Experimental Analysis of Surface Roughness in CNC Taper Turning of Aluminum 6061 Using Taguchi Technique

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Abstract

The work and study presented in this paper aims to investigate the effect of various cutting parameters as well as nose radius on surface roughness, in CNC Taper Turning of Aluminum (6061) in dry condition. The effect of cutting conditions (speed, feed and depth of cut) and tool geometry (nose radius) on surface roughness has been studied and analyzed. For the experimentation Taguchi's L27 Orthogonal array has been employed. Analysis of Variance is performed to determine the significance for each parameter. The Nose Radius is identified as the most significant parameter followed by Feed Rate. It is observed that Surface Roughness value decreases with increase in Nose Radius and increases with increase in Feed Rate.

Keywords
ANOVA, Surface Roughness, S/N Ratios, Taguchi, Taper Turning

1. Introduction

Surface roughness is an essential attribute used to determine and evaluate the quality of a turned product. However, the study and optimization of surface roughness is not as easy as determining any other variable. The study of Surface Roughness is harder to achieve as it depends on both controllable and uncontrollable factors. The controllable variables include tool rake angle, feed rate, spindle speed, depth of cut etc. while wearing of tool, material friction, tool degradation etc. factors are much harder to control. Surface roughness of a machined product could affect several of the product's features such as surface friction, wearing, light reflection, heat transmission, ability of distributing and holding a lubricant, coating and resisting fatigue [1]. Hence, achieving optimal roughness response has become crucial for industries to improve their quality and merit. Identifying the most influential parameter allows proper selection of tool material that prolongs the life of tool and minimizes the surface roughness. Consequently, a recent advent in Design of Experiments has given vent to various methods such as Taguchi Method, Response Surface Methodology, etc., that have not only allowed scholars and industrialists to efficiently organize the process of optimizing roughness but has also given way to several techniques to reduce the number of trials that have to be carried out to obtain optimal response. Quality control is a process by the virtue of which businesses seek to ensure that product quality is maintained and improved and manufacturing errors are reduced or eliminated. Prajwalkumar M. Patil et al. [12] observed and analyzed the effect of cutting parameters on the surface roughness and hardness. Taguchi method was analyzed by the authors in the optimization of cutting parameters. L9 orthogonal array was employed to carry out the analysis. The analysis of means (ANOM) and Analysis of variance (ANOVA) were carried out to determine the optimal parameters level and obtain level of importance of each parameter. From the ANOVA, the feed had maximum significance in case of R_a and R_z. Murat Sarikaya et al. [11] used Taguchi design and Response Surface Methodology (RSM) Technique under Minimum Quantity Lubrication (MQL) for analyzing CNC turning parameters. The results were analyzed using 3D surface graphs, signal to noise ratios and main effect graphs of means. Also mathematical model output showed that the developed RSM model was statistically significant and suitable for all the cutting conditions because of higher R^2 value. Ilhan Asiltürk et al. [6] used the Taguchi method and L9 orthogonal array to reduce number of the experiments. Analysis of Variance (ANOVA) was applied to investigate effects of cutting speed, feed rate and depth of cut on surface roughness.

Results indicated that the feed rate had the most significant effect on R_a and R_z. The effects of two factor interactions of the feed rate-cutting speed and depth of cut-cutting speed appeared to be important. Chinnasamy Natarajan et al. [3] predicted and analyzed surface roughness factors of a non-ferrous material using Artificial Neural Network (ANN). A model was developed to predict the surface roughness of material (Brass C26000) through Artificial Neural Networks technique by utilizing feed-forward back propagation training algorithm using Matlab (2009a) software for the data obtained. As the spindle speed increases, for lower feed rates, the surface roughness decreases, for higher feed rates, the surface roughness changes considerably. The depth of the cut influences the surface roughness considerably for a given feed rate. The increase in feed rate causes the surface roughness to increase and then decrease. For lower depth of cut, surface roughness decreases and then increases. Ranganath M S et al. [14] presented a paper on analysis of the effect of the cutting speed, feed rate and depth of cut on surface roughness. The author employed an L27 orthogonal array to carry out the analysis. The ANOVA values proved that speed is the most significant factor; the next significant factor was depth of cut followed by feed.

