible manufacturing systems are employed for that purpose along with computerized numerical control (CNC) machines that are capable of achieving high accuracy with very low processing time. In the CNC machining, determining optimal cutting conditions or parameters under the given machining situation is challenging in practice. Conventional way for selecting these conditions such as cutting speed and feed rate has been based upon data from machining handbooks and/or on the experience and knowledge of the part of programmer. As a result, the machine is not run in optimal condition due to such a traditional process parameters selection.

The quality of the surface plays a very important role in the performance of dry/wet turning in CNC TC because a good quality turned surface surely improves fatigue strength, corrosion resistance and creep life. Surface roughness also effects on some functional attributes of parts such as, contact causing surface friction, wearing, light reflection, ability of distributing and also holding a lubricant, load bearing capacity, coating and resisting fatigue etc. (Mihir et. al., 2014).

From the literature review [1-25] we found that for steel alloy material the speed, feed & nose radius are the most affecting parameters for surface roughness and DOC is the least affecting parameters on surface roughness. Most of researches taken input parameters are speed, feed and depth of cut for surface roughness.

II. Problem Description

As we know in actual machining, there are many factors which affect the surface roughness i.e. cutting conditions, tool variables and work piece variables. In CNC turning center, Cutting conditions include speed, feed and depth of cut and also tool variables include tool material, nose radius, rake angle, cutting edge geometry, tool vibration, tool overhang etc. and work piece variable include hardness of material and mechanical properties. It is very difficult to consider all the parameters that control the surface roughness. This study would help the operator to select the cutting parameters with optimal cutting condition. In this research, Taguchi robust design is used to design parameters in order to increase the quality of surface finish and decreasing the cost of equipment for boring operation.

III. Experimental Design Methodology

There are various methodologies by which a given process can be optimized. There are different methodologies that are used to improve the quality of product and process. Some widely used approaches in product/process development are (Srinivas Athreya et. al., 2012)

1. Build-Test-Fix
2. One Factor at a time
3. Design of Experiment (DOE)

Build-Test-Fix

The "Build-test-fix" is the most primitive approach which is rather inaccurate as the process is carried out according to the resources available, instead of trying to optimize it. In this method the process/product is tested and reworked each time till the results are acceptable.

One factor at a time

The "one factor at a time" approach is aimed at optimizing the process by running an experiment at one particular condition and repeating the experiment by changing any other one factor till the effect of all factors are recorded and analyzed. Evidently, it is a very time consuming and expensive approach. In this process, interactions between factors are not taken in to account.

Design of Experiment

The Design of Experiments is considered as one of the most comprehensive approach in product/process developments. It is a statistical approach that attempts to provide a predictive knowledge of a complex, multi-variable process with few trials. Following are the major approaches to DOE:

- Full Factorial Design
- Taguchi Method

The Taguchi Method is a multi-stage process, namely, (1) Systems Design/Concept Design, (2) Parameter Design, and (3) Tolerance Design. The following sections delineate the three-stage process (Nikhil Kumar, 2010) suggested by Dr. Taguchi to achieve desirable product quality.

The Full Factorial Design requires a large number of experiments to be carried out as stated above. It becomes laborious and complex, if the number of factors increase. To overcome this problem Taguchi suggested a specially designed method called the use of orthogonal array to study the entire parameter space with lesser number of experiments to be conducted. Taguchi thus, recommends the use of the loss function to measure the performance characteristics that are deviating from the desired target value. The value of this loss function is further transformed into signal-to-noise (S/N) ratio. Usually, there are three categories of the performance characteristics to analyze the S/N ratio. They are: nominal-the-best, larger-the-better, and smaller-the-better.

Taguchi proposed a mathematical formula called the loss function for estimating the monetary loss caused by lack of quality. The loss function estimates loss even if parts are made within specification limits. This is necessary to allow for the fact that a company that makes all parts within specification limits still has warranty and customer complaints. That is, there is some loss associated with a population of parts no matter how well they are produced. As long as any parts differ from the target specifications, there is some loss. The shape of the Taguchi loss function is shown in fig.1

