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Cutting Parameters Optimization for Turning AA6063-T6 Alloy by Using Taguchi Method

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Abstract
The aim of this research work presented in this paper is to optimize the cutting parameters like spindle speed, feed rate, and depth of cut for minimization of Surface Roughness and maximization of Material Removal Rate (MRR) in CNC turning of Aluminium Alloy (AA6063-T6) using carbide insert tool in dry condition. Experiments were conducted based on the Taguchi design of experiments (DOE) with L_9 Orthogonal Array (OA) and Minitab-17 statistical software is used to analyze the data. The signal –to –noise (S/N) ratio and Analysis of variance (ANOVA) are employed to study the performance characteristics in CNC turning operation. Optimal values of process parameters for desired performance characteristics are obtained with identification of most significant factor. The ANOVA has shown that the most significant parameters for surface roughness are feed rate, spindle speed and least significant factor is depth of cut. For MRR depth of cut, spindle speed is the most significant parameters and least significant factor is feed rate.

Keywords
Design of Experiment, Orthogonal Array (OA), Minitab-17, and AA6063-T6 Alloy

I. Introduction
Turning is the most widely used among all the cutting processes. The increasing importance of turning operations is gaining new dimensions in the present industrial age, in which the growing competition calls for all the efforts to be directed towards the economical manufacture of machined parts and all this is made possible by use of CNC lathe machines, improved tools and proper parameter setting. Surface roughness is used to determine and evaluate the quality of a product, is one of the major quality attributes of a turning product. It is one of the prime requirements of customers for machined parts. In order to obtain better surface finish, the proper setting of cutting parameters is crucial before the process takes place. In addition to surface finish quality, MRR is also an important characteristic in turning operation and high MRR is always desirable.
The present work investigates the effect of cutting parameters in turning AA 6063-T6. Aluminium Alloy 6063 is a medium strength alloy commonly referred to as an architectural alloy. It is normally used in manufacturing intricate parts. It has a good surface finish; high corrosion resistance, good weldability and it can be easily anodized. 6063 is typically used in: architectural applications, extrusions, window frames, doors, shop fittings, irrigation tubing. The experiment is designed using Taguchi's orthogonal array with the three process parameters, spindle speed, depth of cut, and feed rate at three levels. The results obtained are analyzed in order to find the optimal parameter setting for minimum surface roughness and maximum material removal rate.

II. Literature Review
Due to the importance of the subject, problems of optimizing parameters in machining, a few number of works published in this field are reviewed as follows:
Alagarsamy S.V., Rajakumar N. [1] have studied the use of Taguchi's technique for minimizing required surface roughness and maximizing the material removal rate in machining Aluminium Alloy 7075 using TNMG 115 100 tungsten carbide tool. The experimental results revealed that the feed is the most significant parameter for surface roughness followed by speed and depth of cut. They also analyzed that the most significant parameter for MRR is speed and followed by feed and depth of cut. Mihir T. Patel, Vivek A. Deshpande [2] investigated the Effect of Process Parameters on MRR and Surface Roughness in Turning Operation on Conventional Lathe Machine for Aluminum 6082 Grade Material Using Taguchi Method. The most significant parameters for material removal rate were speed, depth of cut and least significant factor for MRR was nose radius. For surface roughness speed, nose radius was the most significant parameters and least significant factor for surface roughness is depth of cut. Ranganath M S, Vipin, R S Mishra [3] investigated the effect of the cutting speed, feed rate and depth of cut on surface roughness and material removal rate (MRR), in conventional turning of Aluminium (6061) in dry condition. The feed and speed are identified as the most influential process parameters on surface roughness. The optimum MRR was obtained when setting the cutting speed and feed rate at high values, but the optimum surface roughness was reached when the feed rate and depth of cut were set as low as possible. Low surface finish was obtained at high cutting speed. Gulhane U. D., Ayare S. P., Chandorkar V.S., Jadhav M .M. [4] investigated the effects of cutting parameters like spindle speed, feed and depth of cut on surface finish and material removal rate of Aluminium 7075-T6. Taguchi methodology has been applied to optimize cutting parameters. Feed rate is the most significant factor influencing surface finish whereas material removal rate is significantly affected by cutting speed.
After reviewing these works, it is decided to investigate and compare the result of turning AA6063-T6. Statistical method of Taguchi was used in this work in order to obtain more reliable and optimum results.