This paper presents the experimental approach for studying the effects of cutting parameters and nose radius on the surface roughness of the tapered work-piece. Taguchi method was adopted for analyzing the surface roughness and Analysis of Variance (ANOVA) was used for finding the most significant factor that affects the surface response. For different levels of the factors, different output values of surface roughness were obtained. A systematic and organized study of the response values and the control factors in the experiment were tabulated. No significant interactions were observed among the control factors. Feed rate and Nose radius were found to be the most significant factors.

2. Taguchi's Methodology

The Taguchi method of quality control is an approach to engineering that emphasizes the roles of research and development, product design and product development in reducing the occurrence of defects and failures in products. This method considers design to be more important than the manufacturing process in quality control and tries to eliminate variances in production before they can occur. Because noise factors are also present in the process that cannot be controlled, this method identifies the values of controllable factors that minimizes the effect of noise factors and provide an optimal response. The concept of S/N ratio originated in the electrical engineering field. Taguchi effectively applied this concept to establish the optimum condition from the experiments. In an experiment there are number of factors which influence the response but are uncontrollable. These external factors are called the noise factors and their effect on the outcome of the quality characteristics under test is termed "noise." The signal to noise (S/N) ratio measures the sensitivity of the quality characteristics with respect to factors not under control. The S/N ratio indicates the degree of the predictable performance parameter of a product or process in the presence of noise factors.

Steps of Taguchi method are as follows:

1. Identification of main function, side effects and failure mode.
2. Identification of noise factor, testing condition and quality characteristics.
3. Identification of the main function to be optimized.
4. Identification of the control factor and their levels.
5. Selection of orthogonal array and matrix experiment.
6. Conducting the matrix experiment.
7. Analyzing the data, prediction of the optimum level and performance.
8. Performing the verification experiment and planning the future action.

3. Experimental Work

3.1 Work piece Material

Aluminum 6061 was selected as the work material. It is one of the most extensively used of the 6000 series aluminum alloys. This standard structural alloy, one of the most versatile of the heat-treatable alloys, is popular for medium to high strength requirements and has good toughness characteristics. Applications range from transportation components to machinery and equipment applications to recreation products and consumer durables. It is widely used for producing automotive components by turning process.

3.2 Cutting Tool Inserts

CNMG cutting tool inserts of nose radius 0.4 mm, 0.8 mm, 1.2 mm. The geometry of the tool is:

Table 1. Details of Cutting Inserts

Insert	Shape	Clearance Angle	Inscribed Circle Size	Thickness	Nose Radius
CNMG120404	Diamond	0^0	12.7 mm	4.76 mm	0.4 mm
CNMG120408	Diamond	0^0	12.7 mm	4.76 mm	0.8 mm
CNMG120412	Diamond	0^0	12.7 mm	4.76 mm	1.2 mm

3.3 Experimental Plan

The experimental work was carried out on Computer and Numeric Control (CNC) turning center LMW LL20TL3 shown in Fig. 1

Figure 1. CNC Turning- LMW LL20TL3

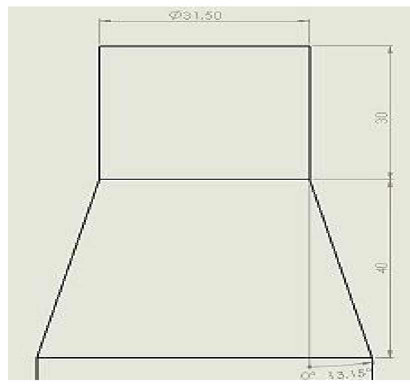

Figure 2. Sketch of Tapered Work piece

Surface Roughness of these machined surfaces has been measured by a Surface Roughness measuring instrument Talysurf Surtronic 3+. Surtronic 3+ is a self-contained, portable instrument for the measurement of surface texture and is suitable for use in both the workshop and laboratory. Parameter used for surface texture evaluation is average roughness (R_a). It is the arithmetic average of absolute roughness profile ordinates. The parameter evaluation and other functions of the instrument are microprocessor based. [13]