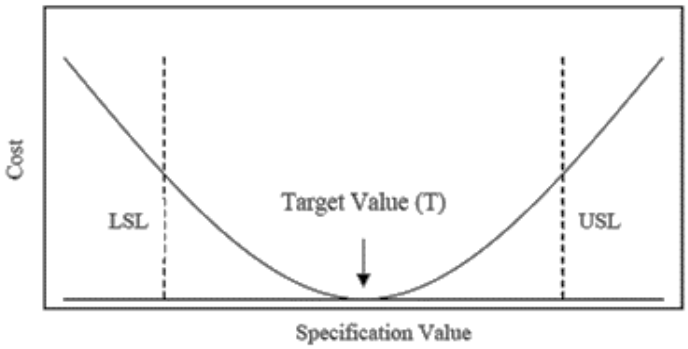

Figure 1 Taguchi Loss Function

This loss function value is further converted into a signal-to-noise (S/N) ratio. Basically, the performance characteristic has following three categories of the S/N ratio (Ross, 2005);

- The Lower-the-Better
- The Larger-the-Better
- The Nominal-the-Better

1. **The Lower-the-Better**

   This category of S/N ratio is selected when the performance characteristic like surface roughness, power consumption, circularity etc. are required to minimize. For ideal case desired value of S/N ratio is zero. The general formula for calculating the S/N ratio is as follows;

   $\text{S/N ratio} = -10\log_{10}[\text{mean of sum of square of measured data}]$

2. **The Larger-the-Better**

   This case is opposite to the smaller the best case and it is obtained by taking the reciprocals of measured data. This category of S/N ratio is selected when objective function like "Material Removal Rate" is required to maximize. The general formula for calculating the larger the better S/N ratio is as follows;

   $\frac{S}{N}\text{ratio} = -10\log_{10}[\text{mean of sum squares of reciprocal of measured data}]$

3. **The Nominal-the-Better**

This case arises when a specified value is most desired, meaning that neither a smaller nor a larger value is desirable. The general formula for calculating the nominal the better S/N ratio is as follows;

$$\text{S/N ratio} = -10\log_{10}[\text{Square of mean/Variance}]$$

The S/N ratios for each level of process or product parameters are calculated depending upon the S/N analysis results. Not taking account of the class of quality characteristic of interest, a larger S/N ratio of the parameters is selected for better quality characteristic of interest. Therefore, the best level of the product or process factors is the level which has the highest S/N ratio.

IV. Experimental Details

Machine Tool

The CNC machines play a very important role in modern industries to enhance the product quality as well as productivity (M. Kaladhar, 2010). Batliboi make CNC turning center is used to carry out the experimentation. The specification of machine is as below:

Table 1 Specification of Sprint 20 TC

Main Specifications	**Sprint 20 TC**
Swing over Bed	500 mm
Turning Dia.	275 mm
Turning Length	1000 mm
Power Chuck	200mm
Spindle Speed	30 – 4000 rpm
Spindle Motor	7.5 / 11KW
Z – axis Stroke	495 mm
X – axis Stroke	150 mm
Max. No. of Tools in Turret	8
Rapid Traverse	20 m / min

Work Material

The work piece material used for present work was E 250 B0 of standard IS: 2062. There are three grade of E 250 steel as per IS: 2062: Grade A, Grade B & Grade C. IS: 2062 standard materials have varieties of industrial application some of them are Rolling Mill Stand, Power Press, Injection Moulding, Plywood Sun Mica Mill & Plastic Die, Plastic Moulding Dies, Machine Parts, Hydraulic Machinery Parts, Hospital furniture, Steel Structures, Large dia. meter pipes, Storage Tanks, Boilers, Pressure Vessels etc. The chemical composition & mechanical properties of E 250 B0 of standard IS: 2062 (BIS-IS: 2062, 2011) is given Table 5.2 & 5.3 respectively.

Table 2 Chemical composition of E 250 B0 of standard IS: 2062

Grade	Quality	C %	Mn %	S %	P %	Si	C. E. %
		Max.	Max.	Max.	Max.	Max.	Max.
E 250	B0	0.22	1.5	0.045	0.045	0.4	0.41

Table 3 Mechanical Properties of E 250 B0 of standard IS: 2062

Grade	Quality	Tensile Strength Min, MPa	Yield Stress, Min MPa			% Elongation at gauge length
			<20mm	20-40mm	>40mm	
E 250	B0	410	250	240	230	23

Cutting Tool Material & Tool Holder

Coated carbide tools have shown better performance when compared to the uncoated carbide tools. For this reason, commonly available Chemical Vapor Deposition (CVD) of Ti (C, N) + Al_2O_3 coated cemented carbide inserts of 0.8 and 1.2 mm as nose radius are used in the present experimental investigation. The tool & tool holder details are as below:

Cutting Inserts: CNMG 12 04 08 PF & CNMG 12 04 12 PF (Sandvik, made)

Tool material: CVD coated cemented carbide

Tool holder: MCLNL 25 25 M 12.