III. Methodology
Traditional experimental design methods are very complicated and difficult to use. Additionally, these methods require a large number of experiments when the number of process parameters increases [5, 6, 7]. A large number of experiments have to be carried out when the number of process parameters and their level increases. Genichi Taguchi was developed a well-known, unique and powerful technique, known as Taguchi experimental design method to minimize the number of tests required for product or process quality improvement. This method uses a special design of orthogonal arrays to study the entire parameter space with only a small number of experiments which could give the full information of all the factors that affect the response parameter instead of doing all experiments. Dr. Taguchi proposed a class of statistics called (S/N) ratio which can be used to measure the effect of noise factors on the process performance. Taguchi proposed three categories

of performance characteristics in the analysis of the S/N ratio, that is, the smaller the better, the higher the better and the nominal the better (Ross, 1996). The S/N ratio for each level of process parameters is computed based on the S/N analysis. Regardless of category of the performance characteristics, the higher S/N ratio corresponds to a better performance. Therefore, the optimal level of the process parameters is the level with the highest S/N value. In addition to S/N ratio, ANOVA (Analysis of variance) [8-9] is used to study the contribution of the factor and interactions and to explore the effects of each process on the observed value.

IV. Materials and Methods

A. Work Material

The experiments were performed with turning of material AA6063-T6. The bars used are of diameter 19 mm and length 65 mm. Following table shows the chemical composition of selected material.

Table 1: Chemical Composition of AA6063-T6 [10]

Element	Mn	Fe	Mg	Si	Cu	Zn	Ti	Cr	Other (each)	Other (total)	Al
Wt.%	Max 0.1	Max 0.35	0.45 - 0.90	0.20 - 0.60	Max 0.1	Max 0.1	Max 0.1	Max 0.1	Max 0.05	Max 0.15	Max 97.5

B. Machine Tool

The experiment was carried out on a 2 axis XL Turn bench Top CNC trainer Lathe machine (Fanuc series) of MTAB Engineers (P) Ltd, India.

C. Cutting Tools and Tool Holders

The cutting tool selected for machining AA6063-T6 is carbide insert tool bearing ISO catalog number DCMT 11T304 NU. The tool holder taken for Carbide inserts is of ISO CODE No SCLCR 1212F09.

D. Process Parameters and Their Levels

The parameter level settings were decided for conducting the experiment, based on a “brain storming session” and also considering the guide lines given in the operator’s manual provided by the manufacturer of the CNC lathe machine. Following table indicates the values of various process parameters and their levels used for the experiments:

Table 2: Process Parameters and Levels Used in the Experiment

Cutting Parameters	Level 1	Level 2	Level 3
Spindle speed (rpm)	1200	1400	1600
Depth of cut (mm)	0.5	0.6	0.7
Feed rate (mm/min)	60	70	80

E. Experimental Procedure

In the present study, the interaction between the cutting parameters is neglected. Therefore, there are 8 (eight) DOF owing to 3 three-level independent parameters in turning operations. The most suitable orthogonal array for experimentation is L_9 orthogonal array. Therefore, a total nine experiments were carried out. The machining process on CNC lathe is programmed by speed, feed, and depth of cut. In total 9 work pieces are prepared. Next experimental trial was performed with five simple replications at each set value. The surface roughness of machined surfaces has been measured by a Talysurf (Taylor Hobson, Surtronic 3+, UK), a surface roughness tester and measurements are repeated 3 times. By using dia. values MRR was calculated as:

$$\mathrm{MRR} = \frac{\frac{\Pi}{4}}{Machining\ time\ in\ min}(D^2 - d^2) \times L$$

Where,
D= diameter of the work piece before machining in mm
d= diameter of the work piece after machining in mm
L= length of work piece machining in mm

V. Analysis of Experimental Results

Table 3 shows the values of the responses obtained from 9 machining trials for AA6063-T6, designed by Taguchi method, the corresponding value of S/N Ratio is mentioned for each run.
In the present study all the designs, plots and analysis have been carried out using Minitab-17.