3.4 Experimentation and Analysis

Fig. 2 represents the dimensions of the machined work piece. Table 2 represents various Factors and their respective levels. The factors considered are speed, feed rate, depth of cut and Nose radius. Three levels for each factor were considered. The feasible orthogonal arrays for experimentation are L9 and L27. L27 orthogonal array was used as sufficient degrees of freedom could be allocated to each factor and residual error for complete analysis. Table 3 shows the experimental design table along with mean value of surface roughness and S/N ratio for each treatment. The First Four columns of the Table 4 include the coded values of control factors. The different units here are: speed-rpm, feed-mm/rev, depth of cut-mm and Surface Roughness Ra-µm. MINITAB 17 software has been employed for the Analysis.

Table 2. Factors and their Levels

LEVELS	1	2	3
Speed (rpm)	1600	1900	2200
Feed (mm/rev)	0.12	0.18	0.24
Depth (mm)	0.25	0.50	0.75
Nose Radius (mm)	0.4	0.8	1.2

Table 3. Design Table

EXPERIMENT NO.					SPEED (rpm)	FEED (mm/rev)	DEPTH OF CUT (mm)	NOSE RADIUS (mm)	Ra MEAN (µm)	S/N RATIO
	A	B	C	D						
1	1	1	1	1	1600	0.12	0.25	0.4	1.6000	-4.0824
2	1	1	2	2	1600	0.12	0.50	0.8	0.5945	4.5170
3	1	1	3	3	1600	0.12	0.75	1.2	0.5470	5.2403
4	1	2	1	2	1600	0.18	0.25	0.8	1.0150	-0.1293
5	1	2	2	3	1600	0.18	0.50	1.2	0.7635	2.3438
6	1	2	3	1	1600	0.18	0.75	0.4	2.8550	-9.1121
7	1	3	1	3	1600	0.24	0.25	1.2	1.4350	-3.1370
8	1	3	2	1	1600	0.24	0.50	0.4	4.5000	-13.0643
9	1	3	3	2	1600	0.24	0.75	0.8	2.0100	-6.0639
10	2	1	1	1	1900	0.12	0.25	0.4	1.7150	-4.6853
11	2	1	2	2	1900	0.12	0.50	0.8	0.5690	4.8978
12	2	1	3	3	1900	0.12	0.75	1.2	0.5595	5.0440
13	2	2	1	2	1900	0.18	0.25	0.8	1.0400	-0.3407
14	2	2	2	3	1900	0.18	0.50	1.2	1.0090	-0.0778
15	2	2	3	1	1900	0.18	0.75	0.4	3.2600	-10.2644
16	2	3	1	3	1900	0.24	0.25	1.2	1.4150	-3.0151
17	2	3	2	1	1900	0.24	0.50	0.4	4.3450	-12.7598
18	2	3	3	2	1900	0.24	0.75	0.8	2.1150	-6.5062
19	3	1	1	1	2200	0.12	0.25	0.4	1.6550	-4.3760
20	3	1	2	2	2200	0.12	0.50	0.8	0.6725	3.4462
21	3	1	3	3	2200	0.12	0.75	1.2	0.5085	5.8742
22	3	2	1	2	2200	0.18	0.25	0.8	1.0625	-0.5266
23	3	2	2	3	2200	0.18	0.50	1.2	1.1195	-0.9805
24	3	2	3	1	2200	0.18	0.75	0.4	2.7750	-8.8653
25	3	3	1	3	2200	0.24	0.25	1.2	1.3250	-2.4443
26	3	3	2	1	2200	0.24	0.50	0.4	4.4100	-12.8888
27	3	3	3	2	2200	0.24	0.75	0.8	2.1400	-6.6083