Measurement of Surface Roughness

There are many methods of measuring surface roughness, such as using specimen block by eye visualization or fingertip, microscope, stylus type instruments, profile tracing intruments, etc. (Er. R. K. Jain, 1971). For present work. roughness measurement has been done using a Mitutoyo Surftest SJ-301 surface roughness tester.

Figure 2 Mitutoyo Surftest SJ-301 surface roughness tester

Selection of Process Parameters for Quality Characteristics

Following process parameters may affect the quality of the turned parts:

- Cutting parameters: cutting speed, feed rate, and depth of cut (DOC).
- Environment parameters: wet, dry.
- Cutting tool parameters: tool geometry, tool material.
- Work piece material: hardness, Metallography

The controllable factors and their levels were decided for conducting the experiment, based on a "brain storming" that was held with a group of people and also considering the guide lines given in the operator's manual provided by the manufacturer of the lathe machine and tool inserts company. The factors and their levels are shown in table 4.

Table 4 Cutting Parameters and their levels

Parameters/ Factors	Levels			
	1	2	3	4
Speed (rpm)	800	1000	1200	1400
Feed (mm/rev)	0.06	0.08	0.1	0.12
Depth of cut (mm)	1	1.25	1.4	1.5
Nose radius (mm)	0.8	1.2	-	-

Orthogonal Array Selection

The selection of orthogonal array based on the following consideration

- Number of factors to be studied
- Number of levels for each factor
- Number of interactions to be estimated

Table 5 L_{16} Mixed Orthogonal Array Design

A (speed)	B (Feed)	C (DOC)	D (Nose Radius)
1	1	1	1
1	2	2	1
1	3	3	2
1	4	4	2
2	1	2	2
2	2	1	2
2	3	4	1
2	4	3	1
3	1	3	1
3	2	4	1
3	3	1	2
3	4	2	2
4	1	4	2
4	2	3	2
4	3	2	1
4	4	1	1

For above mentioned parameters/factors and their levels for single interaction

Degree of freedom (DOF) for Speed = (4-1) = 3
Degree of freedom (DOF) for Feed = (4-1) = 3
Degree of freedom (DOF) for Depth of cut = (4-1) = 3
Degree of freedom (DOF) for Nose radius = (2-1) = 1
The total degree of freedom = 3 + 3+ 3+1= 10
Therefore Minimum number of experiment = Total DOF for parameters +1
= 10 + 1
= 11

For a above mention situation minimum 16 experiments are required to perform. So, L_{16} mixed orthogonal array of Taguchi is selected. L_{16} mixed orthogonal array designed as shown in table 5.

V. Experimental Details

The present paper gives the application of the Taguchi experimental design technique. The scheme of carrying out experiments was selected and the experiments were conducted to investigate the effect of process parameters on the surface roughness in boring operation. The experimental results surface roughness for boring operation is given in Table 6. In present study used mixed L_{16} orthogonal array in which 16 experiments were conducted on CNC TC. In the present study all the designs, plots and analysis have been carried out using Minitab statistical software.

Table 6 Experimental Result of surface roughness for Boring

Trial No.	A (Speed) rpm	B (Feed) mm/rev	C (DOC) mm	D (Nose Radius) mm	Ra (Boring) µm	S/N Ra (Boring) dB	Fit µm	Residual µm
1	800	0.06	1	0.8	1.94	-5.756	1.723	0.2169
2	800	0.08	1.25	0.8	2.03	-6.150	1.832	0.1984
3	800	0.1	1.4	1.2	2.39	-7.568	2.429	-0.0393
4	800	0.12	1.5	1.2	2.99	-9.513	2.591	0.3990
5	1000	0.06	1.25	1.2	1.36	-2.671	1.597	-0.2368
6	1000	0.08	1	1.2	1.47	-3.346	1.883	-0.4129
7	1000	0.1	1.5	0.8	1.02	-0.172	1.449	-0.4288
8	1000	0.12	1.4	0.8	1.33	-2.477	1.682	-0.3515
9	1200	0.06	1.4	0.8	0.63	4.013	0.599	0.0315
10	1200	0.08	1.5	0.8	1.01	-0.086	0.760	0.2497
11	1200	0.1	1	1.2	1.76	-4.910	1.589	0.1711
12	1200	0.12	1.25	1.2	1.78	-5.008	1.697	0.0827
13	1400	0.06	1.5	1.2	0.67	3.479	0.526	0.1445
14	1400	0.08	1.4	1.2	0.65	3.742	0.758	-0.1083
15	1400	0.1	1.25	0.8	0.53	5.514	0.555	-0.0251
16	1400	0.12	1	0.8	0.95	0.446	0.841	0.1089