Table 3: Results for Experimental Trial Runs

Exp. No.	spindle speed (rpm)	Depth of cut (mm)	Feed (mm/min)	Surface Roughness (microns)	S/N Ratio for Surface Roughness	Material Removal Rate (mm^3/min)	S/N Ratio for Material Removal Rate
1	1200	0,5	60	1.03	-0.2567	612	55.735
2	1200	0.6	70	1.24	-1.8684	566	55.056
3	1200	0.7	80	1.51	-3.5795	926	59.332
4	1400	0,5	70	1.11	-0.9065	591	55.431
5	1400	0.6	80	1.78	-5.0084	566	55.056
6	1400	0.7	60	1.08	-0.6685	743	57.420
7	1600	0,5	80	1.23	-1.7981	483	53.679
8	1600	0.6	60	0.92	0.7242	392	51.866
9	1600	0.7	70	0.89	1.0122	707	56.988

A. Analysis of the S/N Ratio

S/N ratio is the tool used for analysis purpose which measures the performance of individual process parameters towards the surface roughness and material removal rate. The S/N Ratio for surface roughness was calculated using smaller the better characteristics.

$$\frac{S}{N_{Smaller}} = -10\ log_{10}[\frac{1}{n}\sum_{i=1}^{n} Y_i^2]$$

And the S/N Ratio was calculated using larger the better characteristics for MRR

$$\frac{S}{N_{Larger}} = -10\ log_{10}\ [\frac{1}{n}\sum_{i=1}^{n}\frac{1}{Y_i^2}]$$

Where n is the number of measurement in a trail/row and Y_i is the measured value in the run/row. Table 4 and 5 shows the Responses for Signal to Noise ratios of smaller the better and larger the better for each level of the parameters.

Table 4: Response Table for Signal to Noise Ratios, Smaller is better

Level	Spindle speed (rpm)	Depth of cut (mm)	Feed rate (mm/min)
1	1.90157	0.98710	0.06699
2	2.19444	2.05086	0.58756
3	0.02055	1.07860	3.46201
Delta	2.17389	1.06376	3.39502
Rank	2	3	1

Table 5: Response Table for Signal to Noise Ratios
Larger is better

Level	Spindle speed (rpm)	Depth of cut (mm)	Feed rate (mm/min)
1	56.71	54.95	55.01
2	55.97	53.99	55.83
3	54.18	57.91	56.02
Delta	2.53	3.92	1.02
Rank	2	1	3

Regardless of the category of the performance characteristics, a greater value of S/N ratio is always considered for better performance. It is evident from the table 4 that feed rate have the greatest effect on surface roughness and is followed by spindle speed, and DOC. Table 5 indicates that for MRR, the parameter that had the most influence is DOC and is followed by spindle speed and feed rate.

B. Main Effect Plots Analysis for Surface Roughness and MRR

The analysis is made with the help of Minitab-17. The main effect plot for Ra and MRR are shown in following figures.