The main effect plot for means is shown in fig.3. They show the variation of response with considered parameters i.e. speed, feed and depth of cut and nose radius. In the plot x-axis represents the value of each process parameter and y-axis is response value. Horizontal line indicates the mean of the response. The main effect plots are used to determine the optimal design conditions to obtain the minimum surface finish. It is evident from Fig.3 that R_a is minimum at the first level of speed (A), first level of Feed (B), first level of Depth of cut (C) and third level Nose Radius (D).

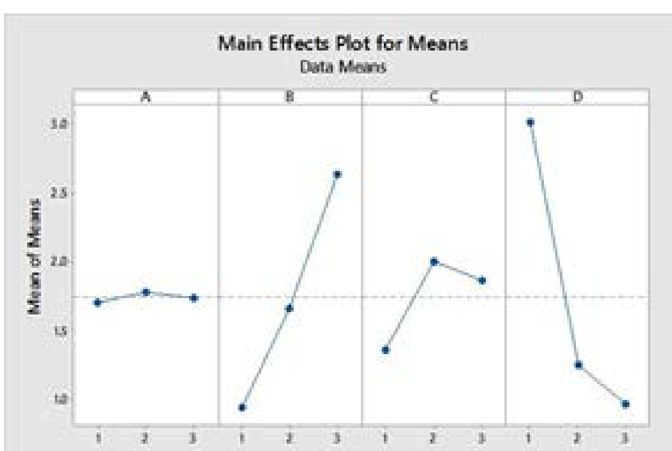

Figure 3. Main Effects Plot for Means

Fig.4 represents Main Effects Plot for S/N Ratio. The objective of using the S/N ratio as a performance measurement is to develop products and the processes insensitive to variance factors. [4] The aim of any experiment is always to determine the highest possible S/N ratio for the result. Process parameters setting with the highest S/N ratio always yield the optimum quality with minimum variance. Consequently, the level that has a larger value is the optimum level of each factor. In Fig.4 level one for speed (1600 rev/mm) has maximum S/N ratio value, which defines that the machining performance at such level gives minimum variation of the surface roughness. Hence, as indicated by main effect plots for S/N ratio, the ideal conditions for least surface roughness (R_a) are speed at level 1 (1600 rev/min), feed at level 1 (0.12 mm/rev), depth of cut at level 1 (0.25 mm)and nose radius at level 3 (1.2 mm).

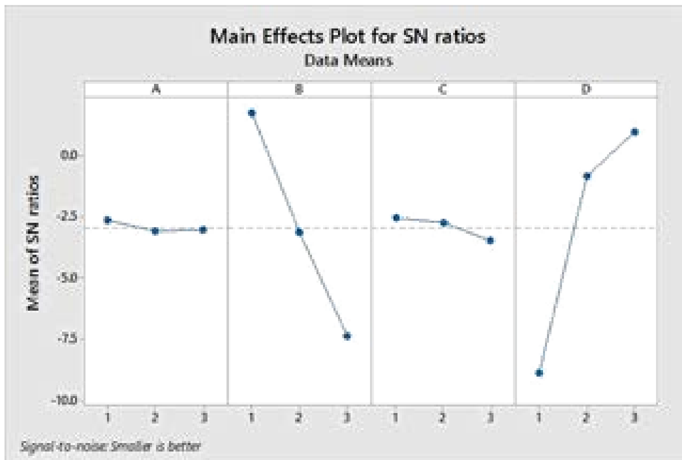

Figure 4. Main Effects Plot for SN Ratios

The purpose of the analysis of variance (ANOVA) is to investigate which design parameter significantly affects the surface roughness. [13] A better feel for the relative effect of the different factors can be obtained by the decomposition of the variance, which is commonly known as analysis of variance (ANOVA). [4] Table.4 and Table.5 shows the analysis of variance (ANOVA) for Means and S/N ratio respectively. In the present investigation, ANOVA and the F-test are applied to analyze the experimental data. Nose Radius and Feed are the most significant factors followed by depth of cut. The spindle speed has very less effect on the response in this experiment.