The average values of Ra (Boring) for each process parameter at levels (1, 2, 3 & 4) for raw data and S/N data are plotted in Figures 3 and 4 respectively. Figures 3 shows that Ra value decrease with increase in speed that is surface finish improves with increase in speed. For feed, as feed increases the Ra value increases that means surface roughness deteriorates. With respect to depth of cut (DOC), Ra increase from level 1 to level 2, from level 2 to 3 Ra decrease, from level 3 to level 4 Ra increase that is decrease surface finish. In case of nose radius as nose radius increase (from level 1 to 2) Ra decrease i.e. higher value of nose radius surface properties declines and lower value of nose radius, Ra decrease meaning thereby that surface properties/texture improves. Figures 3 told that the Ra value minimum at for speed at level 4, feed at level 1, depth of cut at level 3 & nose radius at level 1. Then, optimal sequence for the surface roughness for turning is $A_4B_1C_3D_1$. Similarly, Figure 4 told that the S/N ratio for Ra (Turning) maximum for speed at level 4, feed at level 1, depth of cut at level 3 & nose radius at level 1. Then, optimal sequence for the surface roughness for turning is $A_4B_1C_3D_1$. Both the figure 3 and 4 show the same optimal sequence. It is seen from the Figures 5 and 6 that there are significance interaction between the process parameters in affecting the Ra (Boring) since the responses at different levels of process parameters for a given level of parameter value are almost interact with each other. The contour plot and surface plot for Ra (Boring) for most two significant (speed & nose radius) parameters are shown in figure 7 & 8 respectively. From surface plot Ra is minimum at 1400 rpm (level 1) & nose radius 0.8 mm (level 1) & Ra is maximum at 800 rpm (level 1) & nose radius 1.2 mm (level 2).

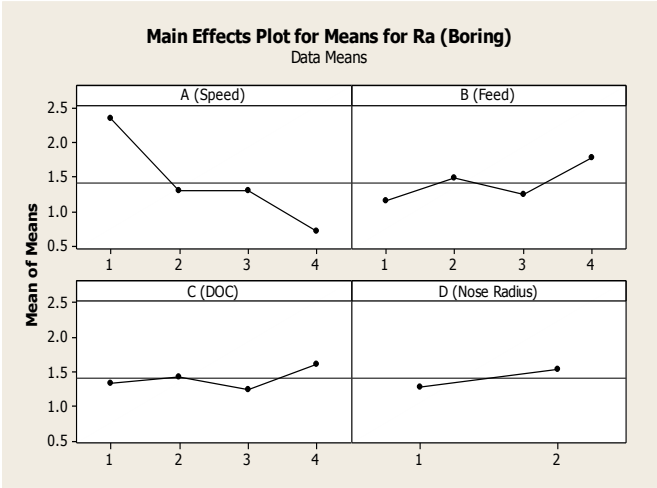

Figure 3 Main effects plot for means for Ra (Boring)

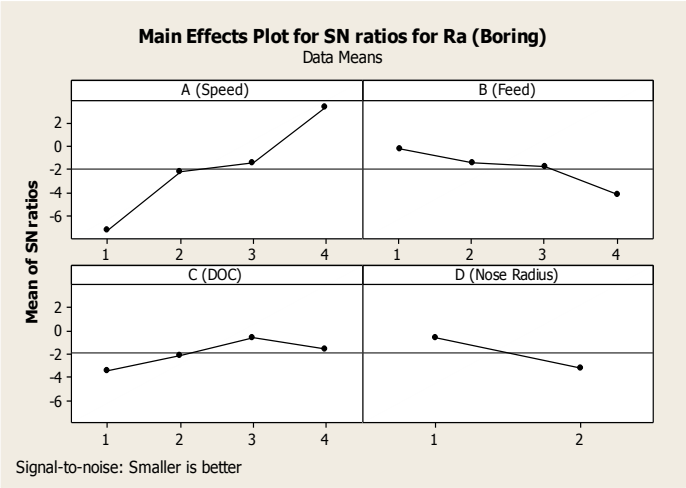

Figure 4 Main effects plot for S/N ratio for Ra (Boring)

