



Study of Effect of Tool Nose radius on Surface Finish and Optimization of Machining Parameters of Turning Process of an Aerospace Material

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Abstract: Turning process is one of the most fundamental cutting processes used in the manufacturing industry. The present work focuses on an experimental study to find the effects of cutting parameters on surface finish and optimize them for better surface finish and high Material Removal Rate (MRR) during turning of Ti-6Al-4V. A combined Taguchi method and Grey Relational Analysis (GRA) is used for the optimization. Analysis of Variance (ANOVA) is employed to find out contribution of each parameter. Four parameters are chosen as process variables: cutting speed, feed, depth of cut and nose radius each at three levels. The experiment plan is designed using Taguchi's L9 Orthogonal Array (OA). Minitab statistical software is employed to create the plan and carrying out the analysis. The effects of various parametric combinations on the turning process are studied and an optimization strategy for a given set of parameter combination for better surface finish of the turned product is developed. The results show that feed rate and nose radius are the most important parameters that affect the surface finish. A prediction model is also developed separately for both surface finish and MRR using multiple regression analysis.

Keywords: turning; cutting parameters; optimization; surface finish; Ti-6Al-4V; Taguchi techniques; GRA; ANOVA

I. Introduction

In modern industry the goal is to manufacture low cost, high-quality products in short time. Automated and flexible manufacturing systems are employed for that purpose along with computerized numerical control (CNC) machines that are capable of achieving high accuracy and very low processing time [1]. Turning is the most widely used among all the cutting processes. Surface roughness has become the most significant technical requirement and it is an index of product quality. In order to improve the tribological properties, fatigue strength, corrosion resistance and aesthetic appeal of the product, a reasonably good surface finish is desired. In order to obtain optimal cutting parameters manufacturing industries have depended on the use of handbook based information which leads to decrease in productivity due to sub-optimal use of machining capability this causes high manufacturing cost and low product quality. Hence, there is need for finding the optimal parameters to obtain high quality products. The design of experiments (DOE) is an efficient procedure for the purpose of planning experiments. Further the data can be analyzed to obtain valid and objective conclusions.

Turning process is affected by many factors, which include cutting speed, feed, depth of cut, tool geometries, environmental conditions, rigidity of machine structure, tool and work piece clamping method, etc. Consideration of all these factors into account for optimization of the process is very difficult. Most studies had been done by considering mainly three factors feed, speed and depth of cut. Tool geometry plays an important role in machining in which nose radius is a major factor that affects the surface finish of work piece. In this study nose radius has been taken into consideration along with cutting speed, feed rate and depth of cut.

II. Objectives

The main objective of this work is to study the effects of machining parameters and tool geometry on surface finish of a turned part of an aerospace material using Taguchi based parameter design. In addition to that an optimization strategy will also be developed for a given set of parameter combination for better surface finish and high MRR of the turned product using a combined method of Taguchi technique and Grey Relational Analysis.

III. Problems with Turning Operation and Ti-6Al-4V Alloy

The turning operation is affected by many parameters. Some of the main problems associated with the quality characteristics of the turned parts include surface roughness, tool wear, burrs, tool vibrations, etc. The machining parameters such as cutting speed, feed rate, depth of cut, features of tools, work piece material and coolant conditions were highly affect the performance characteristics. So it is necessary to select the most appropriate machining settings in order to improve cutting efficiency, lower the process cost, and produce high-quality components.

This work is focused on turning of a titanium alloy, Ti-6Al-4V. Ti-6Al-4V is known as the "workhorse" of the titanium industry, it offers a unique combination of high strength, light weight and corrosion resistance which have made it an important material in aerospace applications. Despite its advantages the machinability of Ti-6Al-4V possesses many challenges. Its low thermal conductivity and work hardening effect reduces the tool life and reduced quality of the product. Formation of built-up-edge at low cutting speed and high chemical reactivity with tool materials at high temperatures, etc. will cause further problems during machining [7].

IV. Taguchi Method

The Taguchi method is a robust design method technique, which provides a simple way to design an efficient and cost effective experiment. In order to efficiently reduce the numbers of conventional experimental tasks, the orthogonal array using design parameters (control factors) and standard quantities (levels) is proposed and further adopted. The performance measure, signal to noise ratio (S/N) proposed by Taguchi is used to obtain the optimum parameter combinations. There are three characteristic equations for S/N ratio; smaller-the-better, nominal-the-best and larger-the-better. Smaller the better is used for making the system response as small as possible, nominal the best used for reducing variability around a target and larger the better for making the system response as large as possible. Here smaller-the-better condition (1) is used to find out the S/N ratio of surface roughness since the surface roughness is to be minimized. For material removal rate the aim is to maximize the output. So larger-the-better condition (2) is used to find out the S/N value of MRR. The related S/N ratio is defined as:

$$S/N_S = -10 \log \frac{1}{n} \sum_{i=1}^n y_i^2 \quad (1)$$

$$S/N_L = -10 \log \frac{1}{n} \sum_{i=1}^n \frac{1}{y_i^2} \quad (2)$$

Where,

y_i = output response (Surface roughness or MRR)