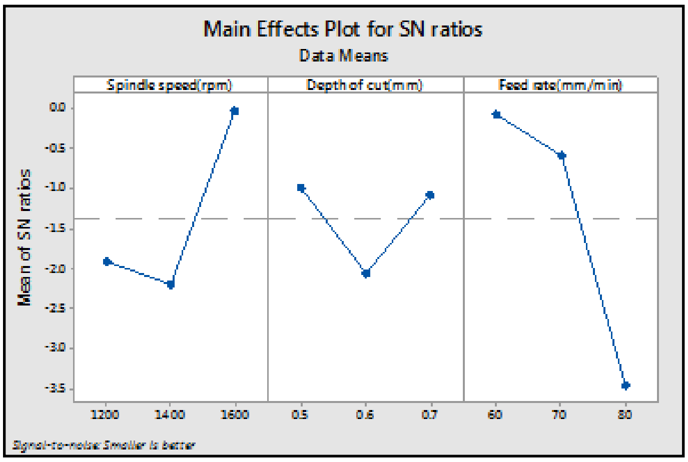

Fig. 1: Main effect plot for S/N ratios: R_a

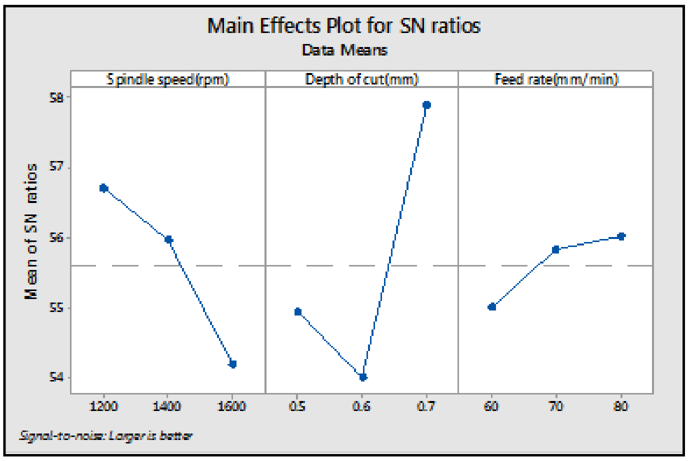

Fig. 2: Main Effect Plot for S/N Ratios: MRR

The main effect plot for surface roughness is shown in fig. 1. These show the variation of individual response with spindle speed, Depth of Cut (DOC), and feed rate parameters separately. The main effects plots are used to determine the optimal conditions for surface roughness. According to this main effect plot, the optimal conditions for minimum surface roughness are spindle speed at level 3 (1600 rpm), depth of cut at level 1 (0.5mm) and feed rate at level 1 (60 mm/min). The main effect plot for MRR is shown in figure-2. According to main effects plot, the optimal conditions for maximum MRR are spindle speed at level 1 (1200 rpm), depth of cut at level 3 (0.7mm) and feed rate at level 3 (80 mm/min).

C. Analysis of Variance (ANOVA)

The ANOVA may be used to investigate which design factors and their interactions affect the response significantly.
The response data was obtained via experimental runs for surface roughness and MRR are at above 95% confidence level and the results of ANOVA thus obtained for the response parameters are illustrated in Table 6 and 7.

Table 6: ANOVA table for S/N Ratios of surface roughness, using Adjusted SS for Tests:

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Contribution (%)
Spindle speed (rpm)	2	8.3497	8.3497	4.1748	130.36	0.008	27.32**
Depth of cut (mm)	2	2.0853	2.0853	1.0426	32.56	0.030	6.82*
Feed rate(mm/min)	2	20.0594	20.0594	10.0297	313.17	0.003	65.64***
Error	2	0.0641	0.0641	0.0320			
Total	8	30.5584					

Table 7: ANOVA Table for S/N Ratios for MRR, using Adjusted SS for Tests:

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Contribution (%)
Spindle speed (rpm)	2	10.1554	10.1554	5.0777	21.84	0.044	27.13**
Depth of cut (mm)	2	25.0762	25.0762	12.5381	53.93	0.018	66.99***
Feed rate(mm/min)	2	1.7390	1.7390	0.8695	3.74	0.211	4.65*
Error	2	0.4650	0.4650	0.2325			
Total	8	37.4355					

Where DF-degree of freedom, Seq SS – Sequential sum of squares, Adj SS-Adjusted sum of squares, Adj MS – Adjusted mean squares, F- a statistical parameter, P-percentage and the *** & ** represents most significant and significant parameters and * as less significant.
It is evident from table-6 that feed rate (p=0.003) makes the largest contribution to the total sum of squares having 65.64% effect on surface roughness followed by spindle speed (p= 0.008) having 27.32% influence on the response whereas depth of cut (p=0.030) influences the response only by 6.82%. ANOVA in table 7 shows that the depth of cut (p=0.018) have 66.99% influence on MRR. The spindle speed (p=0.044) makes the next largest contribution (27.13%) to the total sum of squares whereas the factor feed rate (0.211) makes only 4.65% contribution towards MRR.

VI. Conclusion

This work presented an experimentation approach to study the effect of input parameters on the surface roughness and MRR. The following conclusions are drawn on the experimental investigations carried out:

1. From response Table rankings, it can be concluded that feed rate has the most influencing effect on the quality characteristics of surface roughness followed by spindle speed and DOC. Optimum parameter setting for surface roughness in turning AA6063-T6 is obtained.

2. From response Table for Signal to Noise ratios based on the ranking, it can be concluded that depth of cut has a maximum influence on the MRR followed by spindle speed and feed rate. Optimum parameter setting for MRR in turning AA6063-T6 is obtained.
3. As shown in this study of AA6063 turning with Taguchi's easy-to-use approach for process optimization may be extended to other aluminium alloys considering the growing importance of such alloys. Present work may pave the way for further research with process variables like tool vibration, power consumption, and temperature effects etc. on the same alloy.

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