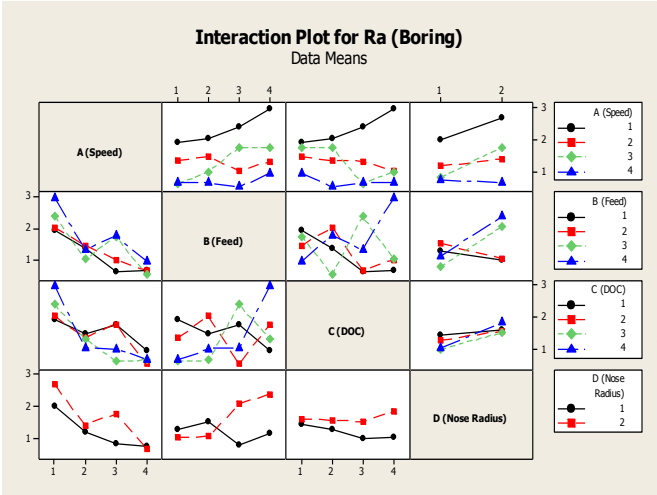

Figure 5 Interaction Plot for Ra (Boring)

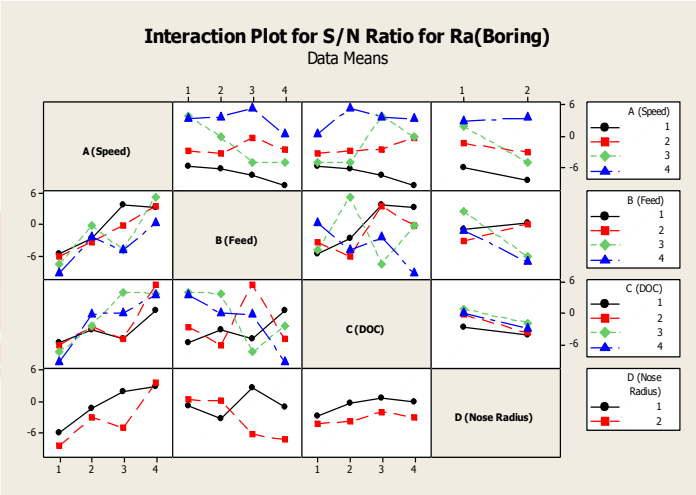

Figure 6 Interaction Plot for S/N Ratio Ra (Boring)