n = number of replications

V. Grey Relational Analysis (GRA)

The grey theory, first proposed by Deng, avoids the inherent defects of conventional, statistical methods and only requires a limited set of data to estimate the behavior of an unknown system. The Grey theory can provide a solution of a system in which the model is unsure or the information is incomplete. Besides, it provides an efficient solution to the uncertainty, multi-input and discrete data problem. The relation between machining parameters and performance can be found out with the Grey relational analysis [8]. In this method the Grey relational grade is utilized to evaluate optimum machining condition. A grey relational grade (GRG) is calculated for each machining condition by considering the multiple output responses i.e., surface finish and MRR (which are conflicting). The GRG is found for the S/N ratio of surface roughness and MRR, which are obtained from Taguchi method. In GRA also there are three characteristic equations for normalization of the data; smaller-the-better, nominal-the-best and larger-the-better. Here the data analysis is done for S/N ratio. Since S/N ratio is to be maximized, larger the better characteristic equation is used for normalization of data. Grey Relational Coefficient (4) and GRG (5) are calculated using the following equations:

$$x_i^*(k) = \frac{x_i^0(k) - \min x_i^0(k)}{\max x_i^0(k) - \min x_i^0(k)} \quad (3)$$

$$\varphi_i(k) = \frac{\Delta_{min} + \delta \Delta_{max}}{\Delta_{oi}(k) + \delta \Delta_{max}} \quad (4)$$

$$\gamma_i = \frac{1}{n} \sum_{k=1}^n \varphi_i(k) \quad (5)$$

where,

$x_i^*(k)$ is the generating value of Grey relational analysis; $\min x_i^0(k)$ and $\max x_i^0(k)$ are the minimum and maximum values of $x_i^0(k)$. “ Δ ” represents variation of generated value from reference value and δ is the weightage coefficient.

VI. Experimental Setup

In this work an L9 orthogonal array is selected for four parameters (cutting speed, feed rate, depth of cut and nose radius), each at three levels (Table 1). The values of the parameter levels are selected according to the data available from the previous literatures, experienced personals, from the tool manufacturer’s information, etc.

Table I Shows Parameter Levels

Levels	Parameters			
	A. Cutting speed (mm/min)	B. Feed rate (mm/rev)	C. Depth of cut (mm)	D. Nose radius (mm)
Level 1	20	0.1	0.5	0.4
Level 2	35	0.2	1.0	0.8
Level 3	50	0.3	1.5	1.2

Table II Shows L9 Orthogonal Array

Run	Parameter Levels			
	Cutting speed (A)	Feed (B)	Depth of cut (C)	Nose radius (D)
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	2	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

A. Work Piece and Cutting Tool

A rod of Ti-6Al-4V with diameter 52 mm and length 137 mm is used for the experiment. The work piece is initially prepared on a conventional lathe machine by providing an initial facing and making a holding portion (with diameter 41 mm according to the standard chuck available). The chemical composition and mechanical properties are shown in the tables 3 and 4.

Uncoated WC/Co inserts are used for the machining purpose. It is observed that carbide tools are most suited for machining Titanium alloys [7]. Three inserts of different nose radius and same grade are selected (Made: SANDVIK Coromant). CNMG 12 04 04 H13A, CNMG 12 04 08 H13A, CNMG 12 04 12 H13A are the inserts used (figure 2). The tool holder (PCLNR 25 25 M12) is selected according to the type of insert used.

Table III Shows L9 Orthogonal Array

Element	Percentage
Ti	89.55
Al	6.40
V	3.89
Fe	0.16
C	0.002

Table IV Shows Mechanical Properties

Hardness (HRC)	36
Ultimate Tensile Strength	950 MPa
Poisson’s ratio	0.342
Modulus of Elasticity	113 GPa
Density	4.43 g/m ³
Thermal Conductivity	6.7 W/mK

Figure 1 Ti-6Al-4V Work piece

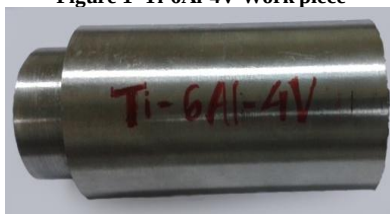


Figure 2 Cutting tool-inserts (0.4mm, 0.8mm, 1.2mm)



B. Experimental Procedure

The machining is done on a 2 axis CNC lathe (Made: HARDINGE SUPERSLANT). The work piece was mounted on a pneumatic chuck and the CNC program for machining is entered according to the selected parameters. A simulation check is done for each run to avoid errors in program and machining. The turning process is carried out according to the experimental chart designed using the orthogonal array.

Figure 3 CNC Machine



Figure 4 Workpiece setting up on Machine



VII. Results and Discussion

Nine experiments were conducted and the work piece after machining is inspected for surface finish. The roughness values (Ra) were measured using Taylor/Hobson Precision Form Talysurf. Corresponding to each Ra values the S/N ratios were calculated using smaller-the-better characteristic. The main effects plots for S/N data means is obtained using MINITAB statistical software and the optimum condition for better surface finish is found from the plot (figure 5). Grey relational grade (GRG) is calculated for the S/N ratios of Ra and MRR. The experimental runs are ranked in the order of GRG (table 5). Data analysis plot for means of GRG is obtained using MINITAB (figure 6).