Table 4. Analysis of Variance (ANOVA) table for Means

SOURCE	DF	Adj SS	Adj MS	F Value	P Value
A	2	0.0278	0.0139	0.08	0.921
B	2	13.0603	6.5301	39.21	0.000
C	2	2.0190	1.0095	6.06	0.036
D	2	22.1818	11.0909	66.59	0.000
A*B	4	0.0515	0.0129	0.08	0.986
A*C	4	0.0572	0.0143	0.09	0.984
A*D	4	0.0362	0.0091	0.05	0.993
RESIDUAL ERROR	6	0.9993	0.1665		
TOTAL	26	38.4331			

Table 5. Analysis of Variance (ANOVA) table for SN Ratios

	DF	Adj SS	Adj MS	F Value	P Value
A	2	1.222	0.611	0.60	0.581
B	2	377.392	188.696	184.18	0.000
C	2	4.476	2.238	2.18	0.194
D	2	498.891	249.445	243.43	0.000
A*B	4	1.837	0.459	0.45	0.772
A*C	4	2.755	0.689	0.67	0.635
A*D	4	1.249	0.312	0.30	0.865
RESIDUAL ERROR	6	6.148	1.025		
TOTAL	26				

Table.6 and Table.7 are the response tables for S/N ratio and Mean. The response tables explain that the nose radius is the most dominant factor followed by feed, depth of cut and speed.

Table 6. Response Table for SN Ratio

LEVEL	A	B	C	D
1	-2.6098	1.7640	-2.5263	-8.8998
2	-3.0786	-3.1059	-2.7296	-0.8127
3	-3.0410	-7.3875	-3.4735	0.9831
Delta	0.4688	9.1515	0.9472	9.8829
Rank	4	2	3	1

Table 7. Response Table for Means

LEVEL	A	B	C	D
1	1.7022	0.9357	1.3625	3.0128
2	1.7808	1.6555	1.9981	1.2465
3	1.7409	2.6328	1.8633	0.9647
Delta	0.0786	1.6971	0.6356	2.0481
Rank	4	2	3	1

The diagnostic checking has been performed through residual analysis for the developed model. The Residual plots for surface roughness are shown in Fig.5 and Fig.6. These fall on a straight line implying that errors are distributed normally. From Fig.5 and Fig.6 it can be further concluded that all the values are within the control range, indicating that there is no obvious pattern and unusual structure and also the residual analysis does not indicate any model inadequacy.