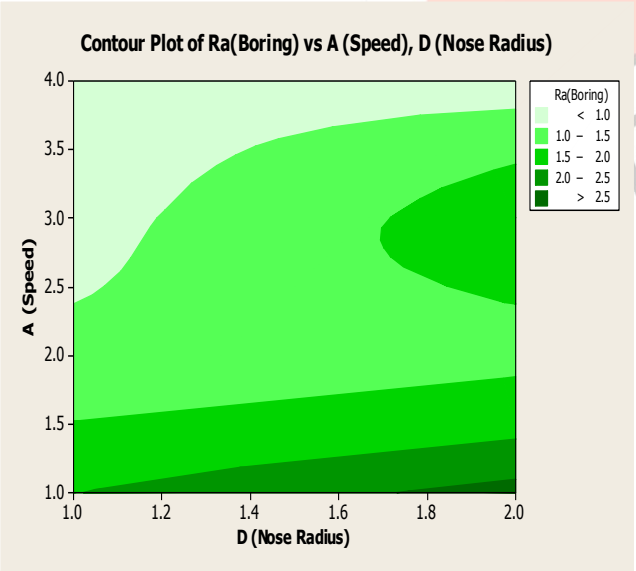

Figure 7 Contour Plot of Ra (Boring) vs. Speed, Nose Radius

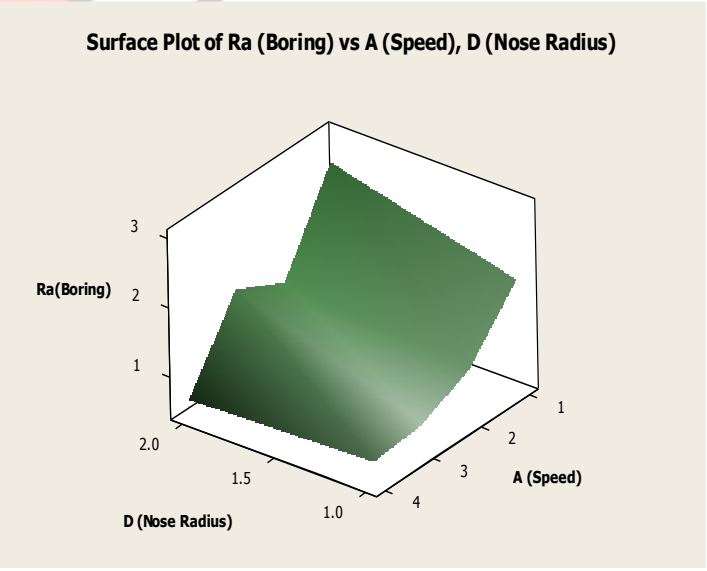

Figure 8 Surface Plot of Ra (Boring) vs. speed, Nose radius

ANOVA table for raw & S/N data (Tables 7 and 8) is clear that spindle speed, nose radius and feed are most significance parameters for Ra (Boring). The spindle speed is the most contributing parameter (around 70%) and is followed by nose radius (around 11.09%). For Ra (Boring) lower the better type quality characteristics is selected.

Table 7 ANOVA for Ra (Boring)

Source	DOF	SS	MS	F	P	Contribution (%)
A (Speed)	3	5.56307	1.85436	179.06	0.000*	74.92
B (Feed)	3	0.82577	0.27526	26.58	0.002*	11.12
C (DOC)	3	0.16137	0.05379	5.19	0.054	2.17
D (Nose Radius)	1	0.82356	0.82356	79.52	0.000*	11.09
Error	5	0.05178	0.01036			
Total	15	7.42555				

Table 8 ANOVA for S/N Ratio Ra (Boring)

Source	DOF	SS	MS	F	P	Contribution (%)
A (Speed)	3	223.240	74.413	48.83	0.000*	72.66
B (Feed)	3	31.973	10.658	6.99	0.031*	10.41
C (DOC)	3	16.505	5.502	3.61	0.100	5.37
D (Nose Radius)	1	27.901	27.901	18.31	0.008*	9.08
Error	5	7.619	1.524			
Total	15	307.238				

$$\text{Contribution (\%)} = \frac{\text{Sum of Square term}}{\text{Total Som of Square}} \times 100$$

Where,
DOF = Degree of freedom,
SS = Sum of Squares,
MS = Mean of Squares
F = Statistical parameter (Fisher's ratio)
P = Power level indicates statistically significance
Note: * Significance at 95% confidence level for all ANOVA tables (P < 0.05)

VI. Estimation of Optimal Design

In this section, the optimal values of the Ra (Boring) along with their respective confidence intervals have been predicted. The results of confirmation experiments are also presented to validate the optimal results. The average values of the response characteristics obtained through the confirmation experiments must lie within the 95% confidence interval. The optimal surface roughness is predicted at the selected optimal setting of process parameters.
The optimal setting of selected process parameters is: $A_4B_1C_3D_1$

The estimated mean of the response characteristic Ra (Boring) can be computed as:

$$\mu_{A_4B_1C_3D_1} = \overline{T} + (\overline{A}_4 - \overline{T}) + (\overline{B}_1 - \overline{T}) + (\overline{C}_3 - \overline{T}) + (\overline{D}_1 - \overline{T})$$
$$= \overline{A}_4 + \overline{B}_1 + \overline{C}_3 + \overline{D}_1 - 3(\overline{T})$$
$$= 0.7 + 1.15 + 1.25 + 1.18 - 3(1.23)$$
$$= 0.59$$

Similarly we can find out estimated mean of the response characteristic S/N Ratio for Ra (Boring):

$$\mu_{A_4B_1C_3D_1} = 7.6173$$

Where,
$\overline{T}$ = Overall mean of response parameter
$\overline{A}_4, \overline{B}_1, \overline{C}_3, \overline{D}_1$ = Average value of response for parameter A for level 4, B for level 1, C for level 3 and D for level 1 respectively