Table V Shows Experiment chart with Results

Run	Ra (μm)	S/N of Ra (dB)	MRR (cm^3/min)	S/N of MRR (dB)	GRG	Rank
1	0.6115	4.2644	1.00	0	0.5828	5
2	1.2413	-1.8775	4.00	12.0412	0.5088	8
3	2.4528	-7.7994	9.00	19.0848	0.5495	7
4	0.5064	5.9079	3.50	10.8814	0.7409	2
5	2.1627	-6.7064	10.50	20.4238	0.5921	4
6	2.7917	-8.9173	5.25	14.4032	0.4591	9
7	0.5132	5.7946	7.50	17.5012	0.8240	1
8	0.9687	0.2762	5.00	13.9794	0.5718	6
9	3.3099	-10.3984	15.00	23.5218	0.6667	3

Figure 5 Data Analysis Plot for S/N ratio of Ra

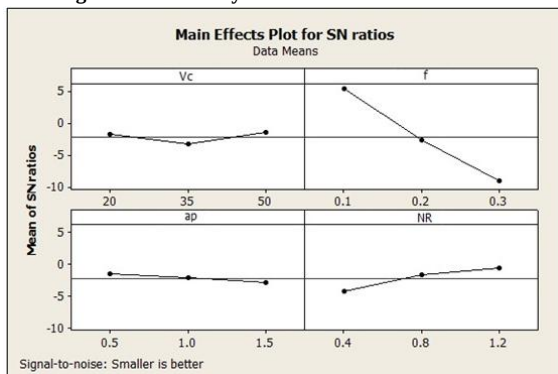
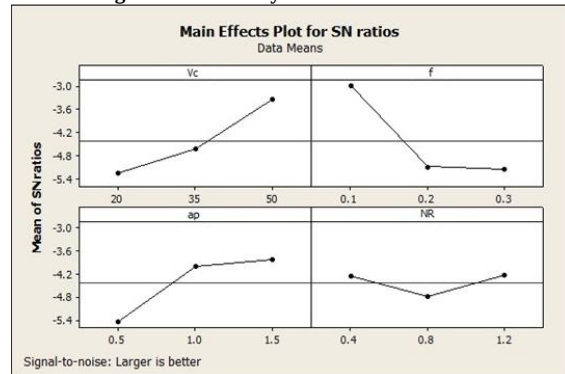


Figure 6 Data Analysis Plot for means of GRG



The optimum condition for lower surface roughness is found by S/N analysis as A3-B1-C1-D3. A confirmation experiment is carried out for this parameter setting and the surface roughness is obtained as $0.4151\mu\text{m}$. The optimum condition for the combined response (surface roughness and MRR) is found by GRA as A3-B1-C3-

D3. The confirmation experiment gives surface roughness $0.4523\mu\text{m}$ and MRR $7.5\text{ cm}^3/\text{min}$. ANOVA table shows that the feed (77.14%) is the most important parameter that affects the surface finish, followed by nose radius (15.26%), cutting speed (1.34%) and depth of cut (0.77%). Thus it is obtained that the tool nose radius has a significant effect on the surface finish of the turned product after feed rate.

Table VI Shows ANOVA Results

Factor	DOF	Sum of Squares	Variance	Contribution (%)
Factor A (V_c)	2	5.4142	2.7071	1.34
Factor B (f)	2	311.0042	155.5021	77.14
Factor C (a_p)	2	3.1381	1.569	0.77
Factor D (r_f)	2	22.1032	11.0516	15.26
Error	0	0	-	-
Total	8	403.1744		100

A Multiple linear regression model is developed with the help of MINITAB.

$$Ra = -0.413 + 0.00540V_c + 11.54 f + 0.2528 a_p - 0.898 r_f$$

Its adequacy is checked using adjusted R^2 , and it is found that 92.06 % of variability is explained by the above model. The multiple linear regression model for MRR is obtained as follows

$$\text{MRR} = -6.5 + 0.15 V_c + 28.75 f + 5.25 a_p - 3.75 r_f$$

The value of adjusted R^2 of the model is found to be 82.92 %, which is adequate.

VIII. Conclusion

This paper discussed an experimental study of turning operation of Ti-6Al-4V. From the S/N analysis and ANOVA, it is found that tool nose radius (15.26%) is an important factor that affects surface finish along with feed rate (77.14%). An optimization strategy for good surface finish and high MRR while turning Ti-6Al-4V alloy is developed using Taguchi technique and Grey Relational Analysis. The optimum combination is found as cutting speed (50 m/min), depth of cut (1.5 mm) and nose radius (1.2 mm) at level 3 and feed rate at level 1 (0.1mm). A prediction model is developed for both surface roughness and MRR using multiple regression analysis.

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