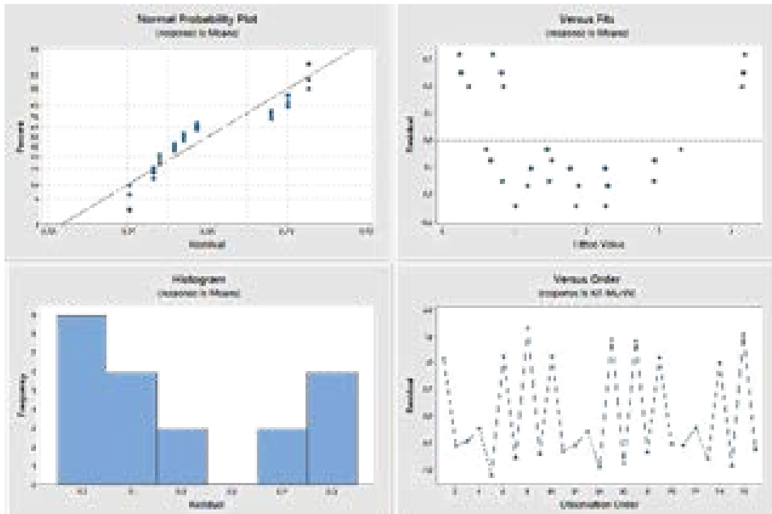

Figure 5. Residual Plots for Means

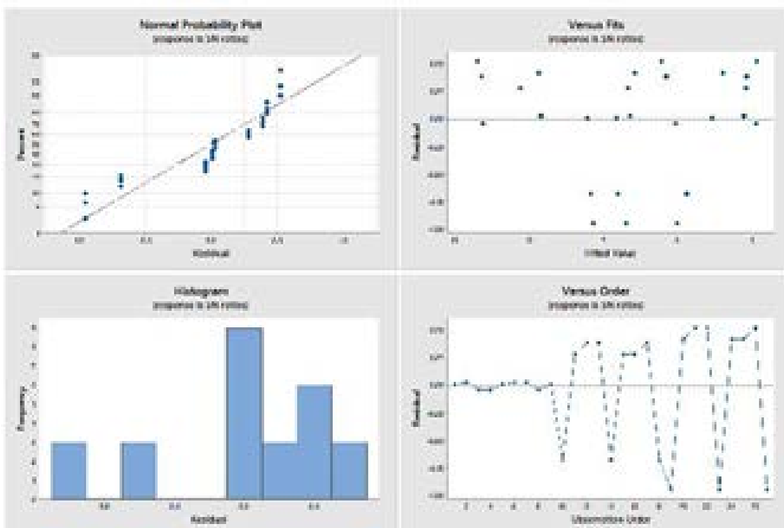

Figure 6. Residual Plots for SN Ratios

Regression Model:

Surface Roughness = 0.72 + 0.00001 * (speed) + 15.6 * (feed) + 0.96 * (doc) - 2.99 * (nose radius) - 0.00076 * (speed*feed) + 0.00002 * (speed*doc) + 0.00022 * (speed*nose radius)

4. Conclusions

This research presents a way of optimizing cutting as well as tool parameters in a simple machining process of taper turning wherein the optimum setting of the control factors by main effects plots was found to be A1B1C1D3 (highest S/N Ratio) 1600 rpm, 0.12 mm/rev, 0.25 mm and 0.12 mm. This result is ideal when the prime requirement is to minimize surface roughness while machining Aluminum 6061-T6. The surface roughness decreased with increase in nose radius for the range 0.4-1.2 mm and increased with increase in feed rate for the range 0.12-0.24 mm/rev. ANOVA Table and F-statistic value showed that the percentage contribution of nose radius and feed were maximum followed by depth of cut. Taguchi gives a systematic and efficient method for evaluating optimum operating conditions. The research can be extended to more number of responses for further increment in operational efficiency.

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Biography

Sanchay Gupta is a student at Delhi Technological University (Formerly Delhi College of Engineering) pursuing Bachelor of Technology in Mechanical Engineering and is currently in fourth (final) year. He is currently working on optimization method viz. Taguchi Technique. He has been a part of Deltech Baja, a prestigious society in the college that designs, manufactures and tests an off-road vehicle from the scratch and has published a research paper on effect of tool geometry on the surface roughness. He has worked as an intern in L&T Hydrocarbon Engineering and ISGEC Heavy Engineering Ltd.

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Vishal Sardana is pursuing Bachelor of Technology (Mechanical) from Delhi Technological University, Delhi, India. He is currently working on the optimization of cutting parameters on surface roughness and evaluation of safety index for machining process. He is a member of ASME. He has published research paper in IOSR Journal of engineering. He has worked as an intern at Air India Ltd. and Daikin Air Conditioning India Pvt. Ltd. He has been felicitated with OP Jindal Engineering and Management Scholarship for being selected among top 100 scholars in India for year 2016.

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