Estimation of Confidence Interval:
For estimated average of a treatment condition used in a conformation experiment to verify predication the confidence interval can be calculated as below (Ross, 2005)

$$CI = \sqrt{F_{\propto,1;v_e} V_e \left(\frac{1}{\eta_{eff}} + \frac{1}{R}\right)}$$

Where,
$F_{\propto,1;v_e}$ = F ratio at confidence interval of $(1 - 0.05)$ against DOF 1, degree of freedom of error f_e
$F_{0.05,1;5} = 6.61$
N = Total number of results,
R = Sample size for conformation of experiments;
V_e = Error variance

$$\eta_{eff} = \frac{N}{1+(\text{Total degrees of freedom associated in estimated of mean})} = 1.4545$$

Then,

$$CI = \sqrt{6.62 \times 0.01036 \left(\frac{1}{1.4545} + \frac{1}{4}\right)} = 0.2533$$

The 95 % confidence interval of the predicted optimum means is:

$$= \left(\mu_{A_4B_1C_3D_1} - CI\right) < \mu_{A_4B_1C_3D_1} < \left(\mu_{A_4B_1C_3D_1} + CI\right)$$

$$= -0.3396 < \mu_{A_4B_1C_3D_1} < 0.8463$$

Similarly for 95 % confidence interval of the predicted optimum S/N ratio is:

$$= \left(\mu_{A_4B_1C_3D_1} - CI\right) < \mu_{A_4B_1C_3D_1} < \left(\mu_{A_4B_1C_3D_1} + CI\right)$$

$$= 4.544185 < \mu_{A_4B_1C_3D_1} < 10.69042$$

VII. Conformation of Experiment

The confirmation experiment is the final step in confirming the conclusions drawn based on Taguchi's parameter design approach. The optimum conditions are set for the significant factors and a selected number of tests are run under constant specified conditions. The average of the results of the confirmation experiment is compared with the anticipated average based on the parameters and levels tested. The confirmation experiment is a crucial step and is highly recommended by Taguchi to verify the experimental conclusions (Ross, 2005). Four confirmation experiments were thus conducted at the optimal settings of the turning process parameters recommended by the investigation. The average value of Ra (Boring) while turning E 250 B0 of Standard IS: 2062 material with CVD -coated carbide inserts was found to 0.54 µm. This result was within the 95% confidence interval of the predicted optimal value of the selected responding characteristic Ra (Boring). Hence the optimal settings of the process parameters, as predicted in the analysis, can be implemented.

VIII. Linear Model Analysis

Taguchi for Ra (Boring) has been applied at 95% confidence, so all factors and their interactions having p (probability) value less than 0.05 will be statistically significant for Ra (Boring) and must be further taken care of. Refer Table 9 & 10 the analysis of variance (ANOVA) results very clear support that speed, nose radius and feed have significance influence on Ra (Boring). Residual plots are used to evaluate the data for the problems like non normality, non-random variation, non-constant variance, higher-order relationships, and outliers. It can be seen from Figures 9 and 10 that the residuals follow an approximately straight line in normal probability plot and approximate symmetric nature of histogram indicates that the residuals are normally distributed. Residuals possess constant variance as they are scattered randomly around zero in residuals versus the fitted values. Since residuals exhibit no clear pattern, there is no error due to time or data collection order. Again, the R-square and R-square adjusted are both above 85%, and hence, the model is moderately a good fit. The regression equation is as follows.

Regression Equation

Ra (Boring) = 2.54418 - 0.00245625 A (Speed) + 9.8625 B (Feed) – 0.355286 C (DOC) + 1.13438 D (Nose Radius)

Summary of Model

S = 0.290089 R-Sq = 87.53% R-Sq(adj) = 83.00%

Table 9 Analysis of Variance for Ra(Boring) for Regression analysis

Source	DOF	SS	MS	F	P
Regression	4	6.49987	1.62497	19.3100	0.000062*
A (Speed)	1	4.82653	4.82653	57.3550	0.000011*
B (Feed)	1	0.77815	0.77815	9.2470	0.011229*
C (DOC)	1	0.07163	0.07163	0.8513	0.375992
D (Nose Radius)	1	0.82356	0.82356	9.7865	0.009606*
Error	11	0.92567	0.92567		
Total	15	7.42554			

Regression Equation

S/N Ratio Ra (Boring) = -13.5845 + 0.0161471 A (Speed) - 60.1867 B (Feed) + 4.61211 C (DOC) - 6.60272 D (Nose Radius)

Summary of Model

S = 1.64320 R-Sq = 90.33% R-Sq(adj) = 86.82%

Table 10 Analysis of Variance for S/N Ration for Ra (Boring) for Regression analysis

Source	DOF	SS	MS	F	P
Regression	4	277.536	69.384	25.6967	0.0000157*
A (Speed)	1	208.584	208.584	77.2499	0.0000026*
B (Feed)	1	28.980	28.980	10.7327	0.0073850*
C (DOC)	1	12.072	12.072	4.4708	0.0581299
D (Nose Radius)	1	27.901	27.901	10.3334	0.0082384*
Error	11	29.701	29.701		
Total	15	307.238			

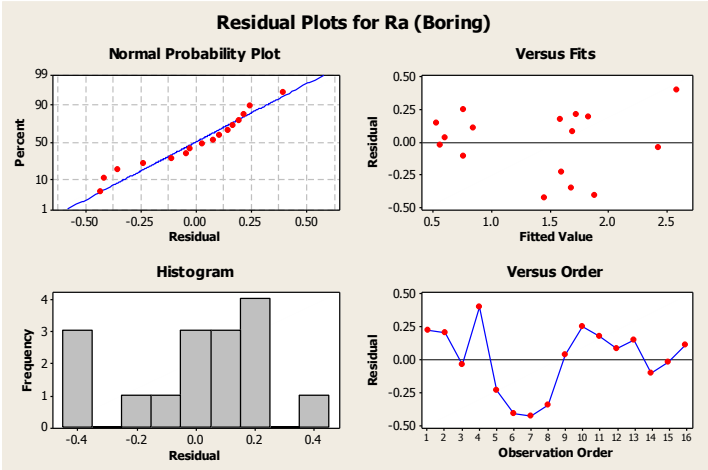

Figure 9 Residual Plots for Ra (Boring)

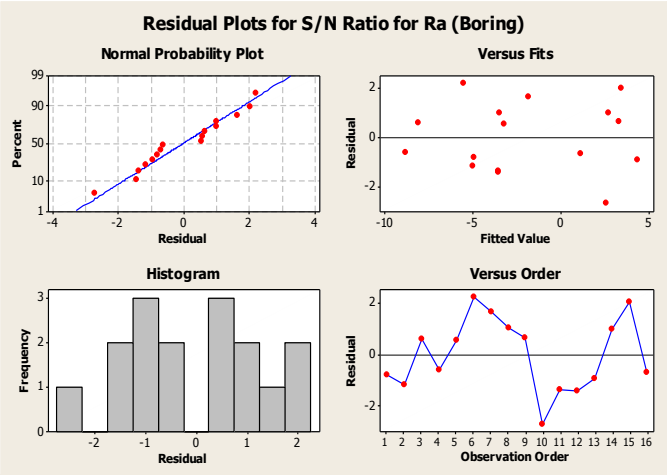

Figure 10 Residual Plots for S/N Ratio for Ra (Boring)

The experiment was conducted at the optimum conditions and the average of the response parameter was 0.59 µm. The error in the predicted optimum value and conformation experimental value is only 8.47%.

Responding Parameters	Optimal setting	Predicted value (µm)	Conformation value (µm)
Boring	$A_4B_1C_3D_1$	0.59	0.54

IX. Conclusion

In present study, optimization of process parameters during boring operation has been carried out. The surface roughness value Ra has been analyzed through Taguchi and ANOVA approach. In summary, the following conclusion has been drawn:

- The Surface roughness is mainly affected by spindle speed nose radius and feed rate. With the increase in feed rate the surface roughness also increases & as the cutting speed decreases the surface roughness increases.
- From ANOVA analysis, parameters making significant effect on surface roughness are speed and feed with contribution of 74.92%, 11.04% and 11.12% respectively.
- The optimal process parameters in CNC TC are: speed of 1400 rpm, feed of 0.6 mm/rev, depth of cut of 1.4 mm and nose radius of 0.8 mm.
- The developed model from regression analysis are reasonably accurate and can be used for predicted surface roughness.
- The error in predicted optimum value and conformation experimental value is less.

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